FARM SCALE BIOGAS AND COMPOSTING TO IMPROVE BATHING WATER QUALITY

February 2006

Prepared for

The Scottish Executive, Water Division

by

Greenfinch Ltd & Enviros Consulting Ltd

Authors

Michael Chesshire (Greenfinch Ltd) & John Ferry (Enviros Consulting Ltd)

1. PROJECT OVERVIEW

1.1 Introduction

A consortium comprising Greenfinch and Enviros was commissioned by the Scottish Executive Environment and Rural Affairs Dept. (SEERAD), in December 2003. The aim of the pilot project was for the provision of research, design, procurement and installation of pilot anaerobic digestion (AD) plants, (also known as biogas plants) and composting facilities (also known as aerobic composting or AC) in south west Scotland to minimise faecal indicator organism (FIO) pollution from agricultural sources to watercourses and bathing waters, especially during the bathing water season. A risk model was developed to provide a comprehensive evaluation of FIO pollution risk. The project also assessed, monitored and modelled the effect of AD and compost treatment on nutrient plant availability and soil leaching potential therefore addressing a broader range of diffuse pollution issues.

The design, procurement and installation of the AD plant were managed by Greenfinch, and the design, procurement and installation of the composting facilities were managed by Enviros. The contract management of the project was provided by Greenfinch, and the monitoring, modelling and research appraisal of the project was conducted by Enviros.

In total 10 plants were installed; 7 AD plants and 3 compost facilities on a total of 9 farms, with one farm having both an AD plant and composting facility. This report details the project in full, including plant design and installation, the findings of monitoring and research undertaken, economic and sustainability appraisals and the resulting conclusions and recommendations.

1.2 Project Objectives

The aims of the project were to:

- Design, procure and install AD plants and compost facilities on study farms in the Saltcoats and Sandyhills catchments of South West Scotland; and,

- Design an environmental and FIO monitoring scheme that would:

    - Characterise the hydraulic connectivity of the catchments and undertake farm steading and manure management audits, to evaluate the pathways between farms and the designated bathing waters;

    - Undertake baseline monitoring to assess FIO load in soil and manures;

    - Undertake event monitoring to assess FIO flux during rainfall event conditions;

    - Undertake processes monitoring to assess FIO kill during biogas and composting treatment;

    - Undertake nutrient monitoring to assess the effect of treatment on total and available nutrients in manures.

- Develop and apply a risk assessment methodology and associated software tool, the Agricultural Risk Assessment Model (ARAM) to test a range of catchment wide treatment scenarios and FIO risks within these catchments; and,

- Conduct a research appraisal to:

  - review the legislation relevant to AD plants and compost facilities on a farm scale and community scale basis;

  - review the climate change, ammonia emissions, and renewable energy aspects of the project;

  - carry out an economic assessment; and,

  - undertake a sustainability appraisal set against the Scottish Executives' strategic and policy priorities.

1.3 Project Background

There are 60 identified bathing waters in Scotland (Scotland's Bathing Water Standards, 2002). The two pilot catchments bathing waters; Sandyhills (Dumfriesshire) and Saltcoats (Ayrshire), have been identified as areas at continued risk of failure of the European Bathing Waters Directive (76/160/EEC) mandatory standards for microbial water quality. Microbial pollution has been identified as one of several factors preventing these standards being met. Contributors to FIO pollution include domestic sources, agricultural pollution and wildlife (including birds). Increased investment for sewage treatment improvement is underway to help, in part, rectify this problem. In the pilot areas however, improved sewage treatment is not considered sufficient to reduce the probability of failure. The Scottish Executive has identified the need to implement measures that can help minimise FIO loads from agricultural activities to the watercourses in these areas.

1.4 Previous Work

The Scottish Executive is committed to achieving the Bathing Water Directive's standards at all 60 identified bathing waters and so is piloting a range of innovative measures to tackle diffuse pollution in "at risk" bathing waters. In addition to this project there are a number of other initiatives, which are addressing linked pathways for FIO pollution of the bathing waters. For instance:

- There is an extensive body of work, including complementary research on the Sandyhills catchment by the Centre for Research in Environment and Health (CREH), also commissioned by the Scottish Executive;

- Scottish Environment Protection Agency (SEPA) is supporting the Scottish Executive's goal and its own commitment to good agricultural environmental practice with regard to controlling diffuse pollution. The Scottish Executive - SEPA signage project is a public information source based on prediction of water quality and is active in the pilot catchments. The current project has adopted some of the parameters used in the signage project;

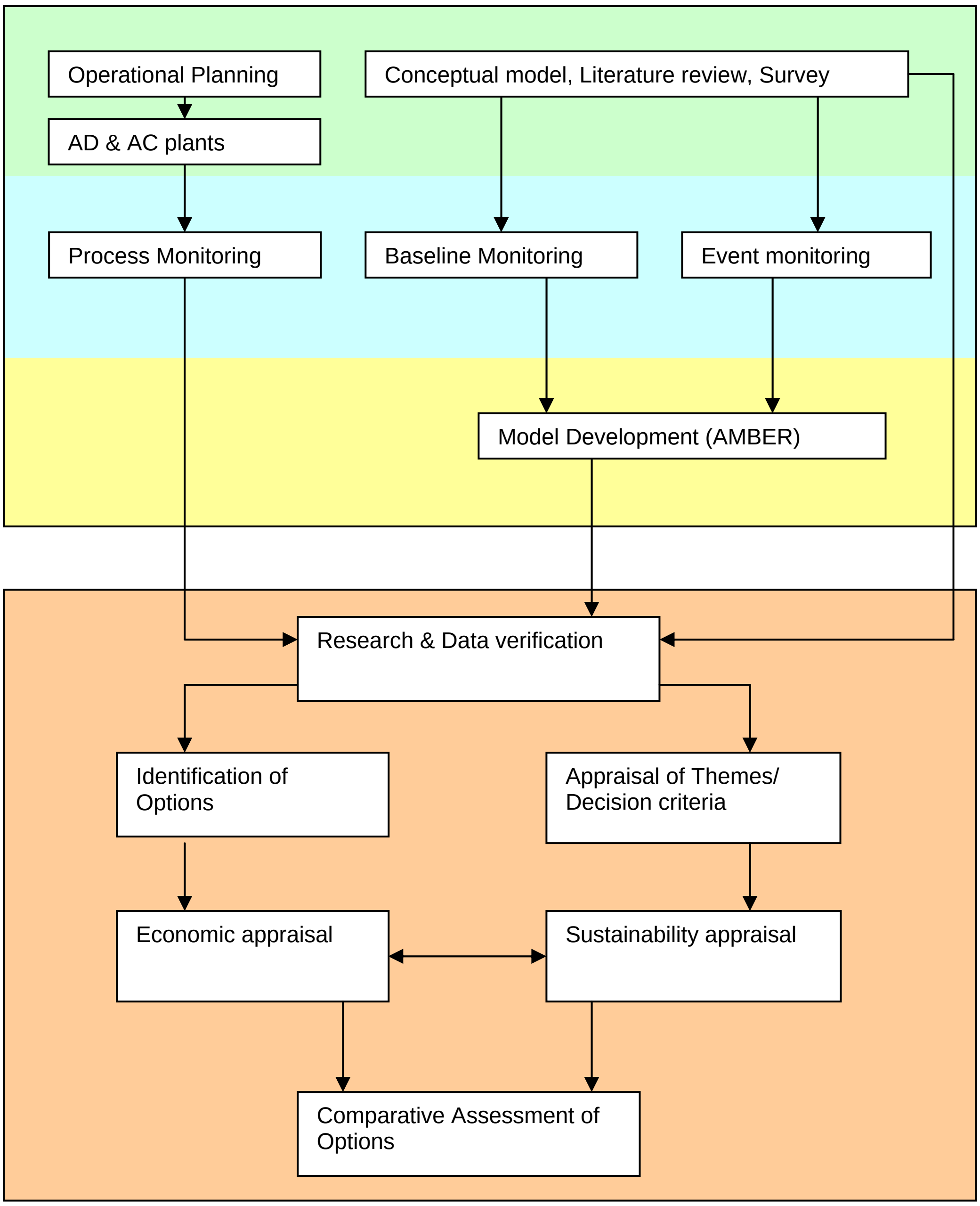
- SAC conducted research that resulted in the installation of fencing along catchment watercourse to prevent livestock access to water and a series of other measures to improve farm infrastructure in the project “Research and Design of Pilot Schemes to Minimise Livestock Pollution to the Water Environment in Scotland”; (Scottish Executive, 2005) and,

- Previous anaerobic digestion work was carried out by the Scottish Executive in association with Scottish Water at Cumnock where cattle slurry was mixed with sewage sludge and treated within a combined treatment facility giving biogas, treated bio solids and a treated effluent liquor using operational infrastructure. Results showed that the average FIO log reduction from the cattle slurry feedstock in relation to the digested biosolids was approximately 2.39 $\log_{10}$reduction.

1.5 Research protocol

Figure 1 shows a schematic of the overall project structure, connectivity and the various strands of research.

Figure 1 Schematic - Appraisal detail



The outcome of the combined environmental and pilot plant research informs the economic and sustainability analyses. This analysis will advise the Executive on scheme value, effectiveness in achieving the objective, and the feasibility and need for a grant scheme if these technologies are to be funded beyond the pilot scheme.

1.6 Project Methodologies

Capital works methodology

The installation and commissioning of the AD plants and composting facilities is described in Chapter 2. The following process was used to provide operational AD plants and compost facilities for initial and medium term research into the effectiveness of on farm treatment of slurry and farmyard manure in protecting designated bathing waters:

- Initial identification of 12 candidate farms within the two catchments was made by the Scottish Executive;
- The consortium undertook initial farm surveys (of the candidate farms) to identify suitable sites for either AD plants or composting facilities and hold discussions with the farmer to assess their interest in participating in the pilot project;
- Having identified suitable sites, formal agreements were entered into between the farmer and the Scottish Executive;
- Design of the AD and AC plants was undertaken;
- Planning applications and building warrants were submitted, as appropriate;
- Following planning and building warrant acceptance, the HSE were informed of the construction works under the requirements of the C(DM) Regulations;
- Procurement of plant and construction contracts were implemented and construction was carried out;
- On completion of the plants, building control and SEPA inspections were undertaken, as appropriate;
- The AD plants and compost facilities were then commissioned and the farmers trained in their use and operation; and,
- As-built drawings, operation and maintenance manuals and a copy of the PEPFAA code were issued to each farmer.

Monitoring and Modelling Methodology

The catchment assessment, monitoring protocols and results are discussed in Chapters 3 and 4. Development and application of the modelling is discussed in Chapter 5. These chapters describe;

- Catchment investigation where hydrology, soil type and other characteristics have been assessed;

- Development of a conceptual structure of farm systems and routes by which FIO may be lost from these to surface waters, through review of scientific literature, review of previous Scottish Executive reports and consultation with the Scottish Executive, SEPA and researchers from CREH;

- Development of monitoring plans and protocols, for the collection of environmental samples (soils; fresh, stored and treated manures) and FIO analysis (total coliforms, faecal streptococci and enterococci) and nutrient analysis (total and available N, P and K) by accredited laboratories and collation and interpretation of data for:

    - baseline (pre-study) monitoring, undertaken in April and June 2004;

    - event monitoring, where a team was maintained on standby through July and the first week in August 2004;

    - process monitoring, to assess the FIO kill efficiency of treatment by composting facilities and AD plants following their commissioning;

    - evaluation of the effect of treatment on the total and available nutrient loads in treated manures.

- Using the Enviros modelling system AMBER, the conceptual model developed was encoded into a software tool, the Agricultural Risk Assessment Model (ARAM). This decision support system went through a number of iterations to meet the needs of the project. During this period the following were undertaken:

    - testing of a range of catchment wide treatment scenarios (composting only, biogas only, combined composting and biogas and zero grazing);

    - provision of an ARAM training seminar, that was attended by the project steering committee, and supporting user information;

    - delivery of ARAM (and the Enviros software system AMBER within which ARAM can be run, with supporting documentation and user support help line) to the Scottish Executive.

- Development of a protocol for the use of ARAM, as agreed with the project steering committee;

- ARAM was then run to assess the FIO flux to surface waters (taken as a direct analogue to bathing water quality) for AD and composting treatment and zero grazing options under rainfall event and non-rainfall event conditions. The contribution by a range of pathways has been assessed, the increase in flux due to landspreading of manures determined, and the ability to minimise this via manure treatment quantified; and,

- The risk reduction factors derived from the ARAM assessment have been applied to historic bathing water data to assess the potential improvements achievable through AD and composting treatment. The findings were fed into the sustainability appraisal.

Research Appraisal Methodology

Building on the two previous strands of plant construction and commissioning and monitoring and modelling, the research protocol that is described in Chapters 6 to 8 included:

- A review of the legislation relevant to AD plants and compost facilities on a farm scale and community scale basis;

- An economic assessment of a range of catchment wide treatment scenarios; and,

- A sustainability appraisal set against the Scottish Executives' strategic and policy priorities.

The research appraisal covered:

- A review of the climate change (including greenhouse gases), ammonia emissions including the minimisation of air pollutants emission and renewable energy aspects of the project; and potential odour issues

- Review of the volumes of material stored and handled;

- How products from a composting facility or AD plant could be used on the farm;

- Whether a grant scheme would be required to facilitate such manure treatment to make an AD or composting approach viable and/or to fund such measures beyond the pilot project; and,

- Recommendations for further study.

1.7 Formal Agreements

The formal agreements with farmers expire on March 31st 2009. Until such time the ownership of the plant is held by SEERAD. Access is also granted to relevant contractors for plant installation, surveying, monitoring, and maintenance activities during this period. The farmer is responsible for routine maintenance of the plant and this is detailed in the operation and maintenance manual.

2. DESIGN AND OPERATION

During the project 10 plants were installed; 7 AD plants and 3 compost facilities on a total of 9 farms, with one farm having both an AD plant and a composting facility. These processes are described below. It is important to note that the project philosophy was to ensure that the design of the plants was robust and that the systems could cope with unforeseen eventualities that may arise, e.g. severe weather conditions affecting the process performance and leading to potential environmental harm. Also, as farmers were initially unfamiliar with the technologies and as operational consistency was essential for research results, the plants were designed to a standard that offered durability and reliability.

2.1 Initial Farm Surveys

SEPA, at the request of the Scottish Executive, identified the main farms in the catchments of the Saltcoats and Sandyhills designated bathing waters as likely candidates for the project. These farms had been identified based on a number of risk criteria: the number of livestock, the proximity of fields to watercourses and the amount of slurry and manure produced. ***Participation in the project by these farms does not imply that they were in any way in breach of current regulations.*** Twelve of these farms within the two catchments were visited in December 2003 in order to introduce the farmers to the project, to assess the animal numbers and types and to survey the slurry and manure systems. The nature of the project was explained. It was emphasised to the farmers that participation was voluntary and should they wish to proceed with an installation then they would be required to sign a Formal Agreement with the Scottish Executive. During the preliminary meeting, much data about the management of the farm were collected, including a farm map and a waste management plan (if available). Inspections of the steading were made to gain an understanding of the farm's waste management system. Key measurements and photographs were taken during this inspection.

Repeat visits were made during January and February 2004 to secure the formal agreements to allow the installation of the treatment plants.

Generally the visits were welcomed by the farmers, most of whom appeared keen to install either an AD plant or a composting facility, and in one case both types of process.

By the end of February 2004 nine farmers had signed Agreements for the installation in total of seven AD plants and three composting facilities (see Table 2.1); one farm was identified as being suitable for both an AD plant and a composting facility. In general those farms which produce mostly slurry were identified for AD plants and those which produce mostly farm yard manure for composting facilities. It was an important factor that none of the farmers were fully conversant with AD or composting technologies before they were approached.

A condition of these Agreements was that farmers would comply with the terms of the Code of Good Practice for the Prevention of Environmental Pollution from Agricultural Activity (PEPFAA Code) and the 4 Point Plan (Guidance for Livestock Farms to Minimise Pollution and Benefit Business) published by the SE.

Table 2.1 Farms participating in project

Farm	Bathing water	Animal numbers	Treatment	Plant capacity and tonnages
Knockrivoch	Saltcoats	240 dairy cows and followers	AD	480 m^3 Digester: 4,300 t winter 800 t summer
Sorbie	Saltcoats	250 dairy cows and followers	AD	480 m^3 Digester 4,400 t winter 900 t summer
Meikle Laught	Saltcoats	112 dairy cows and followers	AD	190 m^3 Digester 1,500 t winter 300 t summer
Ryes Farm	Sandyhills	135 dairy cows and followers	AD	250 m^3 Digester 2,450 t winter 450 t summer
New Farm	Sandyhills	170 dairy cows and followers	AD	320 m^3 Digester 2,900 t winter 600 t summer
Corsock	Sandyhills	150 beef cattle	AD	80 m^3 Digester 1,000 t winter 0 t summer
Fairgirth	Sandyhills	100 beef cattle and 800 ewes	AC	840 m^2 Compost Shed – treating approx. 227 t/month
Upper Clifton	Sandyhills	30 beef cattle and 120 ewes	AC	420 m^2 Compost Shed - treating approx. 112 t/month
Castle Farm	Sandyhills	250 dairy cows and followers	AD & AC	480 m^3 Digester- 4,000 t winter 900 t summer 840 m^2 Compost Shed- treating approx. 207 t/month

2.2 Design of AD Plants

It was recognised at the outset that for the success of the project as a whole, including the research modules, the design of the pilot AD plants should be robust and easy to operate, with maximal potential for FIO kill. This would not necessarily give the least initial cost option, but it would give the best value for money over the long term through minimising ongoing costs. Design commenced in February 2004 and was based on the following key factors:

- Raw slurry is held in an above-ground reception tank which stores between 3 and 7 days of digester feed according to the farm waste management routine.

The farmer is responsible for ensuring that there is sufficient slurry available for digestion. Some of the farms have only a single phase electricity supply and rely on the use of power take-offs from tractors to be able to transfer slurry to the reception tank.

- The contents of the reception tank are homogenised by a chopper pump which also reduces particle size. Although this design feature may involve additional expenditure and may also result in a higher digester heat demand owing to the raw slurry being exposed to the air, it contributes significantly to the reliability of the process and it enables downstream pumps to have flooded suction.

- The digester is a single-stage continuous stirred tank reactor (CSTR) and is designed such that there are no moving parts inside the digester nor equipment which might require maintenance, since the process of emptying a digester for maintenance purposes can be prohibitively expensive. The digester contents are mixed using sequential unconfined gas mixing and are maintained at a constant temperature by the circulation of digesting slurry through an external concentric-tube heat exchanger. The digester is insulated externally with 100 mm of mineral wool which is protected by steel cladding.

- Gas is piped from the digester to a small bell-over-water gas holder which also acts as a pressure regulator. Gas is fed from the gas holder to the gas mixing compressor and to the biogas boiler; this arrangement enables condensate to be automatically drawn off prior to gas utilisation, prolonging equipment life.

- The gas boiler is designed to burn 120% of the estimated biogas production, preventing the discharge of unburned methane to atmosphere and providing the farmer with a simple means of energy utilisation. The boiler provides hot water either for the digester heat exchanger or for surplus heat.

- The digesters used in the project were operated under mesophilic conditions (average temp of 37°C) and a trial pasteurisation phase was conducted on some farms during the monitoring period (62°C for 4 hours)

- The digester is fed and discharged using identical progressive cavity pumps. This enables simple metering of the input and output. The feed pump is protected from coarse materials by an in-line macerator.

- Digested slurry is stored in an above-ground tank capable of holding 90 days of digestate production.

- All above ground tanks are fabricated in glass-coated steel panels and the digester has a stainless steel roof. This design feature ensures that the installation is compatible with a farm and that the tanks will have a long working life.

- Instrumentation is kept relatively simple: the levels in the reception tank, digester tank, digestate tank and gas holder, and the temperature in the digester and in the heating circuits are monitored.

- Operation of the digester, with the exception of filling the reception tank and unloading the digestate tank, is fully automatic and is controlled from a central panel.

- All the mechanical and electrical equipment (with the exception of the gas mixing compressor) is prefabricated in a single 6 metre long steel container. This feature provides a high level of security and enables the key equipment and controls to be fully tested at the factory prior to dispatch.

The design takes full account of safety through the application of risk assessment which is specific to the project rather than generic. A basic biogas plant process diagram process is shown below in Figure 2.1.

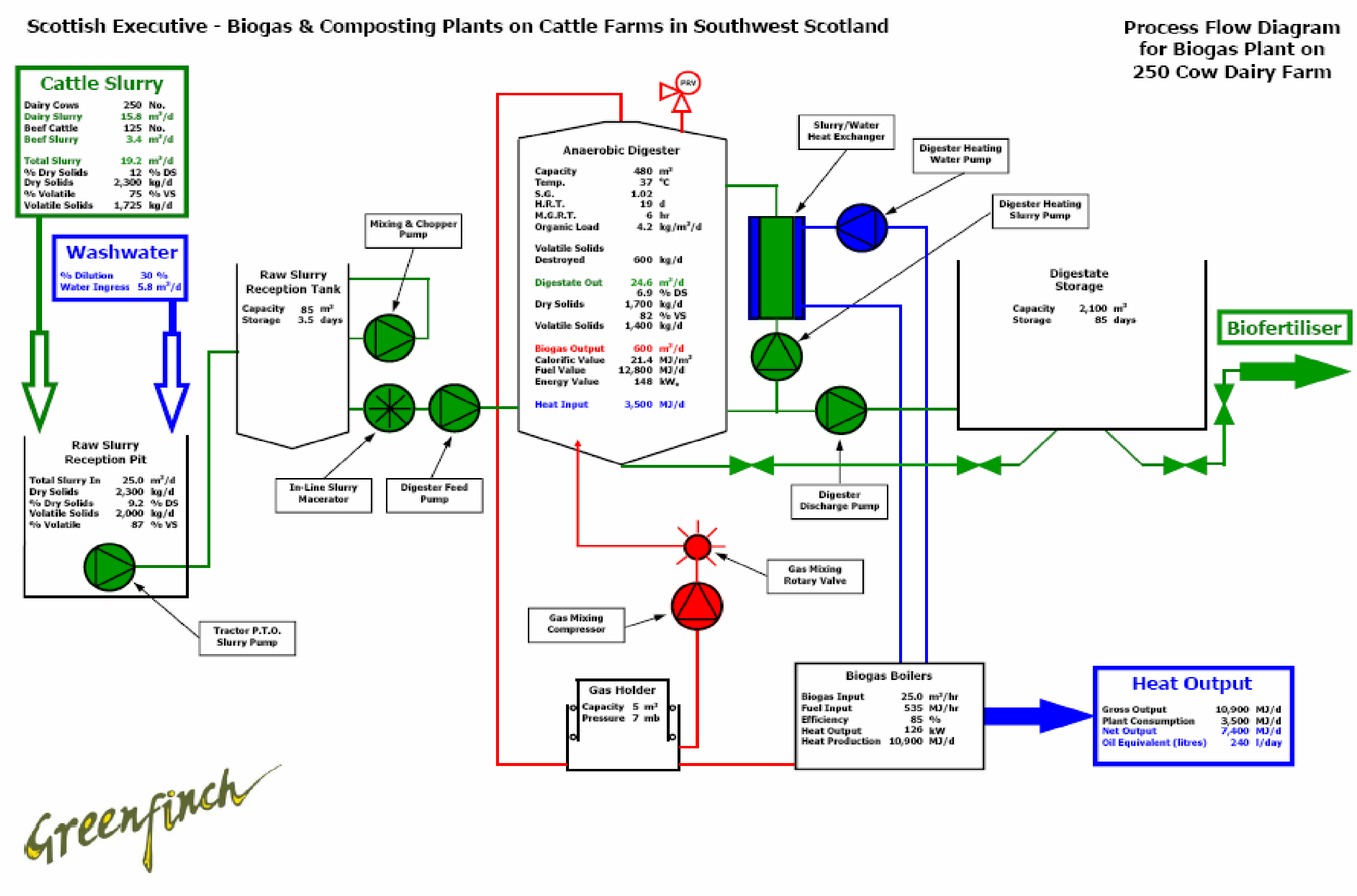


Figure 2.1 Basic Biogas Plant Process Diagram

The explanation of the AD plant operation given above is based on a typical farm of approximately 110 hectares, with 135 adult dairy cows and followers which are fattened to 250kg or 450kg. Slurry is produced from the dairy cows and from the followers older than 12 months, which are housed in the winter for a period of 5 to 6 months depending on the weather and the condition of the land. The cows lie in cubicles with a small amount of sawdust bedding and the store cattle have no bedding. The slurry falls through slats into four underground slurry storage tanks, two for the dairy cattle and two for the store cattle. Slurry is withdrawn from the underground storage tanks using a new submersible mixer pump driven by the power take-off (PTO) of a tractor. The slurry is pumped to the new reception tank which is the first stage of the AD plant.

The operation and maintenance manual for the AD plant generally includes the following drawings:

GF165-81-B	Engineering Line Diagram
GF165-91-A	General Arrangement
GF165-92-A	Plant Room Side Wall Elevations (Internal)
GF165-93-A	Plant Room End Wall Elevations (Internal & External)
GF165-94-A	Control Panel Door Layout
GF165-95-A	Control Panel Internal Layout

A photo of one of the plants is included below

Figure 2.2 Meikle Laught AD Plant

2.3 Design of Composting Facilities

2.3.1 Process

The composting technology adopted was designed to optimise efficient destruction of FIO pathogens by ensuring adequate moisture and oxygen conditions to facilitate the high temperatures required to kill faecal micro-organisms (>55°C to 70°C). It was also necessary to design a robust system that would complement and integrate with existing activities on the farms.

Composting is a process that exploits the natural decay of biodegradable materials. It is an aerobic (requiring the presence of oxygen) process whereby naturally occurring micro-organisms breakdown organic materials as they digest the nutrients released for growth and proliferation. As they multiply, these micro-organisms generate large quantities of metabolic heat, creating high temperatures. To maintain and enhance these biological processes elongated piles (windrows) of this material are set out and periodically turned to relieve compaction and maintain a porous structure, allowing the diffusion of air (oxygen) into the pile. Turning also ensures the material is thoroughly mixed during composting, so that all the material is exposed to the high temperatures found in the centre of the windrow.

2.3.2 Construction Design Philosophy

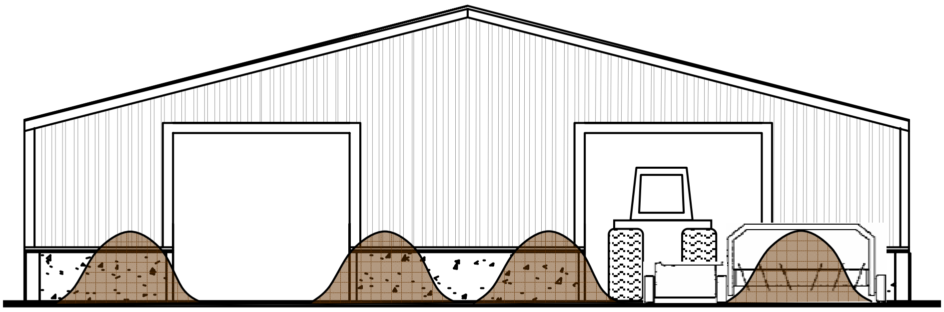
The key elements are to ensure that the design is sustainable in terms of operability, sustainability and cost effectiveness. If these criteria are not met it is unlikely that the farmers would be willing to participate in future schemes even if the composting proved effective in reducing the risk of FIO contamination of bathing waters. As composting is likely to remain a rural activity, the following criteria have been used to guide the design of the composting unit:

- Design must be suitable for a farmer or a small rural plant company to construct;
- Materials used must be ‘off the shelf’ and readily available in such communities;
- Design must be robust enough to allow operation in a working farm environment;
- Environmental threats must be designed ‘out’; and,
- The design of the plant must promote safe working conditions for the farmer.

2.3.3 Composting technology

Appropriate technology was adopted to optimise the composting process objectives given above. An elongated pile (‘windrow’) system that is mechanically agitated (“turned”) by a straddle windrow turning machine was adopted. The machine is tractor pulled and powered (via the PTO shaft). The process is conducted on an impermeable concrete pad covered by a building (see Figure 2.3 below).

Figure 2.3 Composting building layout



This composting system option was chosen to be robust and efficient. Mechanical turning was chosen to maintain adequate aeration rather than forced (fan-assisted) aeration. Efficient turning is required to ensure thorough randomized mixing of material during the thermophilic phase of composting. This ensures that all material is exposed to high composting temperatures for sufficient time to achieve sanitisation.

Figure 2.4 Turner: Sanberger ST series model 300

Model	ST300
Length	4.5 m
Width	5.0 m
Height	1.6 m
Pile	1.5 x 3.0 m
Weight	4.7 tonnes
Power	65-100 HP
Output	500 m^3/h

The PTO driven, tractor-pulled turner (see Figure 2.4 above) was adopted as it could be driven using an existing farm tractor. The turner would also provide thorough and consistent windrow turning, with little operator training required.

2.3.4 FYM mixing/shredding and windrow formation

To ensure the FYM was of the correct particle size, porous structure, and consistent mixture a PTO driven mixer/shredder was adopted (see Figure 2.5 below). This has a side chute arrangement which allows formation of a new windrow during the shredding operation as the machine moves along the existing windrow. The farmers have the option of using this function of the shredder, or a tractor mounted loading shovel to create windrows.

Figure 2.5 Mixer/Shredder: Abbey VF10

2.3.5 Windrow turning and process control

Once the windrows have been formed the windrow turner is lowered into turning position at the start of the pile and driven along the length of the pile (using the tractors creep gear) until the whole pile has been turned (see Figure 2.6 below). Each windrow was composted for at least 28 days with at least 4 turnings during that period. The internal temperature of each windrow was measured using a long-stem thermometer just before each turning.

Figure 2.6 Windrow turning

Conducting composting operations on a sealed concrete pad and under cover was necessary to minimise the potential for liquid (leachate and run-off) containing FIO to enter surface or groundwater. The composting building protected the operations from precipitation, and therefore prevented the risk of flooding in the composting area. Furthermore, the building provided shielding for the composting FYM from becoming too wet and/or cold during inclement weather, which could lower composting temperatures and increase the risk of inadequate sanitisation.

2.3.6 Permitted activities

To remain within the requirements of composting under waste management licensing exemptions (after proposed future amendments to those regulations), only certain composting activities were allowed on each farm.

Only animal faeces, urine and manure, including bedding material, waste animal feed, or plant-tissue waste produced by other farming activities were used as composting feedstock. Only wastes produced from agricultural activities on the land owned by the farmer were composted on that farm.

The maximum quantity of waste being stored prior to composting, composted and stored for maturation, should not exceed a total of 400 tonnes at any one time and should follow good farming practice and in particular avoid contamination of water courses. All composting operations were therefore carried out, in the composting buildings provided, according to this guidance.

2.3.7 Composting Facility Sizing

The size of the composting facility required was based on monthly manure production. Estimated farm animal excretion rates and straw bedding application rates were used to give an FYM production rate per animal kept on each farm. From this the monthly FYM production rate was calculated. As a one month composting retention time would be used, this figure was used to calculate the total volume of material, windrow length, and therefore composting building size required, using the following assumptions:

- Each adult cow produces 53 kg of FYM/straw mix ready for composting per day; or 1.6 t per month;
- On average, followers younger than 6 months give the equivalent FYM production of 25% that of an adult, and followers older than 6 months produce 50% FYM that of an adult;
- Each adult sheep produces 7.9 kg of FYM/straw mix ready for composting per day; or 237 kg per month;
- FYM/straw composting mix has a density of 0.5 t per m^3;
- Windrows will have a cross-sectional area of 3 m^2 (1.5 m height x 3 metres width x 0.66);
- Each windrow will require around 2 metres of space at each end for turner manoeuvring and each windrow wall will require at least a 1 m gap between its longitudinal edge and the composting building;
- The tractor pulling the windrow turner will require at least a 3 m gap to travel between any two adjacent windrows during turning; and,
- The maximum length of a windrow employed will be approximately 40 metres.

An example of the final sizing calculations are shown in Table 2.2 below.

Table 2.2 FYM composting facility size by farm

Example Compost Facility: Only followers produce FYM (housed on straw); 40 followers 0-6 months = 10 adults equivalent FYM production; 80 followers 6-12 months = 40 adults equivalent FYM production; 60 followers >12 months old = 60 adults equivalent FYM production; Total of 110 adults equivalent FYM production.

Monthly composting capacity	175 t; 350 m^3
Total windrow length	117 metres
Total number of windrows	3 @ 39 m lengths
Composting building	45 m x 18 m (l x w); total area = 810 m^2

2.4 Planning

2.4.1 Procedure

The relevant authorities for plants located in the Sandyhills and Saltcoats areas were Dumfries and Galloway and North Ayrshire Councils respectively. A new Building Standards System and Legislation came into force in Scotland in May 2005. It should be noted that the procedures followed for this project may not apply and the new standards would need to be investigated with regard to any future plant design.

At the beginning of the project the relevant authorities were notified of the intended developments under General Permitted Developments (GPD). Following discussion with the authorities (planning offices and building control departments), further detailed assessments and applications were required. The sites were assessed to ascertain if development could be permitted under General Permitted Development or whether full planning permission was required. Six of the biogas plants only required GPD permits, whilst one required full planning permission due to proximity to a dwelling house. All of the composting plants required full planning permission. Planning permits were obtained for all, but one, of the plants by April 2004. The final planning permit was obtained by June 2004.

Building control warrants were required for all of the plants and building control certificates have been obtained following completion and inspection of the works.

SEPA requires a minimum of 28 days prior notification of the plant being commissioned to facilitate, if necessary, a final inspection of the system. SEPA may be consulted by the local Planning and Building Control Authority as part of the planning and building control processes.

2.5 Operation and Maintenance

2.5.1 Operation & maintenance of the AD plants

Operation of the AD plant is automatic, controlled by a programmable logic controller (PLC) in the central control panel. However, the farmer is required to spend an average of half an hour per day checking that plant is operating correctly. For normal operation the following are the only manual operations required:

- Filling the raw slurry reception tank;
- Emptying the digestate storage tank;
- Filling the gas compressor oil reservoir; and,
- Recording readings from the control panel each day.

Each farmer has been trained and issued with a comprehensive operation & maintenance manual. This includes a list of daily, weekly and monthly operations, together with a trouble-shooting guide.

2.5.2 Operation & Maintenance of the Composting Facility

Operation of the composting facilities is mainly concerned with controlling the materials added to the compost pile, shredding material where necessary and the turning of the windrow piles.

Each farmer has been trained in the operation of the shredder and compost turner equipment, the preparation of the farmyard manure and the turning and aeration of the compost material. Operation and maintenance manuals for the composting facility and maintenance manuals for the shredder and the compost turner have also been issued to the farmers.

Daily and weekly tasks to be completed by each farmer are:

- Daily: Record temperature readings taken from the compost (both high (1st stage) and stabilisation (2nd stage) rate) at 5m intervals along the windrow and log the data, time and date in farm logbook;
- If the temperature exceeds 80°C then the windrow must be turned to avoid combustion;
- For 1st stage compost, when the temperature range reaches above 60°C, the windrow must be left for 24 hours and then turned with the compost turner. The date and time of turning must be recorded in logbook;
- For 2nd stage compost, the windrow must be turned once a week or when no longer steaming.

2.6 Summary of AD and Composting

To help evaluate the two technologies a comparison of AD and composting has been drawn up in Table 2.3 below detailing the key features relevant to both processes and the differences between them. Details about the procurement, construction and commissioning of the AD plant and composting facilities are in Annex 1.

Table 2.3 Comparison of composting and AD technologies

	Aerobic Composting (AC)	Anaerobic Digestion (AD)
Energy Output	AC is an exothermic process in which the energy generated by the micro-organisms is in the form of heat which enables the compost to naturally reach temperatures of 55 to 70°C.	AD is not an exothermic process; but requires energy input in the form of heat and produced biogas which comprises approximately 60% methane (CH_4) and 40% carbon dioxide (CO_2).
Feedstock	On cattle and sheep farms the manure suitable for AC is FYM, which is generally produced from the followers of a dairy herd and other livestock maintained in straw bedded courts. The percentage total solids (%TS) of FYM is 15 to 30%.	The manure suitable for AD is slurry, which is produced from dairy cows and from some followers using some form of slurry containment system. The percentage total solids (%TS) of slurry is 4 to 8%.
Process Time	AC is a batch process; windrows of FYM are formed and then turned weekly. Stable compost is produced after six weeks.	AD is a continuous process; slurry is pumped into the digester and digestate pumped from the digester several times a day. Average retention time is 20 days.
Technology	AC is generally a simple technology.	AD is a relatively more complex process to manage.
Heat Input	Unless it is in an open cold and wet position, AC does not require an external heat source.	AD requires an external heat source, either by burning a proportion of the biogas in a gas boiler or by recovering the heat from a combined heat & power unit (CHP) fuelled by the biogas.
Energy Input	The energy input for an AC plant is in the form of tractor diesel which is used for the FYM mixer / shredder and for the windrow turner.	The energy input to an AD plant, in addition to heat, is in the form of electricity to run pumps and macerators.
FIO Reduction	Controlled AC achieves a reduction in FIO of about $\log_{10}4$ (a reduction in FIO numbers of about a factor of 10,000)	Controlled AD achieves a reduction of FIO dependent on temperature - $\log_{10}1$ to $\log_{10}2$ (a reduction in FIO numbers of a factor of 10 to 100) at a mesophilic temperature of 37°C, and $\log_{10}4$ (a factor of 10,000) at a thermophilic temperature of 50°C.
Biofertiliser	AC produces biofertiliser in the form of a semi-solid compost, with both nutrient and soil enhancement value, and is usually applied to the land using a muck-spreader.	AD produces biofertiliser in the form of a liquid digestate, with both nutrient and soil enhancement value, and is usually applied to the land using a vacuum-tanker.
Human Resource Input	A new windrow is formed every six weeks by preparing a shredded mixture of FYM, and is turned weekly by a tractor-driven machine	The farmer is required to fill the raw slurry reception tank once or twice per week and to spend 30 minutes per day on plant supervision

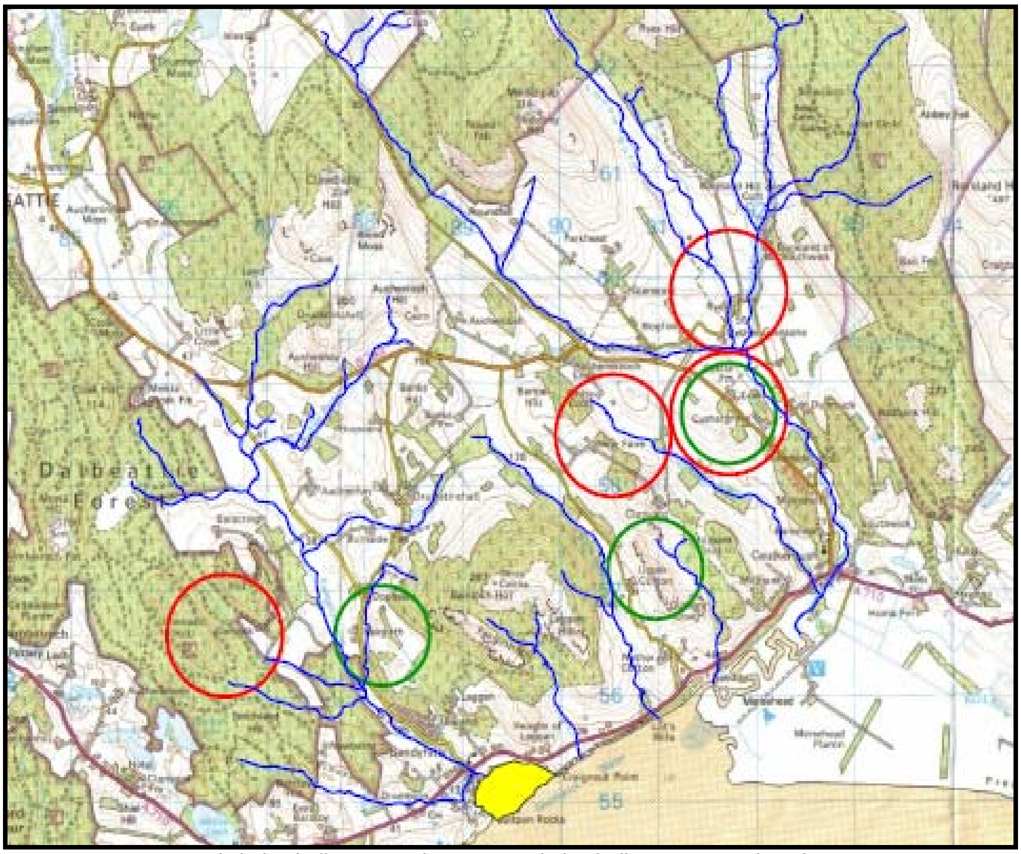
3. PROJECT CATCHMENTS AND FARMS

The characteristics of the local areas around the pilot farms are discussed in this chapter.

3.1 Selected Catchments

The areas under investigation in this project were Sandyhills (Solway coast, Dumfries and Galloway), and the Saltcoats area (Ayrshire). The catchments for these bathing waters are:

- Fairgirth Lane and Southwick Water catchments, forming the Sandyhills bathing water catchment;
- Stanley and Stevenston Burn catchments, forming the Saltcoats bathing water catchment.



Red circles indicate AD plant, green circles indicate composting plant

Figure 3.1 Sandyhills bathing water area with selected farms

The Sandyhills region is an area with a high percentage of land under agricultural use and the catchment areas identified contain approximately 21 farms (see Figure 3.1). The main agricultural activity is dairy farming, with some beef and sheep farming. The topography of the area is a mixture of rocky coastlines of cliffs, isolated coves and raised beaches and undulating improved pastureland interspersed with knolly gorse filled areas. The average annual rainfall is approx 1,000mm.

Red circles indicate AD plant, green circles indicate composting plant

Figure 3.2 Saltcoats bathing water area

The Saltcoats area (see Figure 3.2) is primarily a sand dune coastline system backed by agricultural land. This supports a well established farming community, and has a range of farm land types from fertile coastal plain to hill land. Livestock farming is the main agricultural activity in the area, with dairying predominant. The catchment area of the Stevenston and Stanley Burns include approximately 9 farms. The average rainfall in the area is 1,060mm per year.

3.2 Bathing Water Quality

Bathing water quality at Sandyhills and the Saltcoats South Bay areas have historically been poor. During the period 2000 to 2004 they have exceeded the existing mandatory guidelines for total coliforms and faecal coliforms on a number of occasions.

Microbial counts in bathing water at these sites have been highly variable and have ranged by up to a factor of 5,000. At Saltcoats peak microbial loads in 2000 were up to 5 times higher than in subsequent years. In Sandyhills the highest loads were measured in 2002 and were up to 5 times higher than peak loads in subsequent years. The reason for this variability is uncertain, other factors such as rural domestic sewage have not been investigated, but the combination of rainfall events and livestock management probably contribute to this variability.

Variability in water quality also occurs within any bathing water season. Again peak concentrations can be related to rainfall events, but in Sandyhills there also appears to be a consistent double peak in FIO loads; the first occurring in July and the second in September. In Sandyhills there also appears to be a general increase in FIO loads, particularly for Enterococci through the summer. These changes may also reflect how livestock and livestock manures are managed through the bathing water season.

3.3 Assessment of Catchment Characteristics

To determine the nature of these two catchments the following work was done:

- Consultation with the farmers and detailed analysis from farm audits and catchment walk-over surveys;
- Data collection and consultation with SEPA;
- Literature searches, review of Ordnance Survey data, tidal stream atlases and geological maps;

The following sub-sections describe the characteristics of the Saltcoats and Sandyhills catchments as assessed during this project. These data have been used within the risk assessment described in Chapter 5.

3.3.1 Soil and Sub-Soil Type

Soil and sub-soil types have been identified through consultation with the farmers and characterised into the following categories: sand; loamy soil; sandy loam; fine sandy soil; sandy silt loam; silt loam; silt clay loam; sandy clay loam; clay loan; sandy clay; silty clay; clay; organic (6-20% organic matter); peaty (20-50% organic matter); peat (>50% organic matter); chalk; and, rock other than chalk. Where different soil types occur on the farm the relative areas of each type and their characteristics have been recorded.

In the Sandyhills catchment, sandy loam is the predominant surface soil type. It overlies fluvial deposits close to the river, but there are numerous rocky granite outcrops from the granite hills bounding the small catchments and drift materials are relatively thin. One farm involved in the project had a slightly different soil type where the farmland surface soil was 15% peat overlaying silt loam.

The Saltcoats catchment has a soil type with a higher proportion of clay, having clay, clay loam and sandy loam present in varying proportions both in the surface and subsurface soil types. No near surface rock has been identified in the subsurface layer.

3.3.2 Rainfall Characteristics

The frequency, intensity and extent of rainfall events are important in determining both microbial and nutrient run-off from land. As a detailed analysis of rainfall characteristics was beyond the scope of this project, a more pragmatic approach focusing on rainfall event frequency, mean monthly rainfall and end of soil drainage was therefore taken.

3.3.3 Rainfall Event Frequency

The assessment has been based on data provided by the SEPA Bathing Water Signage Team. Based on consultation with the Team, the average return frequency of event driven reductions in bathing water quality has been identified as approximately every 10 days. This is based on data from the bathing water period (i.e. June to mid September). A detailed review of rainfall data and groundwater saturation deficit in the catchments was not undertaken. No data for microbial water quality was available for other times of the year. Although the work by previous Scottish Executive contracts and SEPA shows a clear and strong correlation between rainfall events (a trigger event being typically an average rainfall of 10 mm (over 24 h) or 15 mm (over 48 h)) and elevated river flows, the system does at times either overestimate or underestimate microbial bathing water quality. No assessment of how these variations related to typical periods of land application of manures has been made and the SEPA system assumes a constant source of FIO in the catchment.

3.3.4 Mean Monthly Rainfall

Mean monthly rainfall data was collected from the UK Meteorological office which provides 30 year averages of monthly rainfall (1961-1990). The following stations were assessed to best represent the catchment areas of Sandyhills and Saltcoats; Auchencairn data was used for the Sandyhills catchment and the Greenhead filters data was used for the Saltcoats area. The mean monthly rainfall results are given below.

Table 3.1 Monthly mean Rainfall Data (mm)

Location	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Annual mean
Greenhead	101	71	94	120	13	108	76	57	78	108	164	126	1116
Auchencairn	98	88	120	99	10	101	72	69	61	129	138	117	1102

3.3.5 End of Drainage

Drainage from soils occurs when the soil water deficit is low. During dry periods this deficit may increase to a point where drainage from soils ceases. In south West Scotland, the end of soil drainage occurs between March and April[1]. This data is important for nutrient leaching assessment in Chapter 5.

3.3.6 Hydraulic Connectivity to Local Waters

The individual catchment watercourses may not drain directly to the designated bathing water, but may instead reach the coast several km distant from this point. SEPA deem all watercourses in the areas studied to influence one of the two bathing water catchments under study. Without a detailed assessment of coastal transport processes it is not possible to fully quantify the contribution these will make to microbial bathing water quality. The assumption is therefore that all FIO fluxes entering the watercourses that discharge to the coast either at the bathing water or a few kilometres up or down the coast have an equal potential to influence the bathing water quality.

The catchment watercourses and the extent of hydraulic connectivity of farm land to these watercourses were assessed. This semi-quantitative assessment was based on the presence, proximity, and frontage of watercourses to farmland and the local catchment and spreading field topography. A rating of between 0 and 100% was assigned to each farm to describe the extent of hydraulic connectivity during event conditions and this information has been used in the subsequent risk assessment. At a low rating the area is hydrologically isolated with little opportunity for FIO

1 Personal communication with Neil Henderson, SEERAD April 2005 Soil drainage figures for SW Scotland

material to be transported to local watercourses and bathing water area. At a high hydrologic connectivity the opposite is true. The assessment concluded that all the initially identified high risk pilot farms were well connected to local watercourses and that during rainfall events surface water run-off or drainage could lead to the rapid transfer of agricultural derived FIO to coastal areas.

In the Saltcoats area the pilot farms were distributed between 2 river catchment areas, that of the Stanley and Stevenston Burns. Stanley Burn discharges directly into the Saltcoats bathing water. The designated bathing water lies within a well defined bay that separates it from the non-designated areas to the north-west and south-east (Figure 3.3). Stevenston Burn discharges to the coast 3-4 km to the south-east of the designated bathing water. It is difficult to fully quantify the impact that discharges via the Stevenston Burn have on microbial water quality at the Saltcoats designated bathing water, due to rapid die-off of FIO in seawater.

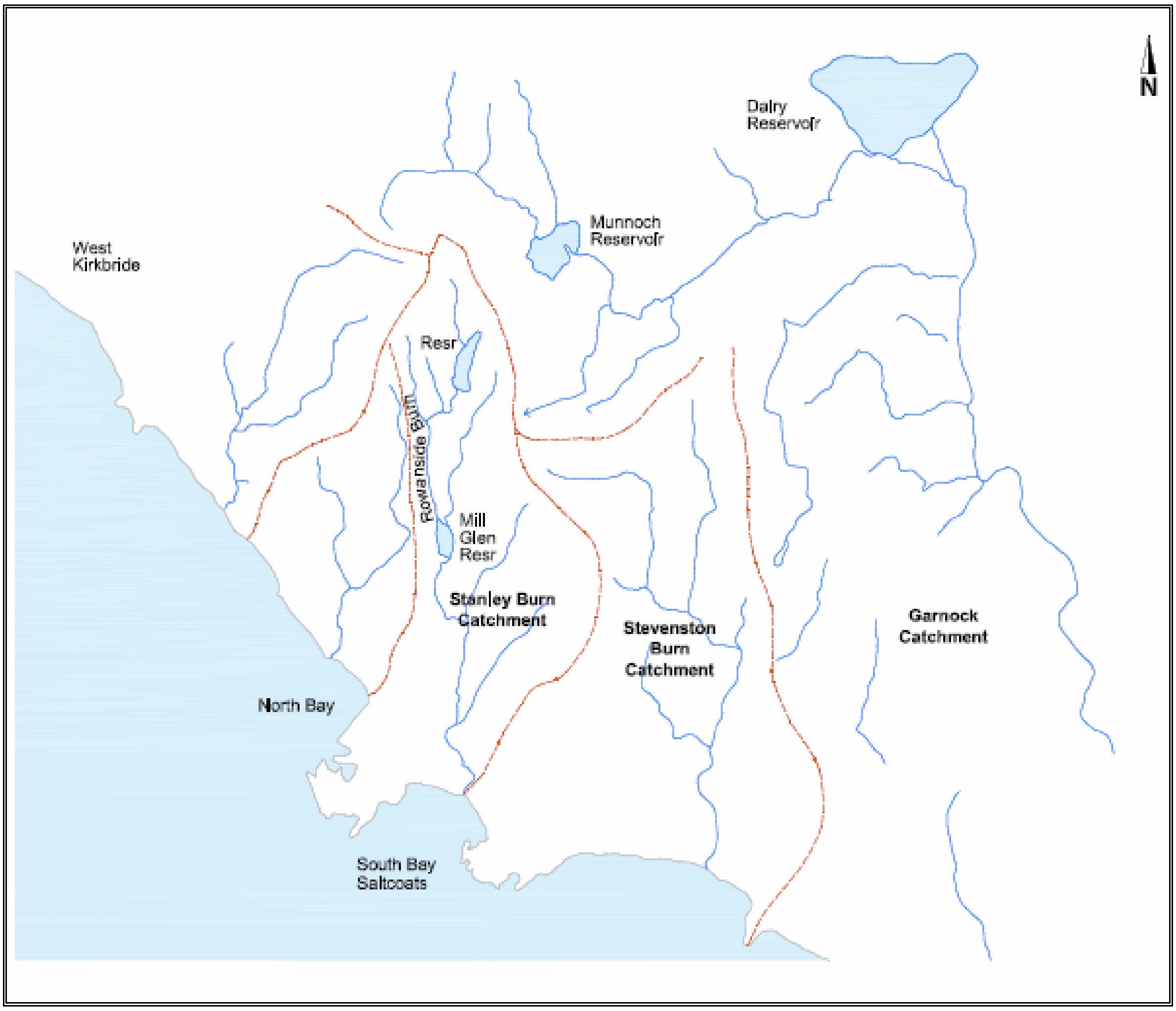
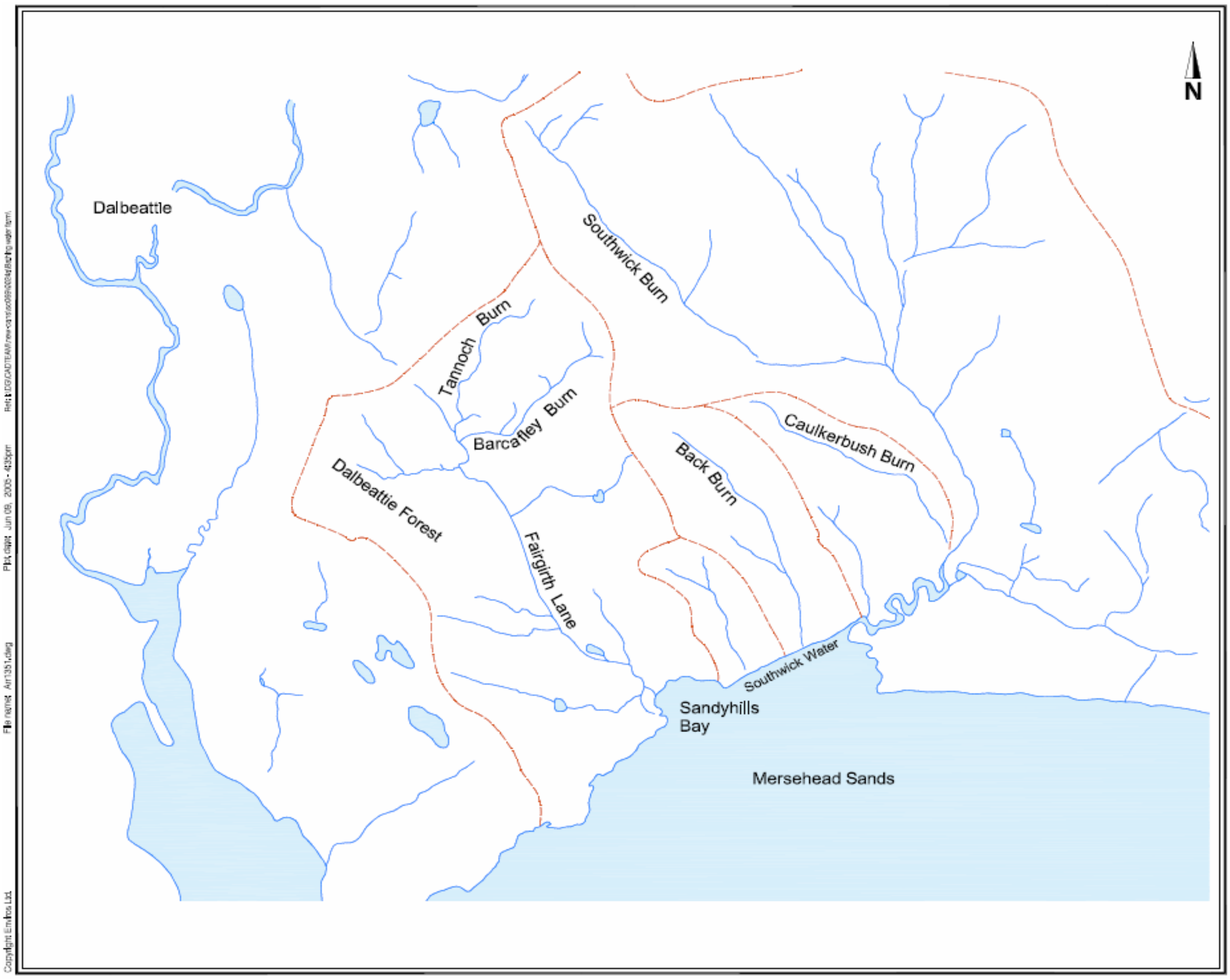


Figure 3.3 Saltcoats Bathing Water Catchment

In the Sandyhills area the pilot farms were distributed between 2 river catchment areas, that of the Fairgirth Lane and the Southwick Water (in reality several minor catchments, e.g the Back Burn and Caulkerbush discharge to coastal water adjacent to the Sandyhills beach, but for simplicity we have considered these to lie within the

Southwick Water catchment). As with Saltcoats the designated bathing water lies within a bay, although this is less well defined and no prominent headland exists. This bathing water receives freshwater flow direct from the Fairgirth Lane and that from Southwick Water discharges to the coast about 2 km to the north-east (Figure 3.4). Again it is not possible to fully quantify the impact that discharges via the Southwick Water have on microbial water quality at the Sandyhills bathing water. However, the close proximity of the Southwick Water to the bathing water, the lack of a bay headland and the direction of flow from Southwick Water implies that material may be transported readily along the coast and this could be important for bathing water quality at the designated beach.

Figure 3.4 Sandyhills Catchment showing important catchments and Sandyhills Bathing Waters



3.3.7 Retention Efficiency

Throughout the catchments pasture, silage, arable, scrub and marsh land areas were identified as these vegetation covers will affect the extent to which material being washed off is trapped. Based on a semi-quantitative assessment a rating of between 0 and 100% was assigned to each farm to describe the run-off efficiency. A low rating represents areas that lack a buffer zone or other structure or feature that might retard the transport of FIO with the water. High retention efficiencies could for instance represent a feature such as a reed-bed where FIO and other particulate material is filtered out. This information has subsequently been incorporated into the modelling assessment. The semi-quantitative assessment undertaken concluded that few buffer areas separated pasture and silage land from water courses and that there was limited trapping of material before run-off waters reached surface watercourses.

3.4 Farm Management Audits

The results from the farm audits are given below.

3.4.1 Farm Steading Audit

A detailed survey of each participating farm was conducted. These surveys were designed to assess drainage and containment of the steading yard and buildings, inadvertent seepage from buildings and yards, seepage of effluent from FYM piles and the potential for FIO from each of these sources to reach surface waters. The proportion of FIO material in each source that could be lost to surface waters was assessed.

Potential and actual mechanisms and pathways by which FIO from the steading could reach surface waters were identified on all farms. These were however deemed to be small (an order of magnitude at least less than field run-off in the winter, and in summer, there are very little livestock in the steading) as long as the management systems in place were correctly maintained. It should be noted however that these losses could probably be reduced further with small improvements to farm infra-structure.

3.4.2 Livestock Management Audit

Consultation with farmers confirmed the number of livestock present and the possibility of livestock having access to water courses.

Although livestock numbers and types varied across the pilot farms, there was a general similarity in practice with cattle housed on the steading through the winter from October-November through to March-April (the exact times depending upon the particular weather that year). Some of the farms also housed ewes during the lambing season. For each farm the typical periods of livestock housing and grazing were recorded.

Throughout most of the farmland area in the mid to upper Fairgirth Lane and Southwick water catchments. The Scottish Executive has undertaken a related project whereby watercourses are fenced, cattle walkways have been introduced to minimise run-off from roads and livestock do not have direct access to water. However, the lower reaches of Fairgirth Lane are not fenced. No formal projects have been commissioned to isolate livestock from watercourses in the Saltcoats catchment.

3.4.3 Manure Management Audit

Through site walk-over surveys and consultation with the farmers, the farm specific manure production, storage and spreading practices were identified and recorded. These audits showed that most farms produced some level of FYM from either cattle or sheep housed during the winter or spring in straw bedded courts. All dairy herds and some beef herds also produced slurry. A farm survey of all the farms in the project was conducted prior to the design stages of the AD and composting plant. Using this data, in conjunction with SEPA estimates of slurry and FYM production on the project farms, it is estimated that from the three Saltcoats area pilot farms approximately 8,200 tonnes of slurry and 2,850 tonnes of FYM are produced and stored annually. Over the six pilot farms in the Sandyhills area 8,700 tonnes of slurry and 2,800 tonnes of FYM were produced annually. The assessments in this project have been based on these figures.

The vast majority of FYM and slurry was produced during the winter when livestock were housed on the steading. On dairy farms where cattle are returned to the steading twice times daily for milking, slurry continues to be produced during the summer, although this is only about 10% of the winter production rate.

On a dairy farm approximately 90% of the total dung produced during the bathing water season will be voided directly to pasture. This situation will be typical of the Saltcoats catchment where the primary livestock are dairy cattle. In the case of beef herds and sheep that remain out at pasture during the bathing water season 100% of the dung produced during the bathing water season will be voided directly to pasture. In the Sandyhills catchment (with a mixture of dairy, beef and sheep) over 90% of the dung produced during the bathing water season will therefore be voided directly to pasture.

Manure management practices and volumes varied widely from farm to farm depending upon the livestock numbers, housing types, diets and duration of housing on the steading.

Farm yard manure was typically removed from straw bedded courts on a monthly basis, some farmers then applied this directly to land, while others stored it for up to 2 years. However, on average the typical storage period (as temporary field heaped middens) was between 6 and 12 months. Land spreading of FYM typically occurs during the spring and autumn. Little FYM is spread during the bathing water season (4-8% of the annual production).

Slurry is typically moved from the small reception tanks to slurry stores on a weekly basis. However, a limited number of farmers did indicate a preference to spread slurry straight to land. In this instance, storage of the slurry is only used when ground conditions are unsuitable, preventing access of agricultural vehicles on to the land.

Slurry application to land is more common during the bathing water season than that of FYM and is typically applied after silage cuts in May-June and July-August (20-30 % of annual production).

The typical spreading times, mass and area over which slurry and FYM is applied have been determined through detailed discussion with the farmers. It should be noted that the questioning was designed to identify typical practices and that adverse weather conditions can lead to some variability in the management of FYM and slurry.

The farmers were also asked whether they envisaged that the spreading times would change following commissioning of the biogas and composting plants. Some farmers were unable to provide a response; others anticipated no change in practice. However, in Saltcoats there was a general preference expressed to increase the amount of slurry spread during the summer period and to reduce the amount of FYM spread. In the Sandyhills area the opposite was true, with an anticipated 50% reduction in summer slurry spreading, but with an increase in FYM spreading.

4. ENVIRONMENTAL MONITORING

A programme of environmental monitoring was undertaken to assess FIO levels and nutrient concentrations. This information has been used in the development and application of risk assessments for FIO fluxes, nutrient leaching and process efficiency. The monitoring had three parts:

- Baseline Monitoring
- Event Monitoring
- Process Monitoring

The baseline and event monitoring focused on FIO levels only while the process monitoring also assessed FIO kill and nutrient concentrations in raw and treated manures.

4.1 Monitoring Procedures

4.1.1 Baseline Monitoring

The baseline monitoring was designed to assess FIO (total coliforms, *E. coli* and Enterococci) loads in fresh and stored animal manures and slurries, and in pasture and silage field soils. Two baseline surveys, April 2004 and June 2004, were conducted before the pilot plants were commissioned. These provided data on FIO counts where livestock were predominantly housed on the steading (April) and after a period of livestock out at pasture (June).

Sample collection, storage and delivery times were based on established protocols to maintain sample integrity. Analyses for total coliforms, *E. coli*, Enterococci and dried solids were undertaken by Scottish Water Laboratories and data have been processed to provide mean and ranges for each slurry, manure or soil type.

4.1.2 Event Monitoring

An event monitoring programme was initiated during July 2004 and used a rapid response team set up to collect land and steading run-off water samples for FIO analysis.

4.1.3 Process Monitoring

FIO Levels and Kill

The process FIO monitoring was designed to assess the FIO load in untreated, treated (either by anaerobic digestion or aerobic composting) and post-treated samples. Post-treated stored samples were also analysed to check for microbial regrowth. Sampling of slurry pre and post AD treatment was relatively straight forward. Sampling locations at the reception tank, digester and from the storage tank were used.

It should be noted that within the storage tank solid material may settle to the bottom, or a crust may form on the surface. Although every effort was made to ensure that the tanks were fully mixed it is possible that the samples collected may not be fully representative of the all material being stored.

Representative sampling of composts for microbial analysis is more difficult, and results are subject to high levels of variation. Although uniform in look and feel, at a smaller scale, compost can be highly heterogeneous. Therefore, to ensure a representative sample was taken a number of small (grab) samples were collected and aggregated and thoroughly mixed into one uniform composite sample prior to delivery to the laboratory. Cross contamination between samples was avoided through use of sterile containers and clean sampling equipment.

The monitoring programme was designed to give an indication of FIO kill efficiency across a range of sites and processes. A monthly monitoring programme was implemented between September 2004 and March 2005. However, monitoring at any one site could only commence after the treatment processes were fully commissioned and this limited the number of samples that could be collected, particularly from the biogas plants that were not commissioned until 2005. For each process, the FIO kill efficiency has been represented as a $\log_{10}$ reduction where $\log_{10}$ 1 represents a factor of 10 reduction, $\log_{10}$ 2 represents a factor of 100 reduction, and, $\log_{10}$ 3 represents a factor of 1,000 reduction.

Analyses for total coliforms, *E. coli*, Enterococci and dried solids were undertaken by Scottish Water Laboratories as in the baseline monitoring programme.

Nutrient Monitoring and Compost Quality

Analysis of nutrients in slurry was initially undertaken by Scottish Water Laboratories. However, analytical services to outside customers were withdrawn after April 22nd 2005, samples taken after this date were therefore analysed by Direct Laboratories in Wolverhampton. Analysis of compost quality was also conducted by Direct Laboratories as this laboratory was able to provide nutrient testing compliant with the British Standards Institution (BSI) Publicly Available Specification (PAS) 100 for composting materials testing standards.

The influence of anaerobic digestion and composting on the following determinants was undertaken: total solids (g/l); nitrate-N (mg/l); total nitrogen (mg/l); total phosphorus (mg/l); total potassium (mg/l); chloride (mg/l); loss on ignition (%wt/wt); and ammonium-N (mg/l) were assessed through the analysis of untreated and treated and, where available, post-treated samples that had subsequently been stored. Post-treated stored samples were collected to assess whether there was any subsequent change in the compost and digestate quality with storage. In addition, selected compost samples were also analysed for extractable phosphorus (mg/kg) and extractable potassium (mg/kg).

Sample collection, storage and delivery times were based on protocols as set out according to PAS100 standards for compost to maintain sample integrity. Although these are less stringent than those that need to be applied to samples for FIO counting, rapid transfer to the laboratory was the normal practice. There are no UK standards applicable to AD digestate at present. The nearest European equivalent is the German RAL 256 standard for liquid and solid digestion residues.

In addition to the nutrient monitoring, selected compost samples were also assessed against PAS100 guidelines.

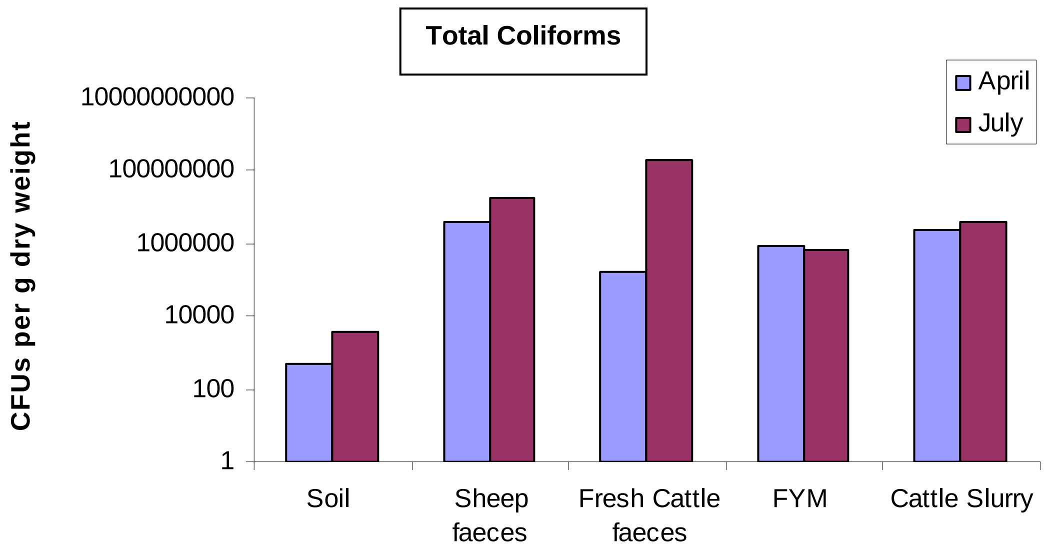
4.2 Baseline Monitoring Results

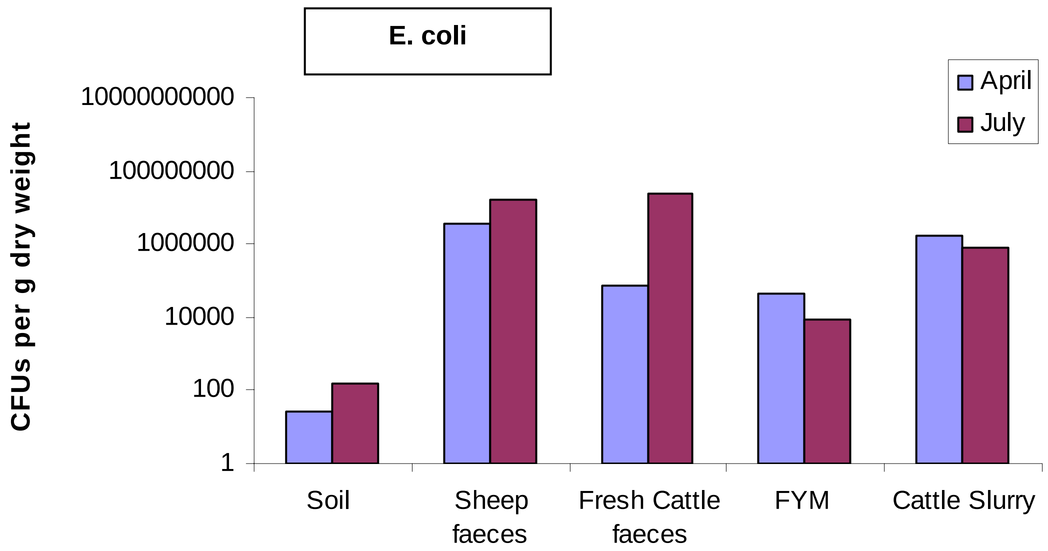
The results from the April and July baseline surveys are summarised in Figure 4.1. In total 61 samples that included soil, fresh and stored slurry and manure samples were taken. All baseline samples showed a wide degree of variability.

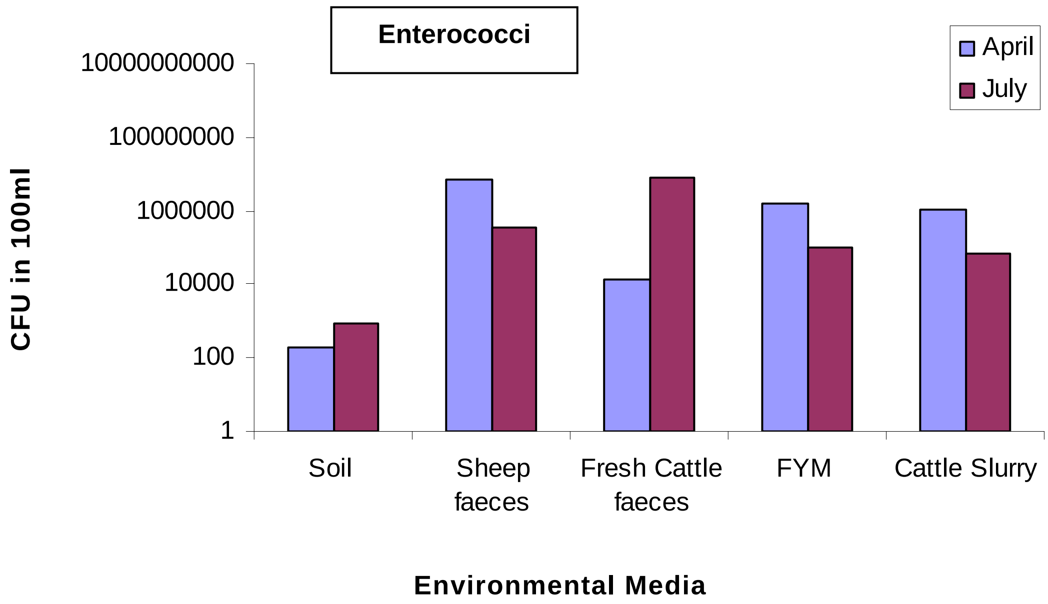
4.2.1 Soil

Values of FIO in pasture and silage field surface soil were of the order of a few tens to a thousand colony forming units per gram (cfu g^{-1}), although some values were below the limit of detection and have been assigned a value of zero. The results indicate an increase in total coliform and *E. coli* levels in soil between the April and July surveys of about an order of magnitude, although Enterococci levels remained similar.

Figure 4.1 Baseline Assessment of Mean FIO counts in Environmental Media







4.2.2 Sheep and Cattle Faeces

FIO loads in fresh sheep and cattle faeces were between 10^4 and 10^8 cfu g^{-1}. They varied between the April and July surveys with levels being slightly higher during the April survey. The April sampling occurred during the cattle winter housing period and so most samples were taken from the farmyard setting. In July the samples were taken primarily from direct deposits to fields during the summer grazing period. It is possible that longer day lengths and increased exposure to sunshine helped kill bacteria that would result in lower microbial content rates.

During April, FIO loads in sheep faeces were higher than those in cattle faeces, but in July the situation was reversed. It has been previously reported that higher FIO loads are found in sheep faeces compared with that from cattle. However, no consistent difference was found.

4.2.3 FYM and Slurry

Mean FIO loads in FYM collected from animal bedding areas on the steading and slurry collected from the reception tanks below the cubicle houses were comparable with those measured in fresh faeces. However, the range was quite variable due to dilution of slurry with water, possible FIO kill by dairy disinfectant water influx to the slurry pit, and the wide range of ages of material sampled, ages that could not always be determined with any degree of accuracy without continual monitoring presence on the farm. The results indicate that there can be up to a $\log_{10}$ 3 reduction in the FIO load of aged compared with fresh material.

4.2.4 Dry solids

The percentage dry solids were also measured in the samples collected. In soils these were approximately 50 %, while those in sheep faeces were 20 – 30 % and those in fresh cattle faeces were 12 – 25 % (and depended upon the presence of bedding material). Values for FYM were comparable with those of fresh cattle faeces while those of the slurry were lower (a mean 4 – 7 %). The lower values in slurry may imply a diluting effect due to urine, parlour or other wash-water and rain-water ingress into the slurry store. Anaerobic digestion biogas generation, heat production and FIO kill are likely to be lower when the percentage solids in the slurry are low.

4.3 Event Monitoring Results

The monitoring team was maintained on stand-by throughout July 2004 and during the initial week of August 2004. However, despite repeated visits when rain events were anticipated, the weather was very dry and limited event-driven pathways were captured. Where samples were collected these were from open drainage ditches running around the edge of fields. The results show *E. coli* loads of 3,800 to 6,200 cfu per 100 ml and *Salmonella* loads of between 200 and 1,000 cfu per g^{-1}. These loads were comparable to those reported in the literature for run-off associated with agricultural land.

4.4 Process Monitoring Results – Anaerobic Digestion

The strategy adopted during this assessment was to collect process samples from across the different sites. This aimed to provide an initial and broad coverage rather than a specific and detailed assessment at any one site. A total of 63 samples were collected on a month by month basis from November 2004 to March 2005, from 4 of the 7 treatment plants. Some of the plants were only commissioned in early 2005 and therefore monitoring did not extend through this period. During each visit 3 samples were collected:

- Untreated slurry collected from after maceration on the inlet line to the digester;
- Digestate collected from the digester outlet pipe; and
- Stored digestate collected from the slurry tank.

4.4.1 FIO Kill

The mean FIO counts in raw slurry, digested, digested and stored and pasteurised slurry are illustrated in Figure 4.2 to provide an overview of the effectiveness of the treatment process and the reduction in FIO load at each stage. A more detailed assessment is also given below.

Pilot AD plants

The log reduction achieved through mesophilic AD was usually in the range 2.1 to 2.6, although figures were recorded outside this range, in particularly during commissioning.

The FIO kill results, presented as a $\log_{10}$ reduction for each sampling visit are given in Table 4.1. Farm A is a beef farm, while farms B, C and D are dairy farms.

It should be noted that the FIO $\log_{10}$ reduction was low after the plants were initially commissioned, but seemed to improve considerably across all plants between December and January. The issue was particularly severe at Farm A in December, when there was virtually no kill calculated. At this time, the percentage solids in the feedstock material were low (4.1%), potentially through the ingress of rainwater into the slurry. However, these were not the lowest percentage solids measured and at Farm C in December a reasonable log kill of between 1.4 and 1.7 was achieved with a 2.5% solids concentration in the feedstock. During the early phases of commissioning at Farm A, the plant was commissioned using stored slurry, and until the cattle had been housed on the steading there was insufficient slurry for proper operation.

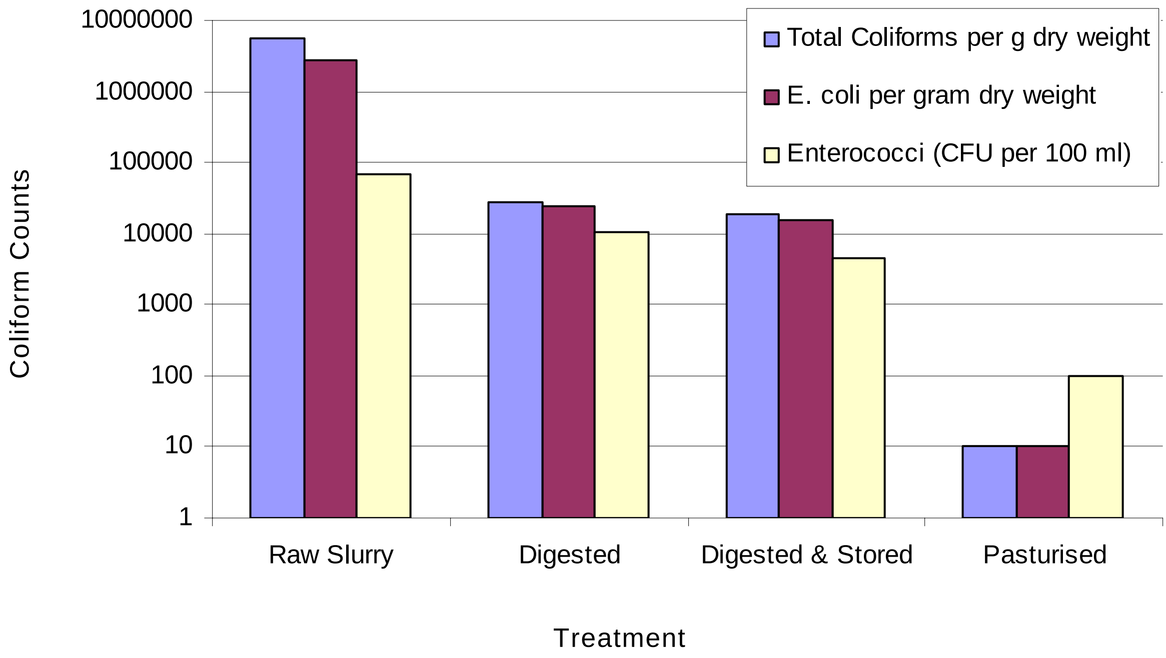


Figure 4.2 Mean FIO levels in raw, digested, digested and stored and pasteurised slurry.

Results from March and April show a more consistent log kill across the sites, with values reaching 4.5. At this time the percentage solids in the feedstock ranged from 5.3 to 7.5%. Across the study better FIO kill is associated with the dairy sites compared to the beef cattle site, particularly at Farm D.

Table 4.1 FIO log kill and solid content by farm and by month

Farm	FIO & %S	Month					
		Nov	Dec	Jan	Feb	Mar	Apr
A	TC	1.3	0.02	2.5	ND	2.2	1.6
	EC	1.0	0.3	2.5	ND	1.1	1.6
	E	0.6	0.7	1.2	ND	0.0	0.8
	%S	4.7	4.1	4.9	ND	7.0	5.9
B	TC	1.0	1.3	2.7	ND	2.8	2.2
	EC	0.6	1.3	2.7	ND	1.7	2.2
	E	0.2	0.3	0.3	ND	0.5	1.4
	%S	ND	5.1	6.4	ND	7.3	6.8
C	TC	ND	1.6	2.3	ND	2.6	ND
	EC	ND	1.7	2.4	ND	2.6	ND

Farm	FIO & %S	Month					
		Nov	Dec	Jan	Feb	Mar	Apr
	E	ND	1.4	1.2	ND	2.6	ND
	%S	ND	2.5	7.0	ND	7.5	ND
D	TC	ND	ND	ND	ND	4.5	ND
	EC	ND	ND	ND	ND	4.3	ND
	E	ND	ND	ND	ND	ND	ND
	%S	ND	ND	ND	ND	5.3	ND

TC = Total coliforms, E = *E. coli*, E = Enterococci, %S = percentage solids in raw slurry, ND=No data

Post Treatment Storage

The log reduction achieved through mesophilic AD plus post-digestion storage was usually in the range 2.3 to 2.8. It is concluded that the effect of storage is a further log reduction of 0.2 above that achieved by mesophilic AD.

In every sample measured the percentage solids in the stored slurry (1.3% to 4.7%) was lower than that in the raw feedstock (2.5% to 7.5%) or the treated digestate (2.2% to 5.9%). This reduction may result from the settlement of solids in the slurry store. Alternatively, it may be indicative of dilution of the slurry with rainwater. It is therefore not possible to definitively state that this further reduction in FIO counts is due to die-off during post-treatment storage.

Pasteurisation

Two pasteurisation trials were run during April and May 2005. This trial was conducted on digestate. The pasteuriser consisted of a tank with an 85 litre capacity, equipped with a heat exchanger in its base. The digestate slurry was re-circulated vigorously in the tank with an external pump. The pasteurisation time was 4 hours, and a temperature of 62°C was maintained.

Figure 4.2 and Table 4.2 show that pasteurisation has reduced the levels of FIO to low levels, in some cases below the levels of detection indicating complete eradication. This represents a log reduction in excess of 5 or potentially 6 compared with untreated slurry.

Table 4.2 FIO content of pasteurised digestate (without storage)

Sample	Total Coliforms per g	*E. coli* per g	Enterococci (CFU in 100ml)
Pasteurised digestate Farm 1-sample 1	<10	<10	<100
Pasteurised digestate Farm 1-sample 2	<1	<1	150
Pasteurised digestate Farm 2- sample 1	<10	<10	0
Pasteurised digestate Farm 2-sample 2	<1	<1	200

Microbial Regrowth

The pasteurisation trials also looked at the possibility that stored pasteurised digestate could become subject to recontamination through microbial regrowth. A series of digested and pasteurised slurry was stored for two week and four week periods using both open and closed storage systems, and then retested. The results are in Table 4.3.

Table 4.3 Pasteurised digestate storage FIO recontamination trial

Sample	Total Coliforms per g	*E. coli* per g	Enterococci (CFU in 100ml)
Trial 1 Baseline Results	***<10***	***<10***	***<100***
14 days open storage	6	<1	71
28 days open storage	<1	<1	<1
14 days closed storage	<1	<1	26
28 day closed storage	<1	<1	<1
Trial 2 Baseline Results	***<1***	***<1***	***150***
14 days closed storage	<1	<1	<1
14 days closed storage	2	<1	240
Trial 3 Baseline Results	***10***	***10***	***100***
14 days open storage	<1	<1	70
28 days open storage	<1	<1	290
14 days closed storage	<1	<1	60
28 day closed storage	<1	<1	1000
Trial 4 Baseline Results	***<1***	***<1***	***400***
14 days closed storage	4	<1	190
14 days closed storage	<1	<1	560

The results show that there has been little recontamination during post-treatment storage, with again many samples recorded as below the level of detection. Any regrowth that occurred tended to be limited to Enterococci. This is greater in closed containers and may be due to the fact that the closed storage conditions were favourable for Enterococci growth. In both the farms during Trial 2 closed storage was disrupted due to the tank lid blowing off. This may have led to some recontamination and the slightly increased level of Enterococci. Again, the closed sample has a higher level of FIO. The rest of the samples seemed to show a decrease in FIO load with increased storage. This gives further confidence to the treatment scenario of AD with pasteurisation, by showing that even if the digestate is stored for a period before land application, recontamination is unlikely to occur.

4.4.2 Assessment of Nutrient Changes

A range of total and extractable nutrients were assessed in raw, digested, and stored digestate. The results are summarised in Tables 4.4 and 4.5 for each farm assessed during December 2004 and January, March and April 2005. During each visit the percentage solids, total N, nitrate, ammonium-N, total phosphorous and total potassium were measured.

The results for nitrogen related nutrients (Table 4.4) show that in the raw feedstock total nitrogen concentrations ranged from 2,200 to 4,400 g l^{-1}; in the digestate total nitrogen ranged from 2,400 to 4,100 g l^{-1}; and in the stored digestate from 1,500 to 3,200 mg l^{-1}. Across the sampling regime there was a general reduction in the total nitrogen concentration between raw feedstock and the stored digestate. Nitrate concentrations showed a similar reduction with values ranging from 0.3 to 10 mg l^{-1} in the raw feedstock, 0.4 to 6.6 mg l^{-1} in the digestate and 0.3 to 5.8 in the stored digestate. Ammonium concentrations varied from 644 to 2,270 mg l^{-1} in the raw feedstock, 536 to 1,900 mg l^{-1} in the digestate and 654 to 1,780 mg l^{-1} in the stored digestate. Again on each site visit there was a general decrease in the ammonium between fresh material and treated and stored material.

Some loss of nitrogen in the biogas is possible, however the ranges of total nitrogen concentration in raw feedstock and digestates was similar, indicating that these losses are probably small.

Table 4.4 Total Nitrogen, Nitrate and Ammonium Concentrations in raw, treated and stored slurry

Farm & Nutrient (mg l^{-1})		Month											
		Dec			Jan			Mar			Apr		
		R	T	S	R	T	S	R	T	S	R	T	S
A	TN	2,500	2,400	1,600	2,400	2,400	1,500	2,500	2,500	1,500	2,200	2,400	1,700
	N	2.8	6.6	3.6	6.6	4.2	3.1	1.5	0.4	0.3	10	6.1	5.2
	A	1,510	1,230	929	929	905	678	644	827	654	956	951	898
B	TN	4,100	3,200	1,500	2,900	3,400	2,800	3,600	3,700	2,700	3,400	3,700	3,200
	N	4.7	2.7	1.6	3.8	4.2	3.5	0.3	0.4	0.3	5	6.1	5.8
	A	2,270	1,900	1,020	1,340	1,510	1,220	1,420	536	848	1,420	,1640	1,780
C	TN	2,600	2,500	ND	4,100	2,800	ND	4,400	4,100	3,100	ND	ND	ND
	N	1.0	0.7	ND	5.3	3.5	ND	0.4	0.7	0.3	ND	ND	ND
	A	1,520	1,640	ND	1,390	1,430	ND	1,380	1,850	1,090	ND	ND	ND
D	TN	ND	ND	ND	ND	ND	ND	3,500	3,700	3,200	ND	ND	ND
	N	ND	ND	ND	ND	ND	ND	0.6	0.3	0.3	ND	ND	ND
	A	ND	ND	ND	ND	ND	ND	1,400	1,100	985	ND	ND	ND
Mean TN		3,100	2,700	1,600	3,100	2,900	2,200	3,500	3,500	2,600	2,800	3,100	2,500
Mean N		2.8	3.3	2.6	5.2	4.0	3.3	0.7	0.5	0.3	7.5	6.1	5.5
Mean A		1,767	1,590	975	1,220	1,282	949	1,211	1,078	894	1,188	1,296	1,339

TN = Total Nitrogen (mg l^{-1}), N = Nitrate (mg l^{-1}), A = Ammonium (mg l^{-1}), R = Raw slurry, T = treated slurry, S = Treated and stored slurry

The lower nitrogen concentrations observed in the stored slurry may arise through rainwater dilution of the slurry. Furthermore, whilst the samples of raw slurry and digestate were taken from fully mixed tanks, it was difficult to mix the large open-top digestate storage tanks. These were subject to settlement and it is possible that the samples which taken were taken from the top of the tank had a lower nutrient concentration than the tank as a whole.

With reference to other nutrients, in some instances the total phosphorous concentration increases with treatment, but in others it does not. Total potassium concentrations tend to increase, but again this is not consistent through the samples. Changes in chloride concentrations are again variable. The percentage solids consistently decrease from raw to treated samples and then further in stored digestate. The loss in solids is mainly due to the conversion of organic matter into methane, carbon dioxide gas and water during the digestion process.

Table 4.5 Total Phosphorus, Total Potassium and Chloride Concentrations in raw, treated and stored slurry

Farm & Nutrient (mg l^{-1})		Month											
		Dec			Jan			Mar			Apr		
		R	T	S	R	T	S	R	T	S	R	T	S
A	TP	698	494	122	383	495	232	470	558	763	332	425	229
	TK	4,520	2,970	1,730	2,260	2,400	1,740	2,320	2,760	2,860	2,100	2,520	2,410
	Cl	1,030	674	1,280	1,330	1,390	1,110	151	140	120	1,190	1,390	1,180
	%S	6.5	3.4	1.3	4.9	3.6	1.6	7.0	5.3	4.2	5.9	5.2	4.8
B	TP	441	260	ND	513	601	656	737	652	454	592	659	533
	TK	2,350	2,240	ND	3,020	3,820	2,960	3,440	3,990	3,110	4,410	4,580	4,380
	Cl	ND	ND	ND	2,360	2,610	1,850	213	298	227	2,230	3,030	2,850
	%S	2.3	2.0	ND	6.4	5.4	4.7	7.3	6.0	4.0	6.8	5.9	3.7
C	TP	ND	ND	ND	860	573	ND	968	964	665	ND	ND	ND
	TK	ND	ND	ND	3,940	2,690	ND	4600	4,580	3,450	ND	ND	ND
	Cl	ND	ND	ND	2,450	1,430	ND	184	213	180	ND	ND	ND
	%S	ND	ND	ND	7.0	2.7	ND	7.5	5.3	3.8	ND	ND	ND
D	TP	ND	ND	ND	ND	ND	ND	562	716	634	ND	ND	ND
	TK	ND	ND	ND	ND	ND	ND	1,970	2,160	1,930	ND	ND	ND
	Cl	ND	ND	ND	ND	ND	ND	129	115	92	ND	ND	ND
	%S	ND	ND	ND	ND	ND	ND	5.3	4.2	3.6	ND	ND	ND
Mean TP		570	377	122	585	556	444	684	723	629	462	542	381
Mean TK		3,435	2,605	1,730	3,073	2,970	2,350	3,083	3,373	2,838	3,255	3,550	3,395
Mean Cl		1,030	674	1,280	2,047	1,810	1480	169	192	155	1,710	2,210	2,015
Mean S		4.4	2.7	-	6.1	3.9	3.2	6.8	5.2	3.9	6.4	5.6	4.3

TN = Total Phosphorus (mg l^{-1}), TK = Total Potassium (mg l^{-1}), Cl = Chloride (mg l^{-1}), %S = Percentage Solids, R = Raw slurry, T = treated slurry, S = Treated and stored slurry

4.4.3 AD Process and Digestate Quality

The AD process has been successful, in that all plants are now running continuously. However, there have been some differences in the FIO kill, biogas production, digestate condition and operational characteristics between the different plants.

The slurry passing through the biogas reactor is a continuous stream with a mean residence time of 20 days. Raw slurry and digestate samples collected concurrently do not therefore represent the same material. Some of the differences observed may also relate to changes in the quality of the raw slurry input. This may arise through the change from the use of stored slurry held since the previous season to use of fresh material that becomes available when the cattle return to the steading. Differences may also arise due to different amounts of rainwater ingress into the slurry. Again this may vary from farm to farm and also with time due to variations in rainfall. Other points of note are given below:

- All of the farms were found to have lower dry matter content than that normally expected from dairy slurry (typically in the range of 4 to 7.5% instead of an anticipated 9.5%). This may be due to water ingress from steadings, either from rainwater or dairy wash water. This may result in lower operating temperatures, lower biogas yields and lower FIO kill.

- Slurry that had been stored for a number of months prior to AD treatment gave a poor biogas yield; this was particularly a problem in farm A during December and January.

- One of the plants experienced pump problems due to fibrous material clogging the intake line, which would seem to suggest that perhaps the diet of the cattle differs from some of the other farms, or possibly that some bedding material has entered the slurry. This problem was satisfactorily solved during the first months of operation.

- The diet of the animals on the farms will influence the production of methane. For example, if the cattle are fed energy dense feed (spent brewer's grain, sugar beet) as opposed to less energy dense (silage) there will be a higher energy content in the slurry. This would then provide a greater energy source for the methanogenic bacteria in the digester and result in greater methane production.

- All of the farmers have commented upon the reduction in odour of the digestate material in comparison with untreated slurry, and have noticed a marked reduction in odour when the material is spread on land.

- However some odour has been noted at some of the biogas plants if any of the biogas vents to air rather than being burned.

- Farmers have noted that the digestate is more uniform and thinner in consistency and easier to spread than slurry, which aids spreading efficiency.

- Farmers have noted an increase in field yields following application of digestate, and a reduced need for artificial fertiliser application.

It is worth noting that the AD plants needed some initial operation time to achieve expected process efficiency. However, with the limited data set available it is not possible to fully substantiate this or to present a data set that shows full operational capacity. Notwithstanding this, it was identified that the log_{10} reduction values recorded for total coliforms and *E. coli* were greater than expected from AD treatment. The relatively limited datasets available mean that it is not possible to fully assess this. This could represent further die-off or potentially dilution of the post treated slurry with rain or other clean water.

The German RAL 256 standard for digestion products gives recommendations for odour quality of digestate, and quantitative limits for heavy metal quantities, degree of digestion, pathogen load and alkaline substances. However, no definitive limits are set for the nutrient content of digestate under the German RAL standard. Also there is no UK accepted standard and so it has not been possible to evaluate the digestate from the farms involved at present.

4.5 Process Monitoring Results – Aerobic Composting

All three composting facilities (Farms E, F and G) were routinely monitored throughout the commissioning and operational phases between November 2004 and March 2005.

Farm E was a sheep farm generating FYM with a high straw content, while farms F and G were beef and dairy farms respectively. At farm F, part of the FYM generated arose from straw set out in an open yard.

In total, 36 samples were collected over a five month period from each of the farms. Separate samples were also collected from Farm E for assessment against PAS100 guidance. During each sample collection the following information was collected:

- Approximate age and starting date of the compost windrow;
- Highest temperature reached of the windrow during composting;
- Position of samples collected in the windrow;

The samples were then sent for analysis to determine the FIO level (total coliforms, *E. coli* and Enterococci) and nutrient content (total nitrogen, water soluble ammonia, water soluble nitrate, total phosphorus, extractable phosphorus, total potassium, extractable potassium, water soluble chloride, loss on Ignition and the carbon to nitrogen ratio).

It should be noted that the sampling programme relied upon the farmers taking daily measurements of the compost temperature to allow careful evaluation of how the temperature in the windrow was developing. However, full temperature and windrow turning records were not kept by all farms and interpretation has had to be limited to the measurements available.

4.5.1 FIO Kill

Unlike anaerobic digestion which is a more discrete and controlled process operating over a set timescale, composting can be more variable.
To illustrate this variability the FIO loads measured in the compost are presented below for each farm in Tables 4.6 to 4.8. The minimum and maximum FIO kill compared against fresh manure that was measured in the composting material are then illustrated in Table 4.9.

Table 4.6 FIO levels and Compost Characteristics at Farm E

Farm E		Month							
		Nov	Dec		Jan		Feb		Mar
Compost Age (d)		SP	17	SP	SP	Fresh	7-14	SP	4
Total FIO Counts/g dry weight	TC	37	440,000	19	680	10,000,000	58,000	18	45,000
	EC	37	29,000	19	21	1,000,000	440	18	45,000
	E	40,000	64,000	1000	2,200	260,000	11,000	200	77,000
Temp (°C)		ND	ND	ND	ND	ND	ND	ND	ND
% Dried Solids		54	24	22	47	22	34	55	31
C:N Ratio		ND	17.3	19	8.3	19	15	9.3	20

(SP= stockpile)

Table 4.7 FIO levels and Compost Characteristics at Farm F

Farm F		Month											
		Nov			Dec			Jan		Feb		Mar	
Compost Age (d)		3	14	SP	30	SP	13	48	18[1]	60-70	36[1]	105	75
Total FIO Counts/g dry weight	TC	230,000	230,000	2,100	250,000	120,000	95,000	11,000	5,000,000	1,000,000	28,000	240,000	85,000
	EC	150,000	140,000	360	1,200	86,000	11,000	2,000	230,000	120,000	5,300	52	17,000
	E	36,000	60,000	400	100	300	4,700	600	2,600	800	8,200	6,200	7,300
Temp (°C)		ND	19-30	ND	45-50	ND	45-50	ND	ND	ND	ND	ND	ND
% Dried Solids		23	30	30	30	39	25	19	19	20	22	19	23
C:N Ratio		ND	ND	ND	13	11	24	19	17	13	20	18	17

1. compost very wet with effluent seeping out of the bottom

(SP= Stockpile)

Table 4.8 FIO levels and Compost Characteristics at Farm G

Farm G		Month						
		Nov	Dec[1]	Jan	Feb	Mar		
Compost Age (d)		28-421	21-282	28	42	7	73	7
Total FIO Counts/g dry weight	TC	18,000	6,600	30	15,000	10,000	3,200,000	1,900,000
	EC	38	34	30	400	35	260,000	45
	E	1,300	240,000	2,200	7,300	40,000	32,000	22,000
Temp (°C)		42-58	ND	60	60	ND	44	44
% Dried Solids		26	29	33	27	28	22	22
C:N Ratio		ND	10	12	12	10	11.9	12

1. Mushroom growth on windrow.

Table 4.9 FIO Kill through Composting

	Total Coliforms (CFU per g)	*E. coli* (CFU per g)	Enterococci (CFU in 100ml)
Min log reduction	Increases were observed	Increases were observed	Increases were observed
Max log reduction	5.7	3.8	3.1

The results show a maximum $\log_{10}$ reduction of 5.7 for Total Coliforms; a $\log_{10}$ reduction of 3.8 reduction for *E. coli*; and a $\log_{10}$ reduction of 3.1 reduction for Enterococci. However, the results also show minimum $\log_{10}$ reductions that indicate an increase in FIO. This is due to there being very wide ranges in FIO kill between different farms.

From tables 4.6 to 4.8 it can be seen that most of the successful FIO kill achieved was from composting conducted at farm E. This may in part be due to a different management approach to the composting operation.

Some of the lower kills related to relatively immature compost. For many of the samples the FIO levels in the stockpiled material that has been removed from the windrow are low (particularly at Farm E). However, there were instances when the FIO loads of the stockpiled material were still high (for instance at Farm F) where total coliform levels were 120,000 CFU g^{-1}, *E. coli* 86,000 CFU g^{-1} and Enterococci of 4,700 CFU in 100 ml; in material that was then applied to land.

Where records were available compost temperatures achieved 45 to 50°C. Some samples were measured at 60°C, and at one occasion reached 74°C. However, over a two week period one windrow was limited to temperatures of between 19 and 30°C. Comment was also made by the farmers that temperatures tended to be lower at the end of the windrows near the open ends of the composting sheds. Due to the limited data it is not however possible to draw clear conclusions between compost temperature and FIO kill.

The highest percentage solids were measured at Farm E, which could explain the increased success in FIO achieved at this farm. Ideal moisture content for composting is around 35 to 40% dry solids. These moisture levels were achieved more frequently at Farm E, whereas other farms had generally lower dry solids contents. In one instance, where a windrow was particularly wet due to possible influx of rainwater during transport to composting shed, (Farm F), despite a relatively long composting period (36 days) there were still relatively high levels of FIO present (1,000 to 10,000 cfu g^{-1}).

A further factor in FIO kill was the turning frequency used by farmers to aerate the FYM. If turning was too infrequent, combined with high moisture contents, low aeration levels could have reduced heat production and subsequent composting temperatures.

These results show that composting process, if carefully controlled, is capable of very large (up to 500,000-fold) reductions in FIO. However, minimal kill can occur where FYM moisture contents are not kept in optimum ranges, and where turning is too infrequent.

4.5.2 Assessment of Nutrient Changes

The results for the nutrient assessment of composts are given for each farm in Tables 4.10 to 4.12 below.

Table 4.10 Nutrient Concentrations in Compost at Farm E

Farm E	Month							
	Nov	Dec		Jan		Feb		Mar
Compost Age (d)	SP	17	SP	SP	Fresh	7-14	SP	4
Total Nitrogen (mg l^{-1})	3.2	28	34	38	25	2.9	3.3	1.9
Nitrate (mg l^{-1})	180	5	210	390	7	<5	5	5
Ammonia (mg l^{-1})	17	59	89	100	1,300	300	140	190
Total Phosphorus (mg l^{-1})	9,900	5,300	11,000	11,000	5,000	10,000	12,000	4,700
Extractable Phosphorus (mg l^{-1})	350	210	370	400	190	380	380	240
Total Potassium (mg l^{-1})	44,000	32,000	49,000	42,000	36,000	20,000	48,000	28,000
Extractable Potassium (mg l^{-1})	6,900	2,200	7,500	6,700	2,600	2,300	6,600	1,900
Chloride (mg l^{-1})	4,500	1,600	4,900	4,500	2,100	1,900	4,200	1,700

Table 4.11 Nutrient Concentrations in Compost at Farm F

Farm F	Month											
	Nov			Dec			Jan		Feb		Mar	
Compost Age (d)	3	14	SP	30	SP	13	48	18[1]	60-70	36[1]	105	75
Total Nitrogen (mg l^{-1})	1.5	2.3	27	23	20	21	26	20	3.3	2.0	2.2	2.7
Nitrate (mg l^{-1})	31	7.0	7.0	36	5.0	10	7.0	54	42	15	5.0	14
Ammonia (mg l^{-1})	51	7.0	34	7.0	19	3.0	52	8.0	9.0	88	76	9.0
Total Phosphorus (mg l^{-1})	4,200	9,100	8,300	9,100	5,400	7,900	5,400	10,000	7,800	5,900	7,800	7,700
Extractable Phosphorus (mg l^{-1})	240	250	320	250	200	310	240	340	33	25	29	28
Total Potassium (mg l^{-1})	16,000	42,000	28,000	39,000	22,000	28,000	31,000	40,000	32,000	27,000	37,000	28,000
Extractable Potassium (mg l^{-1})	1,300	6,200	2,600	6,000	1,500	1,900	2,600	3,400	2,300	2,200	3,400	2,600
Chloride (mg l^{-1})	1,100	4,000	2,300	4,100	9,300	1,200	1,500	2,300	1,300	97	2,000	1,700

1. compost very wet with effluent seeping out of the bottom

In comparison with slurry, treated FYM showed a wide variation in nutrient concentrations, however increase in the nitrate, potassium and phosphorus content and water soluble chloride content were all measured. This increase was due to nutrients being concentrated through the breakdown of organic matter and the resultant loss of compost mass to the atmosphere in the form of carbon dioxide and water. The results show that, on average, most nutrients were concentrated in this way.

Other nutrients such as total nitrogen decreased in concentration from potential loss through ammonia volatilisation. This is dealt with in greater depth in Chapter 5. Nutrients may also have been lost from the compost as dissolved salts in leachate, particularly if material was allowed to become wet from rain ingress. As expected, ammonia contents were reduced on average; usually associated with an increase in nitrate (through oxidation of ammonium salts into nitrates by nitrifiying bacteria).

Table 4.12 Nutrient Concentrations in Compost at Farm G

Farm G	Month						
	Nov	Dec	Jan	Feb	Mar		
Compost Age (d)	28-42	21-28	28	42	7	73	7
Total Nitrogen (mg l^{-1})	3.2	3.3	3.3	3.2	3.4	2.0	2.1
Nitrate (mg l^{-1})	6.0	98	8.0	31	46	5.0	5.0
Ammonia (mg l^{-1})	5.0	4.0	29	23	5.0	85	8.0
Total Phosphorus (mg l^{-1})	7,900	7,200	12,000	11,000	11,000	3,900	4,900
Extractable Phosphorus (mg l^{-1})	240	270	300	350	300	200	250
Total Potassium (mg l^{-1})	44,000	42,000	33,000	37,000	40,000	12,000	15,000
Extractable Potassium (mg l^{-1})	43,000	47,000	3,300	4,200	3,800	1,100	1,800
Chloride (mg l^{-1})	2,300	2,900	3,100	3,200	6,500	490	1,100

4.5.3 PAS100 Compliance

Mature and stockpiled compost samples from Farm E were also assessed for PAS100 compliance. The industry standard for compost quality in the UK is the British Standards Institution (BSI) Publicly Available Specification (PAS) 100 for composted materials (or BSI PAS100). The BSI PAS100 was developed by the Composting Association and the British Standards Institution following extensive consultation across the UK compost industry. BSI PAS100 specifies the minimum requirements for the selection of input material, process control and monitoring during composting, and the final quality of the composted materials; as well as standards for the product information and labelling.

The results from the PAS100 tests are given in Table 4.13. These show that:

- the compost was well within the limits set for metals (copper, zinc, cadmium etc), and in most cases the sample only contained approximately one quarter of the recommended limit.

- A particle size distribution test was also conducted. This was done using a sieving method, and found that 28 mm was the largest particle size, with over 50% within 10 mm. The bulk density was found to be 0.30 t per m^3 for loose bulk density and 0.51 t per m^3 for compacted bulk density. The particle size distribution of a batch of compost will be one of the determinants that is used to grade the compost.

- The mean *E. coli* content of the compost was compliant with BSI PAS100 standards. However on some occasions maximum values did exceed this standard. The *Salmonella* content was measured on a few occasions at the beginning of the monitoring trial. Although *Salmonella* was detected, values were near to the limit of detection.

- Other analyses of compost product quality included total nutrients such as nitrogen, phosphorus, and potassium (N, P, and K). The content of these nutrients in the final compost was in line with other composts produced in the UK derived from other materials such as green waste.

Table 4.13 Analyses of FYM derived Compost

Parameter	BSI PAS100 limits	Farm results		
		Mean	Min	Max
Dried Solids (% w/w)	—	34.0	19.3	54.8
Total Nitrogen (%DM)	—	2.63	1.94	3.76
Water soluble ammonia (mg/kg)	—	730	3	7,132
Water soluble nitrate (mg/kg)	—	49	0	391
Total Phosphorus (mg/kg)	—	8,905	4,690	14,000
Extractable phosphorus (mg/kg)	—	596	240	2,300
Total Potassium (mg/kg)	—	37,223	14,900	59,000
Extractable potassium (mg/kg)	—	8,618	1,820	37,000
Water soluble chloride (mg/kg)	—	2,682	965	6,540
Organic Matter (loss on Ignition %DM)	—	60.4	36.7	81.3
Carbon/Nitrogen (C:N) ratio	—	14.3	8.3	23.3
pH	—	8.30	8.10	8.70
Cadmium (mg/kg)	1.5	0.05	0.05	0.05
Chromium (mg/kg)	100	8.65	1.50	21.00
Copper (mg/kg)	200	24.75	14.00	37.00
Lead (mg/kg)	200	4.98	2.30	10.00
Mercury (mg/kg)	1.0	0.10	0.10	0.10
Nickel (mg/kg)	50	4.58	2.10	9.20
Zinc (mg/kg)	400	151	94	200
Salmonella spp.	Absent in 25 g	28	13	43
Escherichia coli	1,000 CFU per g	208	10	1,180

4.5.4 Composting Process and Quality

A wide variability in FIO kill and nutrient concentrations was observed in the samples analysed. The timescales of compost treatment operation are partly dependent upon the farmers rather than automated processes. It was not therefore possible to sample the compost at predefined ages. The results are therefore more difficult to interpret. The lack of clear record keeping (windrow age, turning schedule and temperature) also limited the assessment. However, it is clear from the results that the quality of the end material varied widely, both in terms of FIO kill and nutrient content.

These variable results could be due to a number of possible factors. For example, if the composting feedstock mixture was not correctly formed (e.g. material was too wet) high composting temperatures may not be achieved due to lack of adequate aeration (oxygen supply). This would result in low FIO kill. On Farm F, the compost was continually wetter than expected, and at one time was so wet that effluent was seeping out of the bottom. As described previously this probably arises from the fact that straw on the farm is used to bed an open yard and can potentially get water soaked by rain.

Furthermore, if windrows are not adequately turned during high composting temperatures, material at much cooler temperatures on the outer surface of the windrow will not be exposed to high temperatures at the centre of the windrow, and will retain high FIO levels. On one occasion, compost turner breakdown on one farm delayed turning for one week.

If careful composting operating procedures are not followed there is also the opportunity for cross-contamination, whereby processed material is contaminated with unprocessed material, reintroducing FIO into the compost. Where this occurs, there is the possibility of FIO re-growth, especially in material reaching the end of the composting process (e.g. compost storage) where much lower temperatures are achieved. Prolonged storage of compost material that may have encouraged such FIO re-growth was observed on a number of occasions.

Despite the problems identified, compost that is easy to handle, has a low FIO count and is compliant with PAS100 requirements has been produced.

It is advised that a more thorough examination of the process is undertaken in the future. It would be useful to monitor a number of windrows from the initial feedstock mixture through a number of weeks to the final product. Taking samples on a frequent basis (e.g. weekly) would provide a much more detailed profile in the reduction of FIO during composting. Looking at different turning rates could also eliminate the importance of thorough mixing of material during high composting temperatures to ensure that an adequate amount of material is exposed to the temperatures required for efficient FIO kill. More frequent temperature monitoring would also provide information on the importance of temperature in FIO reduction, and could highlight how FIO reduction may occur without excessively high composting temperatures. Factors effecting FIO re-growth in cooler material towards the end of the process could also be examined.

5. MODELLING THE EFFECT OF MANURE TREATMENT ON FIO AND NUTRIENT FLUXES

5.1 Introduction

To assess the risk from diffuse FIO sources a conceptual model of potential agricultural sources of FIO was developed. The conceptual model focused on FIO transport pathways and controlling processes, including treatment, from source through to catchment watercourses. The conceptual model was parameterised and encoded in the Enviros modelling tool, AMBER, to produce an Agricultural Risk Assessment Model, (ARAM). ARAM was used to inform the environmental, sustainability and economic appraisal.

The specific objectives of this modelling phase of the project were to:

- Develop a conceptual model of FIO source-receptor-pathways (S-R-P);
- Use the environmental monitoring data and literature reviews to quantify these S-R-P;
- Formulate this quantitative data into a new software tool, ARAM using the Enviros software system AMBER; and,
- Develop protocols for application of ARAM and apply the model to assess FIO losses to watercourses during different manure management scenarios.

In addition to the development of ARAM, an existing software tool, MANNER, was used to evaluate the potential for nitrogen based nutrient uptake and loss from agricultural systems depending on different manure management practices.

Details about the FIO sources, ARAM assessment tool and the conceptual model development are in Annex 2.

5.2 Scenarios Assessed

Typically, the historical behaviour consisted of the farmers storing slurry for a number of months and FYM (in stores or temporary field heaps) for up to one or two years before land application. These manures are generally surface applied to land throughout the winter and after the first cut of silage. However, it is possible that all farms could spread during the summer. SEPA confirmed that a number of bathing water quality non compliances have been related to manure spreading to land during the bathing water season. This typically follows silage cut in May/June, July/August and potentially again in September.

To assess the FIO risk reduction by the installation of the biogas and composting plants on individual farms, three treatment or management options have been assessed.

- No treatment;
- Full treatment (biogas and composting of all manures across all main farms);
- Zero grazing (with biogas and composting treatment of all manure).

The zero grazing option assumes that there are no FIO losses from the steading and that the farms are fully compliant with legislation and good practice guidance. The other options do assume steading losses as the project called for modelling of a real situation including pathways from the steading as well as those from the land. Evidence of run-off or drainage from the steading was observed on most of the farms visited. Thus the zero grazing option as modelled will give a result superior to the present real life situation.

It is important to note that zero grazing is not a common practice in Scotland, but is included here to evaluate the potential environmental benefits it may offer.

For each of these treatment options ARAM modelled three different spreading event options:

- Non event condition;
- No spreading prior to an event; and,
- Spreading 1 day prior to an event condition;

The combination of treatment and the spreading options give nine scenarios which are assessed. The differences between the FIO fluxes for each scenario illustrate the risk reduction achieved. Results for all these scenarios are presented below and the implications for bathing water quality discussed.

5.3 FIO Fluxes and Bathing Water Quality

5.3.1 Scenario result presentation and description

The results of the nine assessed scenarios are shown in the bar charts, Figure 5.1 (Saltcoats catchment) and Figure 5.2 (Sandyhills catchment) below. In each chart the nine scenarios listed above are represented by three groups of three bars. The three bars in each group represent the different manure treatment and farm management and spreading options. To aid interpretation of the results each column in the figures is labelled:

- The prefix A refers to Saltcoats, while B refers to Sandyhills;
- The second numeral 1, 2, or 3 refers to the **spreading options** described below :
    - **Spreading Option 1** Non event conditions represent the continuous flux of FIO from land or steadings to watercourses when there are no significant rainfall events;
    - **Spreading Option 2** No spreading prior to an event, i.e. there is rainfall driven wash off from yards and hard standing areas and from material deposited to fields by cattle at pasture, but no recent land application of material prior to the rainfall event; and,
    - **Spreading Option 3** The pathways described above are active, but there has also been land application of material, and FIO in this material can be washed into catchment watercourses;
- The final digit i, ii or iii refers to the **treatment options** (described below):

- **Treatment option i** is the first bar (blue) and represents the total flux of FIO from agricultural livestock sources assuming that none of the manures produced are treated before being spread to land.

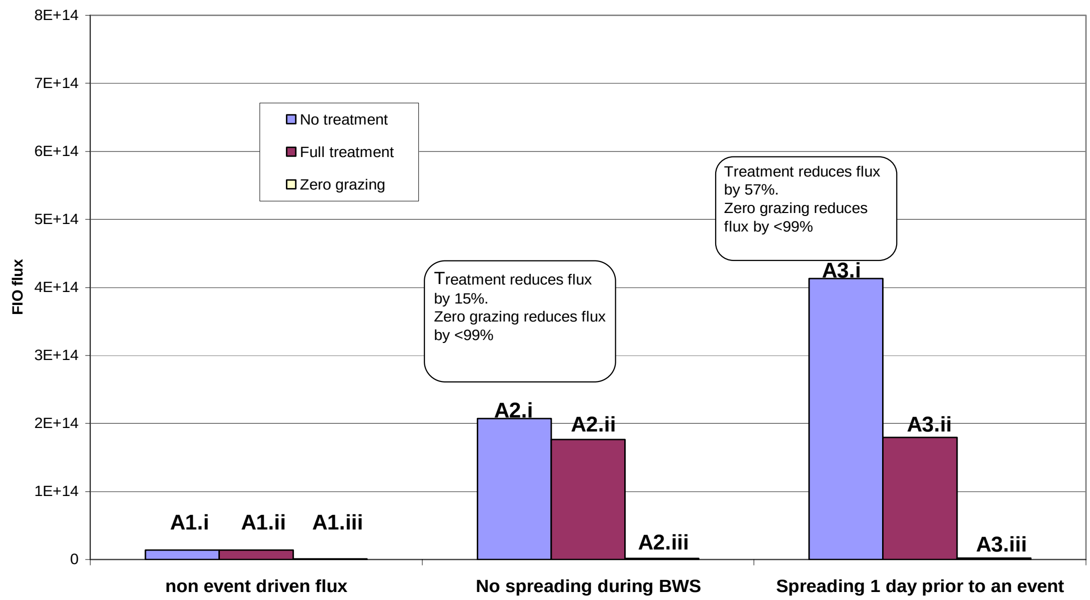
- **Treatment option ii** is the second bar (purple) represents the FIO flux from agricultural livestock sources (including cattle at pasture and steading losses), but assuming that all of the FYM and slurry is treated via composting or biogas before being spread to land.

- **Treatment option iii** is the third bar (yellow) represents the FIO flux from agricultural livestock sources assuming that a zero-grazing management system is employed on all farms, that is, the livestock are housed all year, and all the FYM and slurry produced is treated before being spread back to land.

5.3.2 Results

The 'non-event driven flux' (A1 and B1) group of bars shows the flux of FIO from all the study farms within the catchment. Without event driven conditions, the flux will be due to seepage and drainage from the steading, and from livestock having direct access to watercourses. Treating the manure does not affect the flux.

Figure 5.1 FIO flux with different spreading options from the farms in the Saltcoats catchment



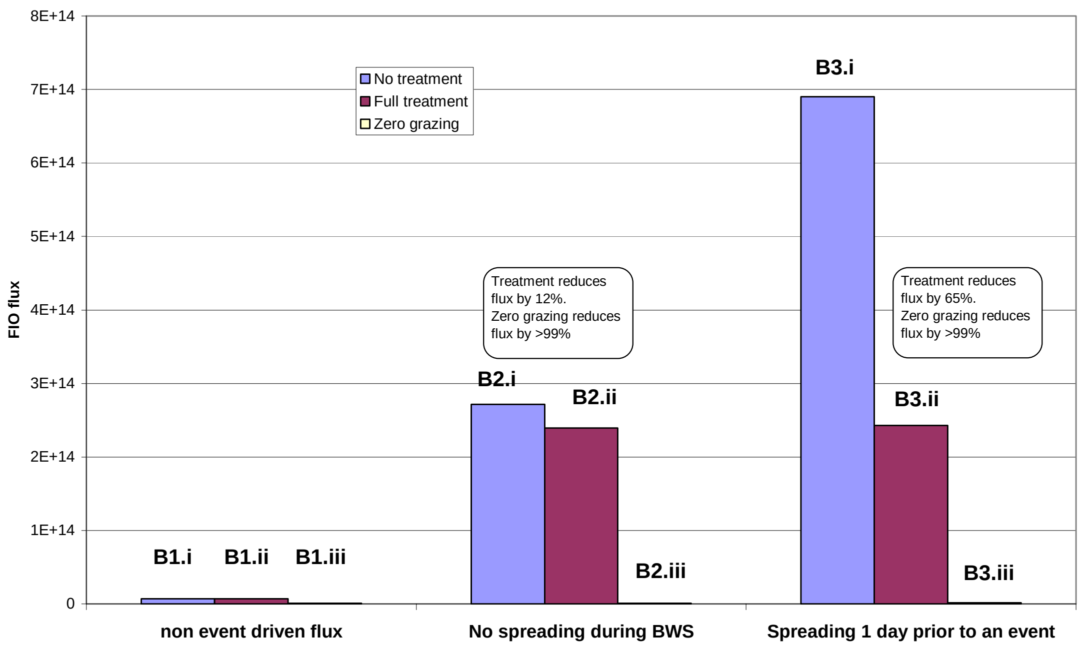
Note. The flux predicted under a zero grazing scenario is low (a factor of approximately 100 less than the other values). However, it is still present.

The 'no spreading' group of bars (A2 and B2) show the FIO flux as a result of the rainfall mobilised FIO run-off as well as the normal baseline non event flux of FIO. This assumes that slurry and FYM are spread to land during winter and early spring, but no slurry spreading occurs during the bathing water season. The majority of the additional FIO flux is therefore due to cattle being on the land during an event driven process, but also due to some additional run-off from the steading.

The ‘spreading 1 day prior to an event’ (A3 and B3) groups of bars show the FIO flux from event driven processes when slurry/FYM has been spread to land on the day before a rainfall event. The flux is due to a combination of livestock being on the land and the FIO from spread material running off also. Spreading to land 10 days prior to a rainfall event has also been modelled and showed little difference with the spreading to land 1 day prior to a rainfall event. It should be noted that although ARAM includes microbial die-off with time, it doesn’t include processes which might lead to a more rapid reduction in FIO availability. This could include for instance crust formation on faecal material voided in the field.

Although the assessment assumes that under zero grazing conditions there are no FIO losses from the steading it is important to note that, although minor, pathways of FIO transfer direct from the steading to drains or watercourses were observed during the farm visits. A recent SEPA study has also found that approximately 60% of farms surveyed were non-compliant with the current legislation “Control of Pollution (Silage, Slurry and Agricultural Fuel Oil)(Scotland) Regulations 2003” which relates to minimum requirement for the collection and storage of slurry, silage effluent and agricultural fuel oil on farms.

Figure 5.2 FIO flux with different spreading options from the farms in the Sandyhills catchment



5.3.3 Discussion

Three potential sources of FIO have been assessed; these are steading, field and livestock sources.

Steading Sources

Steading sources are classed as sources which arise on the steading. Essentially, this derives from livestock movements and feeding during the in wintering period and non collection of dirty water (slurry in terms of the Regulations) from animal housing (byres and high level slatted buildings) and storage of FYM. In general livestock are housed during the winter months and so the FIO flux via this route is at its greatest during the winter. However, on a dairy farm, the adult cows return to the steading for a proportion of each day for milking and so the source still exists during the summer months (at about 10% of its winter value per event). During the zero grazing scenario steading sources are assumed to be zero.

Field Sources

Field sources arise from livestock being at pasture and from manure spreading to land. This source type dominates during the summer when livestock are at pasture and manure is being spread to land. During the zero grazing scenario field sources would be limited to the land spreading of treated manure only.

Livestock Sources

FIO which enters the watercourse from livestock defecating directly into it are referred to as livestock sources. The assessment was based on livestock spending approximately 4% of their time, where they have access, in or nearby to watercourses (Bagshaw [2001]). Assuming that the watercourses are unfenced, direct deposition of faeces into the watercourses contributes approximately:

- 99% of the non-event driven flux;
- 18% of the event driven flux when there has been no spreading;
- 9% of the event driven flux following spreading of treated manure; and
- 4% of the event driven flux following spreading of untreated manure.
- In the zero grazing scenario there are no livestock sources direct to water.

5.3.4 Farm Scale Risk Management Options

The main farms under study in this assessment were dairy or beef farms, some of which also stock sheep. The different types of farm have fundamental differences in management practices, which are reflected in the risk management options.

Beef

On a beef farm, the livestock are generally housed on the steading during the winter (for 4-6 months) and turned out to pasture in the spring. During the summer, the animals do not return to the steading and so the contribution to the FIO flux from steading sources reduces to minimal levels, but the contribution from field and livestock sources increases dramatically.

Dairy

On a dairy farm the situation is similar during the winter, in that the animals are housed on the steading for usually 6 months, but the adult cows are likely to move around the steading from housing to parlour and back again during the day. This movement could cause increased levels of yard run-off compared with a beef unit (where the cattle will generally not move from building to building during the day) due to livestock being moved or corralled in uncovered collection yards prior to and after milking.

Sheep

In most cases sheep remain at pasture throughout the year, but may return to the steading during the spring for the lambing season in some cases. Consequently the contribution to FIO flux from field sources is the most significant.

Based on these management practices, it should be noted that on beef and sheep farms field sources are key in managing risk to bathing water quality, whereas on a dairy unit, steading sources are also important. However during the summer, dairy cows only spend around 10% of their time on the steading and so field sources are still likely to dominate on a dairy farm.

5.3.5 Catchment Assessment - Saltcoats

In the Saltcoats catchment there was a continuous 'baseline' input of FIO to watercourses from cattle with direct access to water and some small losses from buildings estimated as 1.4E+13 FIO per day (A1). This flux is independent of rainfall events.

During event conditions the FIO flux due to run-off of material from the fields that has been voided directly by cattle is predicted to increase by about 12 times compared with the baseline input (A2). If the event is preceded by manure or slurry spreading by the farms the total increase compared to baseline conditions is about 30 times (A3).

During periods when rainfall events and manure/slurry applications coincide the contribution to the FIO flux from the recently land spread manure is 47 to 50 % of the total flux (assuming that all farms have spread).

As discussed in sections 4.4.1 and 4.4.2 composting and AD treatment can reduce up to 99% of the FIO in material spread to land and hence effectively eliminate the contribution via this route. This reduction applies not just to material spread during the summer, but the total FIO transfer to land from spreading prior to the bathing water season will also be reduced.

Based on the scenarios modelled, which assumes all FYM and slurry is treated through the year, the total flux reduction that could be achieved in the Saltcoats catchment through anaerobic and composting processes is between 54 and 57%. The remaining flux is unaffected by the biogas and compost treatment since it is largely the run-off from material voided to pasture.

Also, the proportion of the total flux leaving the farms which enters the Stevenston and Stanley burns separately has been assessed. During non-event conditions 46% of the flux enters the bathing water directly via the Stevenston Burn, 54% enters the bathing water via the Stanley Burn. During event conditions, both with and without slurry spreading the split is approximately 50/50. Both during non-event and event conditions, the flux input to the Stevenston and Stanley Burns can be considered to be relatively equal. i.e. half of the FIO produced in the Saltcoats 'catchment' enters the bathing water via the Stevenston Burn and half via the Stanley Burn.

The assessment has also considered the risk reduction achievable through a zero grazing scenario. The results indicate a >99% reduction in overall FIO flux under this scenario. However, it should be stressed that clear pathways of FIO loss from steadings were observed during farm visits. If these are included within the model the percentage risk reduction may be comparable to that achieved via treatment only (in fact a risk reduction of only 51% is achieved). During standard livestock management practices, when animals are at pasture during the summer, the losses from the steading are insignificant compared with flux due to livestock at pasture. However, under a zero grazing scenario when there is 100% occupancy of livestock on the steading, the risk of FIO loss increases. In this instance not only do previous diffuse sources become a point source, but areas of hard standing on the steading and potential direct drainage from the steading to watercourses can increase the risk if these pathways are not fully controlled. A clear conclusion that can be drawn from this, is that under zero grazing careful controls must be placed on potential routes of FIO loss from buildings and yard areas. This could include roofing of yards, improved containment, and modifications to drainage systems. This is clearly the case for all scenarios, but zero grazing will not be fully effective in reducing the risk to bathing water quality unless these issues are addressed.

5.3.6 Catchment Assessment - Sandyhills

In the Sandyhills catchment there was a continuous ‘baseline’ input of FIO to watercourses from cattle with direct access to water and some small losses from buildings estimated as 7.2E+12 FIO per day (B1). This is about half that predicted for the Saltcoats catchment (1.4E+13 FIO per day).

During event conditions the FIO flux due to run-off of material from the field deposited directly by cattle, is predicted to increase by about 38 times (B2.i and B2.ii). This increase is double that predicted in the Saltcoats catchment. However, the overall predicted FIO flux is 2.7E+14 FIO per day compared to 2.1E+14 FIO per day in Saltcoats so that under event conditions the flux from the two catchments is similar. If the event is preceded by manure spreading by the farms the total increase compared to baseline conditions increases by 88 to 96 times (B3). Under these conditions the total FIO flux to watercourses in the Sandyhills area is about double that in Saltcoats.

During periods when rainfall events and manure/slurry applications generally coincide, the contribution to the FIO flux from the recently land spread manure is 57% to 61%. Based on treatment of manures through the year the total flux reduction that could be achieved in the Sandyhills catchment through biogas and composting processes is between 62% and 65%.

Like the Saltcoats catchment, the proportion of the total flux in the Sandyhills catchment which goes via Fairgirth Lane and Southwick Water has also been assessed. During non-event conditions 60% of the flux enters the bathing water directly via Fairgirth Lane and 40% via Southwick water. During event conditions, with no spreading, 40% of the flux goes via Fairgirth Lane and 60% via Southwick Water. During event conditions with spreading, the importance of the input down Southwick water increases with 70% of the flux entering the bathing water via this route and only 30% entering via Fairgirth Lane.

The assessment has also considered the risk reduction achievable through a zero grazing option. The results again indicate a significant (>99%) reduction in FIO loss to surface watercourses if all pathways off the steading are controlled. If the current steading infrastructures were not improved the risk reduction would be 80% under this scenario. This is higher than that predicted for the Saltcoats catchment indicating that there were less potential pathways identified for these farms. This may be a reflection of previous pilot schemes implemented by the Scottish Executive in some of these farms.

5.4 Putting Risk Reduction into Context

5.4.1 Discussion on Bathing water FIO Compliance

Individual historical bathing water quality data for 2000 to 2004 have been examined. The bathing water data show that microbial loads in seawater can vary by up to a factor of 5,000.

It is likely that very low microbial loads in water relate to dry weather when there is no wash-off or drainage from the land, slow movement of water through the catchment watercourses and little or no mobilisation of sediment and sediment bound FIO in the catchment watercourses. In comparison, the highest values probably relate to instances of strong and persistent rain that have occurred following periods of relatively little rain, during which a large reservoir of FIO may have accumulated on land and in watercourses. This may have arisen through both land spreading (single or repeated events) and animals at pasture. These high values may also relate to periods where spreading and rainfall have coincided.

The range of values in between these high and low extremes probably arises through a combination of the frequency of rainfall events and the time lag between spreading and rainfall. This reservoir concept is supported by CREH findings that after persistent and heavy rain during August 2004 the catchment appeared to be 'washed clean' and although heavy rains persisted, the FIO fluxes were significantly reduced.

5.4.2 Post Treatment Compliance Assessments

Based on the generic conditions used in the set up of ARAM the results expressed above give a potential FIO flux reduction of between 54-57% (Saltcoats) and 62-65% (Sandyhills) for combined slurry and FYM treatment and >99% (Saltcoats) and >99% (Sandyhills) under zero grazing scenarios.

These generic risk reduction factors have been applied to individual historical bathing water quality data for 2000 to 2004, and the results reported in Table 5.1.

Table 5.1 shows:

- the number of instances when microbial loads exceeded the current mandatory pass values of 10,000 (total) and 2,000 (faecal) counts per 100 ml;
- the results when the risk reduction factors calculated above for manure treatment and zero grazing are applied to the measured data and compared against the microbial guideline values;
- in Saltcoats the number of times the limits for faecal coliforms would have been exceeded over the 5 year period was reduced from 14 to 9 with treatment and to 0 times with zero grazing plus treatment of manures before return to the land; and,
- in Sandyhills the number of times the limits for faecal coliforms would have been exceeded over the 5 year period was reduced from 8 to 4 with treatment and to 0 times with zero grazing plus treatment of manures before return to the land.

It should be noted here that bathing water compliance is based on the microbial quality of water meeting certain microbial thresholds. These limits mean that a percentage reduction in FIO input to waters may not automatically lead to an increase in compliance with the guidelines, as the values of FIO content may still be above the required threshold.

It is also important to note that ARAM development has been limited to the assessment of FIO fluxes to watercourses in the catchment. The FIO transport through the catchment, or dilution when these freshwater discharges meet the coast, is not assessed by the model. We have therefore had to make the simple assumption that a reduction of FIO input to watercourses would be mirrored by a corresponding reduction of FIO counts in seawater. As FIO die-off rapidly in the environment this is a reasonable assumption. However, a reduction in microbial loads in bathing water will only occur if the agricultural sources being treated are the primary source of FIO in the marine environment.

Table 5.1 FIO Flux Reduction and Overall Reduction in Risk to Surface Waters during event conditions during the Bathing Water Season

Catchment	Number of samples > current mandatory pass guidelines 2000-2004					
	Without Treatment		With Treatment		Treatment plus Zero Grazing	
	Total Coliforms	Faecal Coliforms	Total Coliforms	Faecal Coliforms	Total Coliforms	Faecal Coliforms
Saltcoats	5	14	3	9	0	0
Sandyhills	3	8	0	4	0	0

Based on the assessment set out above the Pilot Project will lead to an improvement in water quality at the designated bathing waters. The results demonstrate that biogas and composting processes are an effective method of treating animal manures and that a high level of risk reduction is achievable through animal manure processing. However, to ensure the greatest benefit for Bathing Water quality this should be targeted on farms that generate and spread material either during, or within one month prior to, the Bathing Water season. This is most likely to apply to slurry production from dairy herds where land spreading is undertaken after first and second silage cuts in May/June and July/August. The importance of livestock in the field as a potential source of FIO to watercourses is clear from this assessment and the results are comparable with research conducted by SAC that estimates that risk of surface water pollution is about five times higher from grazing than from slurry spreading (Vinten et al., 2003).

5.5 Nutrient Availability and Leaching

In order to provide a preliminary assessment of effect of manure on nutrient availability, leaching and ammonia volatilisation, the DEFRA tool MANNER (MANure Nitrogen Evaluation Routine) was used.

MANNER was used with farm specific data. It must be noted that the MANNER is a tool to evaluate the potential for leaching of nitrate according to the type of material spread to land. It should be used in conjunction with PEPFAA farm management practices to minimise the loss of nutrients through leaching.

5.5.1 MANNER

MANNER is a tool developed for DEFRA which draws together the latest UK research information on factors affecting nitrogen losses via ammonia volatilisation and nitrate leaching following land application of a range of different animal manures, farm waste and sewage derived material. It allows the user to define:

- Time of application;
- Land application rate;
- Dry matter content, Total and available nitrogen (ammonium) in material land spread;
- Surface and subsurface soil type;
- Rainfall and land drainage; and,
- Incorporation methods and any delay to ploughing.

These parameters have been set on a farm by farm basis based on monitoring data collected during the project and the assessments then integrated across farms and each catchment based on the land spreading areas used. In each catchment local rainfall records have been used. For some farms the records of slurry/FYM spreading may not be definitive, as many farms do not keep accurate records of each spreading occasion, so some data is based on farmers recollection only. It must also be noted that the data for the nutrient content of the slurry, FYM, digestate and compost have been based on results from the monitoring analysis that was conducted during the initial months of operation of the treatment plants and may not therefore be definitive.

In this assessment we have assumed that all FYM and slurry within the pilot farms is treated by composting and anaerobic digestion. This follows the methodology applied in the ARAM and economic modelling sections of this project.

5.5.2 MANNER Scenarios

MANNER was used to assess three different scenarios:

- No treatment - assumes that untreated FYM and slurry is applied to land in accordance with previous spreading periods and tonnages of material spread obtained through consultation with the farmer;
- Treated FYM and slurry with spreading periods unchanged from the spreading regime in place before AD and compost installation. This highlights the change in leaching of N and the plant available N content attributable to the two technologies employed;
- Treated FYM and slurry with spreading times changed to reduce nutrient leaching. The restriction of spreading during certain times of the year was assessed to illustrate how nutrient leaching could be reduced and the effect this could have on levels of plant available nitrogen. It is important to note that unless there was an obvious single application that normally occurred in the period restricted and that could be moved to later or earlier in the year, the modelling assessment did not entail alteration or substitution of spreading times.

5.5.3 Nitrate leaching analysis results

Based on the farm and catchment specific data MANNER predictions for N leached annually for the three scenarios described above are given in Figures 5.3 and 5.4 for the Sandyhills catchment and Figures 5.5 and 5.6 for the Saltcoats catchment.

Figure 5.3 Total predicted Nitrate leached per annum in Sandyhills catchment - slurry treatment scenarios

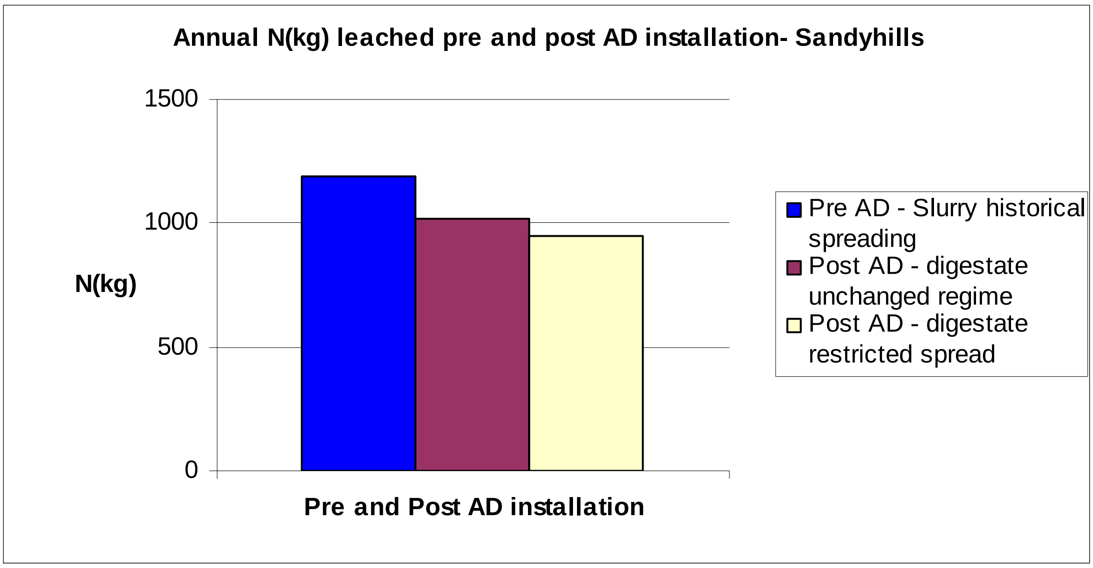


Figure 5.3 shows a decrease in the amount of N leached from 1,190 kg per year from untreated slurry spreading, to a value 1,020 kg per year following AD treatment and to 950 kg following AD treatment and spreading restriction.

Figure 5.4 Total predicted Nitrate leached per annum in Sandyhills catchment – FYM treatment scenarios

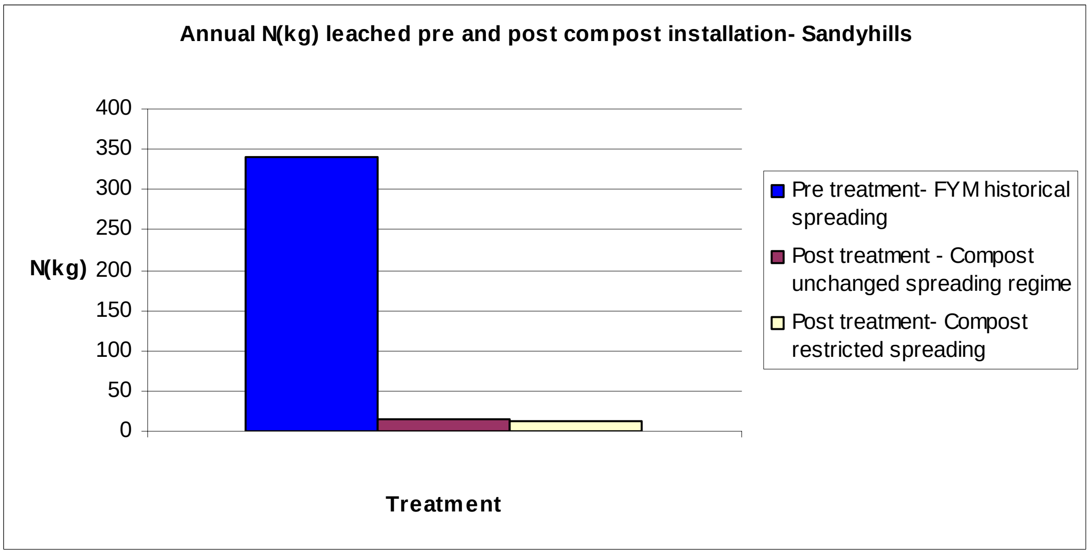
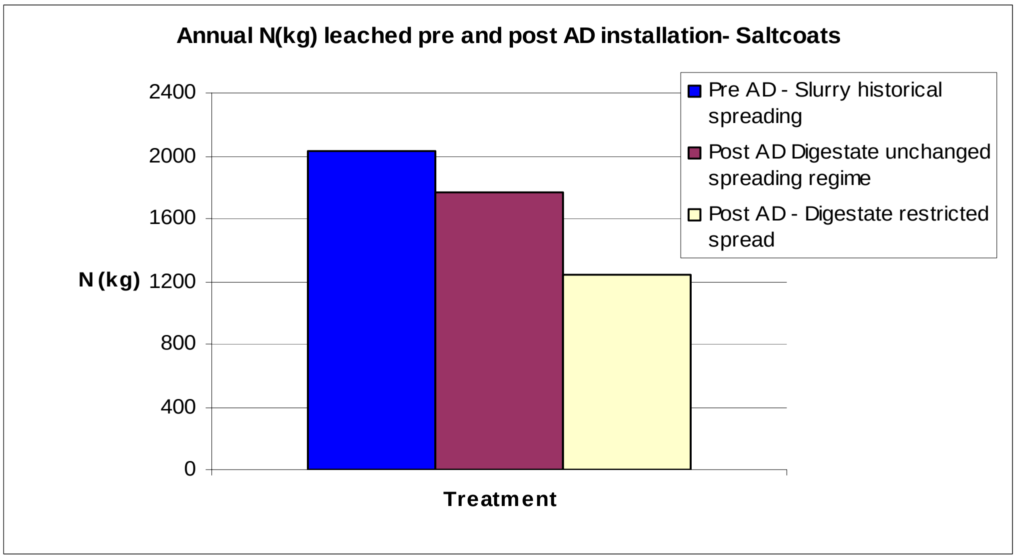


Figure 5.4 shows that there is a very marked reduction in the predicted annual amount of nitrate leached to ground or surface waters following the treatment of FYM by composting with a reduction from 340 kg per year for untreated FYM to 16

kg per year following treatment, and 12 kg per year following treatment and restricted spreading. A similar reduction was predicted in the Saltcoats area for FYM as illustrated in Figures 5.6.

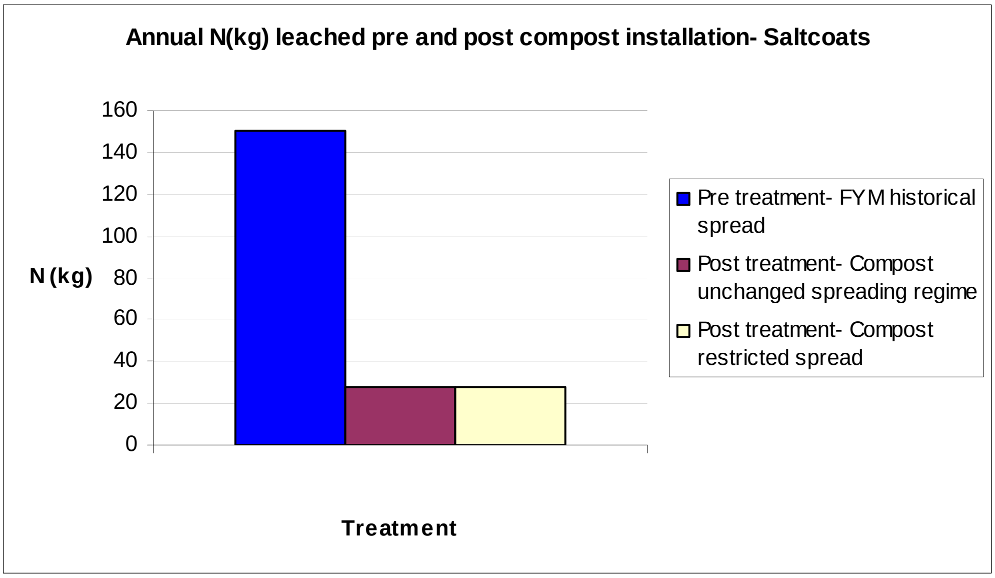
Figure 5.5 Total Nitrate predicted leached per annum in Saltcoats –AD treatment scenarios



The reduction in the amount of N leached following AD treatment (Figure 5.5) in the Saltcoats catchment is similar to that predicted for the Sandyhills catchment. For instance the amount leached was from 2,030 kg per year pre treatment, this reduced to 1,772 kg per year following AD treatment and to 1,242 kg following AD treatment and spreading restrictions.

The annual amount of N leached in Saltcoats from FYM (Figure 5.6) could be reduced from a value of 150 kg to a value of 28 kg following both composting treatment and composting and restricted spreading. In this catchment land spreading of FYM tended to occur in the spring so that there was little change between the two treatment scenarios.

Figure 5.6 Total predicted Nitrate leached per annum in Saltcoats – FYM treatment scenarios



The changes are summarised in Table 5.2 below.

Table 5.2 Changes in N leaching

Catchment	Land spreading					
	FYM (N kg y^{-1})			Slurry (N kg y^{-1})		
	No Treatment	Compost Treatment unchanged spreading regime	Compost Treatment Restricted spreading	No Treatment	AD Treatment 12 month spread	AD treatment Restricted spreading
Saltcoats	150	28	28	2,030	1,772	1,242
Sandyhills	340	16	12	1,190	1,020	950

The MANNER assessment illustrates that there are benefits from the AD and composting treatments in terms of reducing N leaching arising from slurry and FYM spreading to land, and also from spreading in the spring. In the Saltcoats catchment the total N leached could be reduced from 2,180 kg y^{-1} to 1,270 kg y^{-1} (a 40% reduction) and in the Sandyhills catchment 1,530 kg y^{-1} to 962 kg y^{-1} (a 37% reduction). It is also worth noting that compared with FYM application, slurry is the main contributor to N leaching (> 78%). However, it is important to note that the land spreading data and monitoring used in this assessment were provisional.

5.5.4 Plant Available Nitrogen Analysis results

The amount of nitrogen available to plants following the spread of material is assessed in MANNER by taking account of the amount of potentially available nitrogen in the material applied to the field i.e. the readily available nitrogen in the form of ammonium and uric acid, and the likely mineralisation of manure organic nitrogen. Losses through ammonia volatilisation and nitrate leaching are then deducted. The crop available nitrogen (kg/ha) as calculated is equivalent to the fertiliser nitrogen replacement value of the manure.

The amount of plant available nitrogen was modelled for FYM and slurry spreading in both catchments for the same scenarios described above. The results for these are shown below for the Sandyhills (Figures 5.7 and 5.8) and Saltcoats catchments (Figures 5.9 and 5.10).

Figure 5.7 Annual Plant available N- Sandyhills slurry treatment scenarios

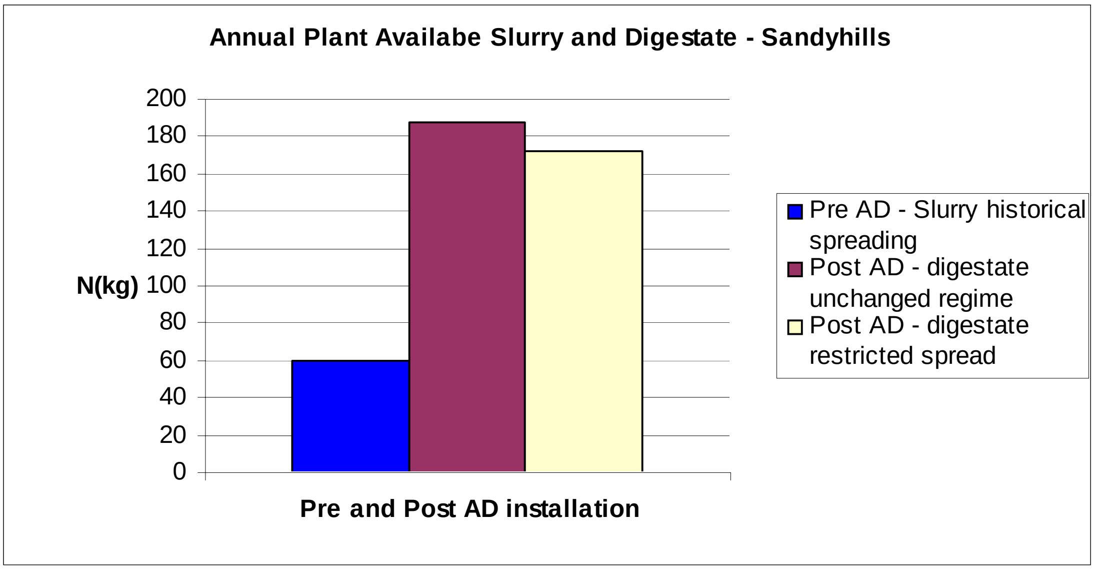


Figure 5.7 shows that AD treatment in the Sandyhills catchment has little effect on the plant available N and for all three scenarios this ranges between 60 and 180 kg.

Figure 5.8 Annual Plant N- Sandyhills FYM treatment scenarios

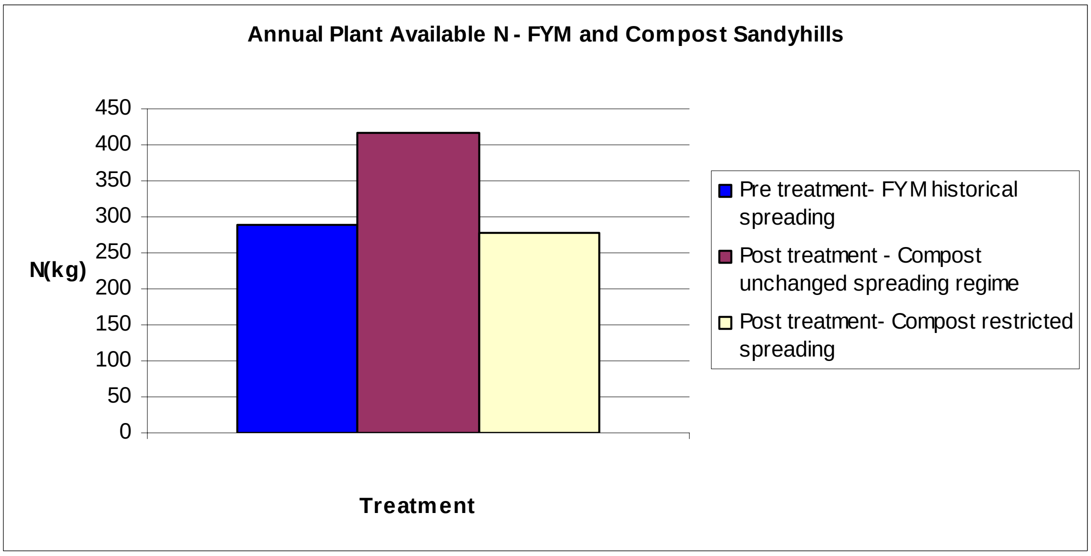


Figure 5.8 shows that composting can have a benefit, increasing the amount of plant available N from 250 kg across the catchment to nearly 400 kg. However, this benefit is negated by restricting spreading to the spring.

Figure 5.9 Plant Available N – Saltcoats slurry treatment scenarios

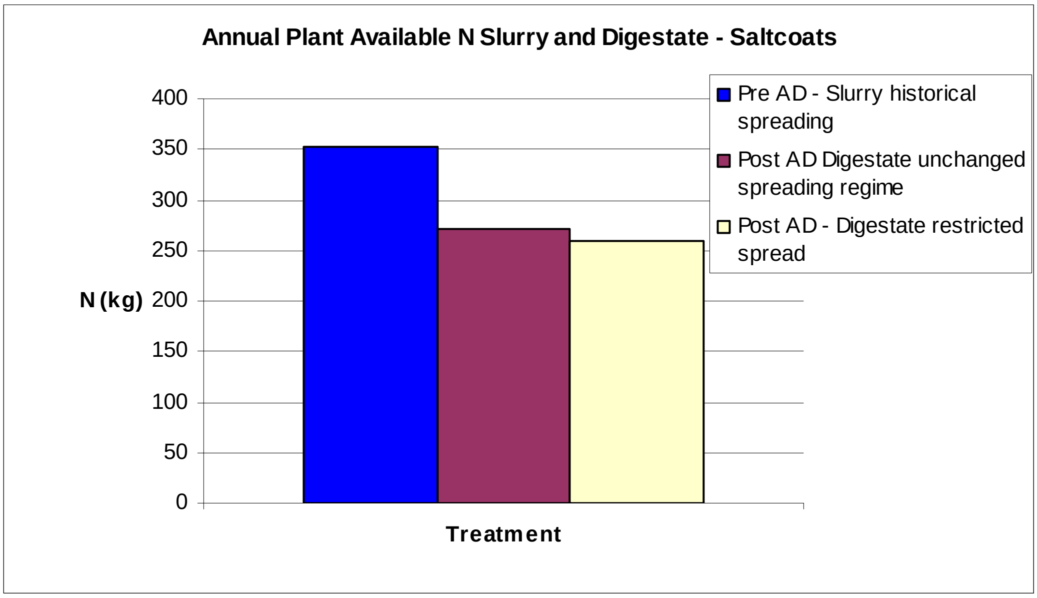


Figure 5.9 shows that across the catchment, AD treatment reduces the amount of plant available N from 350 kg to 260 kg. During restricting spreading times the annual plant N availability is 250 kg.

Figure 5.10 Plant Available N- Saltcoats FYM treatment scenarios

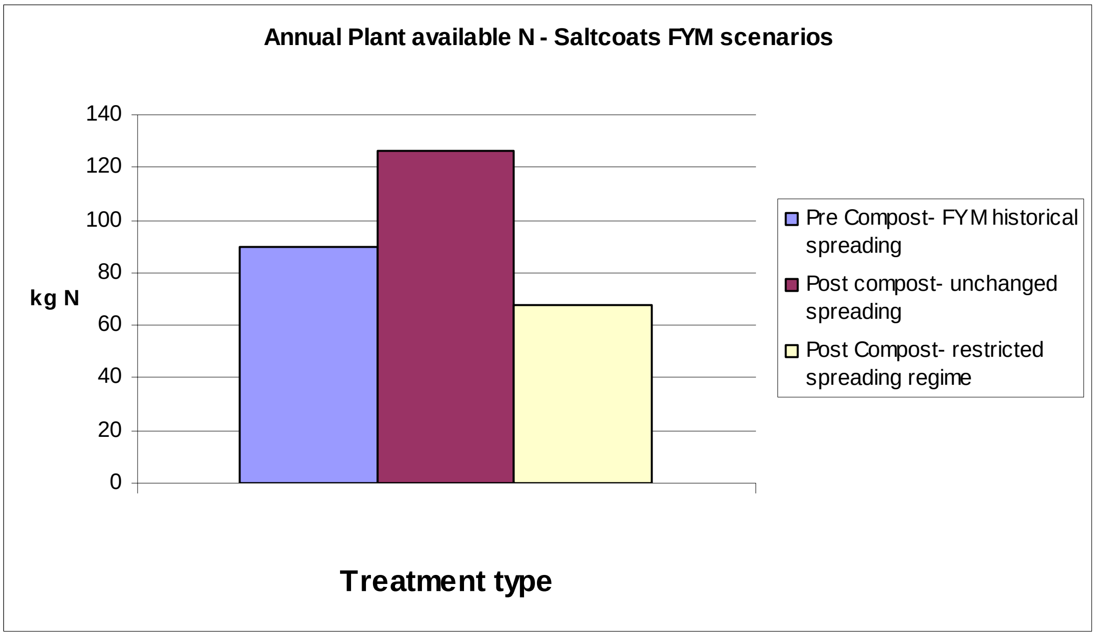


Figure 5.10 shows that composting in the Saltcoats catchment has a positive impact on plant available N with an increase from 90 kg pre compost treatment to a value of

128kg following treatment. With restricted spreading times this could reduce values to 68 kg.

These changes are summarised in Table 5.3.

Table 5.3 Changes in Plant Available N

	Saltcoats catchment – Plant available Nitrogen (kg/ha)			Sandyhills catchment -Plant available Nitrogen (kg/ha)		
Process	Before treatment	After treatment	Restricted spreading	Before treatment	After treatment	Restricted spreading
AD (slurry treatment)	352	272	259	180	188	172
AC (FYM treatment)	90	126	68	288	417	277

5.5.5 Discussion of MANNER results

Monitoring (Chapter 4) demonstrated that there is a reduction in the total nitrogen concentration of manure across the farms with treatments. It was expected that there would be some loss of nitrogen through ammonia volatilisation particularly during composting and this has been demonstrated. However, it was anticipated that AD treatment would increase the amount of plant available nitrogen (ammonium) during the process. Although the results given in Chapter 4 are variable, there is little evidence to suggest that there is a significant change in either total or available nitrogen during the AD treatment. It should be noted that despite these results, the farms involved have commented that the digestate appears to have enhanced nutrient value compared to previous use of undigested slurry/manure. However it has not been possible to further substantiate this within the remit of this project.

The MANNER assessment tool calculates total nitrogen applied, amount leached, amount volatilised and amount remaining available in the soil for plant uptake after these losses. These calculations depend not only upon the total nitrogen and ammonium concentrations in the material land spread, but are also critically controlled by soil type, when the material is land spread and the method of incorporation. Composting can lead to a significant reduction in the mass of spreadable material through the loss of water and some microbial metabolism of the organic content of the FYM. To avoid overestimation of application rates of N the post-treatment results have been adjusted to account for this loss of mass.

The assessment has considered three scenarios to allow a comparison between the spreading of raw slurry and manure, treated digestate and compost and the spreading of treated digestate and compost during Feb to July only. This last scenario was to assess the benefit of application in a period when plant uptake requirements are likely to be highest, and soil drainage minimal.

The MANNER assessment showed that the amount of nitrate leached would decrease in both of the catchments in all treatment scenarios considered. This is attributed to a combination of the reduction in total nitrogen and reduction of ammonium (particularly for composting). This is beneficial to the environment within and surrounding the farms and compliant with GAEC and other farm management schemes. This reduction of N leaching would prove especially beneficial if used on farms within an NVZ area.

MANNER calculated that on the Sandyhills farms total ammonia volatilised from slurry spreading is 1,682kg per year, and reduces to 560kg per year once treated by AD. In the Saltcoats catchment FYM spreading releases 750kg N per year, whereas compost spreading only reduces 136kg per year. This would suggest that there have been ammonia emissions earlier, during the treatment or storage of the material.

The amount of plant available N post-treatment seems to generally improve, again showing a benefit of both AD and composting processes. Although little changes in the total or available N concentrations during the digestion process were observed there were clear reductions in the dry matter content in the digestate. This means that even if there is no change in total N or NH4 concentration improved infiltration into the soil profile reduces volatilisation and increases plant availability. It is also obvious that if ammonium concentrations were to increase there would be more plant available N.

On some farms the spring spreading scenario assessed led to an increased application rate prior to the end of soil drainage (taken as the end of March). As a result the modelling showed a small amount of nitrate leaching and therefore reduced the amount of plant available N. In available nitrogen, applications of compost and digestate would have to be made during April to July.

Ammonia emissions have been calculated during the MANNER assessment to determine the amount of plant available N. However, it has not been possible to assess the releases during the composting or AD processes therefore the overall net change of losses to atmosphere cannot be determined. Chapter 7 examines the implications of ammonia emissions in greater depth. However, it has not been possible to monitor the amount of ammonia volatilised during AD and composting processes or during storage of the treated material, but previous studies have shown that composting leads to large volumes of ammonia emissions, with AD treatment having little affect on ammonia release. This assessment has shown that the amount of ammonia volatilised during land spreading of compost and digestate is lower than that compared to FYM and slurry and may therefore be of benefit. However, over the lifecycle of ammonia generation and volatilisation, it is expected that the total volume of ammonia released has not changed significantly, but that the period of release has shifted from land spreading to release during treatment and storage.

To assess the net change in overall ammonia release, analysis of the staged process of slurry and FYM handling; before, during and after treatment would be required.

6. ECONOMIC ASSESSMENT

6.1 Introduction

The scope of the economic assessment is to establish the economic costs and benefits of minimising FIO pollution from agricultural sources via watercourses to bathing waters. The economic costs are those incurred through the treatment of slurry and FYM and a move to zero grazing where applicable. The economic benefits include the reduction in risk of non compliance with the bathing water directive, health benefits from reduced risk of FIO contamination and potential additional income streams from the treatment of farming wastes. The assessment focuses on the Sandyhills catchment as this is where the majority of pilot facilities were located but the general conclusions may also be applied to Saltcoats. Within the Sandyhills catchment itself, data from the farms included in the pilot have been extrapolated to the other high risk farms not participating in the pilot to obtain an assessment for the entire Sandyhills catchment area.

Throughout this chapter specific terms are used to refer to different aspects of the economic analysis. The key terms are:

- *Mitigation Options*. Mitigation options are techniques for reducing the FIO run-off. There are two categories of mitigation option:
    - Treatment Options. These options treat the slurry and farmyard manure to reduce or eliminate the FIO contamination before it is applied to the field. The two main treatment techniques are AD or composting.
    - Grazing Options. The amount of manure deposited directly on the field can be altered by changing the grazing patterns from normal grazing to zero grazing.
- *Development Options.* Development options refer to different scales and location of treatment options. Four development options are assessed in this study: on-farm treatment on a single high risk farm, on-farm treatment across more than one high risk farm, a community treatment facility situated on a farm and a community treatment facility situated off farm but near an industrial facility with a demand for heat and electricity.
- *Development Scenarios.* Development scenarios reflect combinations of mitigation options and development options.

The rest of this chapter is structured into seven sections:

Subsection 2 Options for Complying with the Bathing Water Directive. This section summarises the technical and grazing options to reduce FIO run-off to the watercourses in the catchment. The expected reduction in health risk achieved by these options is taken from the Agricultural Risk Assessment Model (ARAM) described in Chapter 5.

Subsection 3 Catchment Area Development Options. This section introduces the four development options referred to above.

Subsection 4 The Cost of Mitigation Options. This section describes the capital and operating costs of the three mitigation options, AD, composting and zero grazing. All these costs reflect the additional costs of implementing a treatment option or a move to zero grazing, and do not include any costs associated with existing farming practices.

Subsection 5 The Economic Benefits of Mitigation Options. These benefits refer to additional revenue streams and savings from each option. A range of values (high, mid and low values) are provided for each economic benefit. These ranges are then used to test the sensitivity of the results.

Subsection 6 Results for the Catchment Area. In this section, the net present value (NPV) of each development scenario under different economic cost and benefit assumptions is calculated, along with an assessment of the grant requirements.

Subsection 7 Social Costs and Benefits. This section provides points of reference for estimating the possible wider economic benefits of complying with the Bathing Water Directive using results from other economic studies of bathing water quality.

Subsection 8 Conclusions. This final section draws together the conclusions from the economic assessment and suggests implications for policy.

6.2 Options for Complying with the Bathing Water Directive

The objective of the study is to reduce the risk of non-compliance with the European Bathing Water Directive. To achieve this, the study has looked at two treatment options for reducing the FIO run-off:

- **Anaerobic Digestion (AD) of Slurry.** Most slurry is produced by dairy cows[1] whilst they are housed in the shed or the dairy. The slurry can be fed into an anaerobic digester which treats the slurry to reduce FIO contaminants and produces a combustible biogas and liquid digestate. The digestate can then be applied to the land as a fertiliser with reduced risk of bathing water FIO pollution.

- **Aerobic Composting (composting) of Farmyard Manure.** Most FYM is produced by non-dairy livestock (followers and beef cattle) from the straw bedded housing systems. The FYM can be fed into an aerobic composter to reduce FIO contaminants and produce compost that can either be sold to the market or applied as fertiliser with reduced risk of bathing water FIO pollution.

Each of these treatment options can be combined with different grazing options to alter the amount of manure deposited in the field while the cattle are at pasture. The two grazing options that have been examined in this study are:

- **Normal grazing.** This is the most common farming practice which keeps livestock indoors during the winter and outside during the summer (with the exception of time spent indoors for milking purposes for dairy cows). Whilst the livestock are indoors, faecal material can be easily collected as slurry and farmyard manure and treated in either an AD or composting facility. However, the manure that is voided while cattle are at pasture may enter catchment watercourses during the bathing water season, thus representing a continuing risk of FIO contamination.

- **Zero grazing.** Zero grazing is an alternative farming practice that keeps the livestock indoors the whole year, collecting slurry and FYM throughout the year.

  Zero grazing is not in commonly used in Scottish agriculture and all the implications have not been fully investigated here, however, the ARAM

1 For the purposes of this study we have assumed that all dairy cows produce slurry during the time they spend indoors, all other livestock are assumed to produce farmyard manure, but it is noted that beef cattle can be kept using slurry systems.

modelling suggests zero grazing is a possible solution for complying with the bathing waters directive.

As this was not the primary emphasis of the study, there is a higher degree of uncertainty surrounding the costs and benefits of zero grazing. In our assessment we assume that all this material is treated in an AD or composting facility before being spread to land. We also assume that the farms are fully compliant with relevant legislation and good practice and that there are no losses of FIO from the steading. This would allow most of the faecal material to be collected and treated, thereby minimising the risk of non-compliance with the Bathing Water Directive. It should be noted that the application of zero grazing farming practices did not form a part of the pilot study. As a result there is considerably more uncertainty in the economic benefits and costs of this option.

The combination of these options creates a matrix of FIO mitigation opportunities that can be applied to each farm or catchment.

Extrapolating Treatment Options for Other High Risk Sites

In the Sandyhills catchment the pilot study has involved the construction of facilities at six sites out of a total of nine high risk sites initially identified. The six sites included four AD and three composting plants (one site had an AD and composting plant on same site). To provide an assessment of the treatment and grazing options at a catchment scale the study has been extrapolated to cover the three remaining high risk sites. The treatment option for the modelled sites is determined by the slurry and FYM arisings recorded for each 'high risk' farm in the Sandyhills catchment area. The arisings and the application of AD and composting to each farm are summarised in Table 6.1.

Table 6.1 Farm Arisings and treatment options

	Slurry (tonnes/yr)	FYM (t/yr)	Actual Treatment installed	Modelled treatment	
				AD Installation	Composting Installation
Farm 1	2,900	144	AD	Yes	Yes
Farm 2	3,500	594	AD	Yes	Yes
Farm 3	1,000	0	AD	Yes	No
Farm 4	(<200)	1,080	composting	No	Yes
Farm 5	(<200)	543	composting	No	Yes
Farm 6	4,900	752	AD/ composting	Yes	Yes
Farm 7	440	1,120	Nil	Yes	Yes
Farm 8	530	518	Nil	Yes	Yes
Farm 9	0	178	Nil	No	Yes
Total Sandyhills	13,270	5,028	Nil	Yes	Yes

Non-compliance with the bathing water directive is determined by the occurrence of FIO concentrations exceeding a given threshold. In areas where the primary FIO source is from agriculture, reducing the FIO flux (i.e. the number of FIO microbes that are transferred from land to water) will improve bathing water quality. The analysis conducted in Chapter 5 is based on the assumption that there is a linear relationship between reduction in FIO flux and the improvement in bathing water quality. However, increases in quality must be sufficient so that the bathing water complies with the relevant microbial guidelines. To assess this, the risk reduction has been applied to a set of historical bathing water compliance records and the reduction in the number of non-compliances determined.

By combining the treatment options given in Table 6.1 with the different grazing options, the ARAM model established the reduction in FIO flux from the Sandyhills catchment area that is attributed to each mitigation option. The implications of this reduced flux, in terms of the number of non-compliance incidents that would be expected, are given in Table 6.2.

Table 6.2 Mitigation options and associated risk reduction - Sandyhills

		Normal Grazing	Zero Grazing
Reduction in FIO Flux	No Treatment	0%	Not assessed
	Treatment (Composting and AD)	62-65 %	>99 %
Number of Non-Compliance Incidents	No Treatment	3 (TC), 8 (FC)	Not assessed
	Treatment (Composting and AD)	0 (TC), 4 (FC)	0 (TC), 0 (FC)

TC = total coliforms, FC = faecal coliforms

This shows that, under a normal grazing scenario, AD and composting treatment reduce the number of non-compliances and that for total coliforms these are reduced to zero. However, some instances of non-compliance for faecal coliforms still occur. Under a scenario of zero grazing, full slurry and FYM treatment and no FIO losses from the steading the number of non-compliances would be expected to be zero. However, it should be noted that this assessment is based on the assumption that the FIO counts measured in the bathing water arise solely from agricultural sources. If other sources which are not affected by these options exist, the reduction in non-compliances may be less.

For completeness the Saltcoats findings are given in Table 6.3 (which is outside the scope of this economic assessment area). In the Saltcoats catchment the FIO concentration of the bathing water is significantly greater than the bathing water directive thresholds and zero grazing, in addition to full treatment of all manures, is required to ensure that full compliance for both total and faecal coliforms is achieved.

Table 6.3 Mitigation Options and associated risk reduction – Saltcoats

		Normal Grazing	Zero Grazing
Reduction in FIO Flux	No Treatment	0%	Not assessed
	Treatment (Composting and AD)	54 -57%	>99%

Number of Non-Compliance Incidents	**No Treatment**	5 (TC), 14 (FC)	Not assessed
	Treatment (Composting and AD)	3 (TC), 9 (FC)	0 (TC), 0 (FC)

TC = total coliforms, FC = faecal coliforms

6.3 Catchment Area Development Options

Four development options for the Sandyhills catchment area with different configurations of AD plant and composting facilities have been identified:

- **Individual high risk farm.** If an individual farm in a catchment area is identified as the main source of FIO run-off, then introducing AD and composting onto the single farm may sufficiently reduce the risk of non-compliance with the bathing water directive. The single high risk farm is modelled as a large farm with a 250 head dairy herd.

- **On-farm treatment.** If the source of FIO run-off arises from multiple farms in the catchment, each will require some treatment according to their FYM and slurry arisings and the associated risks. The associated costs and benefits can be summed across the catchment area.

- **Community Treatment (On-Farm).** As with on-farm treatment, this option assumes that all the farms in the catchment area contribute to the FIO run-off and require some treatment of their slurry and FYM arisings. In this development option, however, the slurry and FYM arisings in the Sandyhills catchment area are treated at a community composting and AD facility. It is assumed that the community plant is located near to an existing farm, limiting the ability to use heat by-products from the AD facility and most of the electricity generated has to be exported to the grid. As the electricity network in Sandyhills is single phase, the ability to export electricity is currently restricted due to potential imbalances in the electricity network. We assume that this restriction is lifted prior to this development option being implemented.

- **Community treatment (dairy based).** This scenario is similar to the farm based community treatment in that all slurry and FYM arisings are treated in a centralised facility. However, in this development option, the centralised facility is located next to a dairy. The dairy (or other facility) has a high on-site demand for heat and electricity so all heat by-products and electricity can be consumed on site. *It should be noted that additional cost for transporting heat to the dairy (or other facility) has not been allowed for in this development option.*

Combining the development scenarios with the mitigations options generates a matrix of development and environment impact scenarios. These are assessed below.

6.4 The Cost of Mitigation Options

In the following subsections the economic assumptions are separated into the capital costs, annual costs and revenue streams for each of the mitigation options - AD, composting and zero grazing.

6.4.1 Capital Costs

The capital costs cover all the costs that have to be paid by the installer of the equipment prior to its operation. They include the cost of the equipment, the cost of installation and the cost of permit applications. Any differences between the costs applied to the on-farm and the community development options are also noted.

Anaerobic Digestion

The capital costs of the anaerobic digester have been determined for each farm according to the recorded slurry arisings and the digester capacity requirements.

The AD plant will generate two outputs – biogas and digestate. The biogas can be burned in a boiler to produce hot water or in a combined heat and power (CHP) unit to produce electricity and heat. The digester has a heat requirement for maintaining an elevated temperature, which is provided either by burning a proportion of the biogas or by using the heat from the CHP unit. In the former case there will be surplus heat from the biogas boiler; in the latter case there will be a smaller amount of surplus heat from the CHP unit. The second output of the AD plant is digestate. This is a fertiliser that can be applied directly to the fields with reduced risk of bathing water FIO pollution.

Six capital costs associated with the anaerobic digester are modelled:

- *Digester.* Biogas is generated by the digester according to the amount of feedstock added. For each tonne of slurry added to the digester 24 m^3 of biogas is generated. The biogas has a methane content of 60% and a calorific value of 21.4 MJ/m^3. Unless a CHP unit is applied to the site, we assume that the biogas is combusted in a boiler which operates with a heat generating efficiency of 85%. For each kWh of biogas generated approximately 0.29 kWh of heat is required to be entered into the digester to maintain the optimum temperature. The remaining heat can be used on the farm. In the pilot study, storage and receptor tanks were installed for the AD facility. The results of the pilot study, however, suggest suitable facilities already exist on most farms to act as a storage and receptor tank to the AD facility. The economic analysis assumes additional storage and receptor facilities are not required.

- *CHP.* The cost of the CHP is the additional capital cost of upgrading the biogas combustion facility to a CHP unit that utilises the biogas to generate electricity and heat. The conversion efficiency of the CHP engine depends on the size of the application. With a larger community plant a combined conversion efficiency of 85% is achieved (33% electrical and 52% heat efficiency) with an expected operating availability of 90%. With the smaller on-farm facility a lower conversion efficiency of 80% is achieved (28% electrical and 52% heat efficiency) and there is a reduced availability of 80%. CHP units can only be applied to the large farms where sufficient biogas is produced.

- *Energy Crops.* The slurry can be supplemented with energy crops (as slurry is generated primarily during the winter months under a normal grazing pattern). This increases the utilisation rate of the digester during the summer months with only a slight additional capital cost associated with the capacity of the digester and loading requirements. For each tonne of energy crops added to the digester 100 m^3 of biogas is expected to be generated which is approximately four times the amount of gas produced from a tonne of slurry.

- *Separator.* The second output of the digester is the liquid digestate. Whilst the digestate can be applied directly to the fields as a fertiliser, it can also be separated into its solid and liquid components. The solid component is similar to compost and can be sold (if there is a market for compost). It is assumed that 10% of the digestate can be recovered as solid material when a separator has been added to the digester and energy crops are introduced as a feedstock.

- *Start up.* The start up costs cover the initial cost of the fuel required to heat the digester up to its optimum temperature. Once the digester temperature has been raised sufficiently, the biogas generated can be combusted to maintain the digester temperature. This model assumes that the digester only has to be started once and does not need to be restarted during its operational lifetime.

- *Grid connection.* The cost of grid connection is only applied when a CHP is included with the AD plant. This cost includes the capital cost of connecting the generating engine to the local electricity supply network safely. We have assumed that all necessary network re-enforcements are undertaken by the grid operator and that costs are applied to the farmer according to the OFGEM guidance[2].

The capital cost assumptions for each farm are shown in Table A3.1.

Aerobic Composting

The costs for installing a composting facility are determined by the volume of FYM generated by each farm and whether the FYM is treated on the farm or at a communal facility. The volume of compost is approximately 40% of the volume of FYM input.

For all composting facilities, there are costs associated with:

- *Slab.* The concrete base for the composting facility.

- *Polytunnel* .We have assumed that all composting facilities will be built using a light-weight polytunnel. The pilot studies were completed using a shed rather than a polytunnel. However, the economic model has been completed using a polytunnel, due to the lower initial capital costs. The additional operational and maintenance costs associated with a polytunnel, compared with a shed, have also been included in the model.

- *Turner.* The only additional machinery requirement for a composting facility built on a farm is the turner. We have not included the cost of a shredder within this analysis as the pilot study found that in general the turner mixed the FYM sufficiently and additional shredding was not required.

- *Environmental licence.* To compost material an environmental licence or waste management licences may be required. The costs of obtaining these licences are included according to whether the composting facility is installed on a farm or in a communal area.

In additional to these costs the communal composting facility has additional costs of buying additional equipment and environmental licensing:

- *Product store.* When a composting facility is built on farm it is assumed that the existing buildings have sufficient capacity to operate as a product store.

- *Weighbridge, leachate, tractor and security fencing.* These are additional costs associated with establishing a new composting site and managing it effectively.

- *Planning permits.* Due to the size of the communal composting facility, planning permission will be required. This cost is not expected to occur with small farm composting facilities.

2 The expected cost of grid upgrade is £82 / KW installed capacity, this is estimated by OFGEM in Electricity Distribution Price Control Review, Nov 2004.

These capital cost assumptions have been separated according to the volume of FYM produced in Table A3.2.

Zero Grazing

The assessment assumes that there are no additional capital costs associated with zero grazing and that the farms can extend the use of existing cattle housing, storage capacity and infrastructure. Extending the use of these buildings will introduce changes to the operating costs. For the farms that were included in the pilot study, there was considered to be sufficient capacity available to warrant this assumption, however, as the pilot study did not include operational experience of zero grazing additional capital costs can not be ruled out. It also assumes no extra cost to secure steading integrity from FIO leaks.

6.4.2 Annual Operating Costs

As with capital costs; operating costs are separated by mitigation option (AD, composting and zero grazing).

Anaerobic Digestion

The annual costs of the anaerobic digester again are determined according to the farm and the amount of feedstock generated. These costs include the costs of labour, operation and maintenance of the digester. In addition, there is a cost associated with the land the AD facility is built on. These costs are given in Table A3.4

The annual cost table also includes an annual cost of business rates. There is some uncertainty surrounding the application of business rates to farms and the parameters of existing exemptions to AD plants. Following communication with the Scottish Assessors Office we have included business rates and applied the appropriate relief for small businesses and farm diversification. As a general rule the assessors' office suggested that an AD plant is more likely to be liable to business rates if it expects to export electricity.

For the community plant the costs are scaled according to the size of the facility, and there is an additional generator distribution use of system charge (GDUoS) included. This is only applied to the community facilities due to their size and potential for export electricity.

With the community development option, there will also be additional transport costs for slurry movements to a central plant and back to farm post treatment.. This will cost an estimated average of £4 per tonne of slurry[3]. In addition, there will be a cost of biohazard control; which is assumed at £10,000[4] for the community site. This cost of biohazard control is split between anaerobic digestion and composting according to the weight of material.

Aerobic Composting

The annual operating costs of the aerobic composter are determined primarily by additional labour costs required to manage the composting process. On the basis of the pilot study, composting will require an additional 2.5 hrs labour time each week. With an expected labour cost of £10 per hour[5] this generates an average cost per

3 Enviros estimate based on agricultural transport costs for slurry material.
4 Enviros in-house estimates based on experience with biohazard control at municipal facilities.
5 Farm Management Pocket Book, (Nix, 2005) suggests that an average hourly labour cost of £8.54 including national insurance contributions and employer's liability insurance. We have assumed a slightly higher rate to include staff

tonne of compost of £1.39. The labour costs are then combined with a maintenance cost (expressed as a percentage of the capital cost) and the additional value of the land required to install a composting facility. These annual costs are shown in Table A3.5.

As with AD, business rates are applied to the composting facilities. However, due to the lower capital cost and existing business rate relief schemes, business rates are only expected to have an impact on the communal composting facility. In general, a composting facility is more likely to be liable to business rates if it expects to export compost to a market.

With the community development option, there will be an additional cost of transport associated with the movement of FYM and compost around the catchment area. It is estimated that this will cost an average of £1 per tonne[6]. In addition, there will be a cost of biohazard control, £10,000[7], which is split between AD and composting according to the weight of material.

Zero Grazing

Zero grazing extends the time that the cattle are kept indoors from six months to the full year. As a result, there are additional costs associated with the cattle's upkeep, their health and the maintenance costs of the building (any additional revenues or productivity gains are considered in the next section).

The annual costs assumed for zero grazing are given in Table A3.3.

The application of zero grazing is independent of whether the slurry and FYM arisings are treated on the farm or through a community treatment facility. For community development scenarios the cost of zero-grazing is included for the whole of the high risk catchment area.

6.5 The Benefits of Mitigation Options (Revenue Streams)

In the economic model potential revenue streams are developed for anaerobic digestion, aerobic composting and zero grazing. These income streams and the values attributed to them are given below.

Anaerobic Digestion

There are potentially four different incomes streams available to the AD plant. Below we have provided a description of when each income stream is realised and the income that is attributed to it.

- *Heat Generation,* The main output of the AD plant will be biogas which is combusted to generate heat. A part of the heat output will be used to maintain the operation of the AD plant; however, there will also be a surplus that can be used in nearby facilities. The model assumes that any surplus heat that is used displaces heating oil and that there is no comfort taking (when people increase their demand for heat as the cost is reduced). We have used the average value of fuel oil as published by the DTI's energy statistics for Q1 of 2005; this gives a value of £25.19/MWh, equivalent to 27 p/litre. (Since the Q1 figures were published the price of fuel oil has increased substantially. Whilst it is not

management requirements and overtime payments if additional part-time labour is unavailable. A sensitivity on wage costs suggests that a lower wage rate of £8.5/hour would improve project NPVs by between £1,000 and £7,000.
6 Enviros estimate based on agricultural transport costs for compostable material.
7 Enviros in-house estimates based on experience with biohazard control at municipal facilities.

possible to state that these prices will be sustained we have included a price of £30/MWh for fuel oil in the high price sensitivity).

The demand for heat, however, depends on the location of the AD plant. The estimated heat demand on a farm is based on an average farm having a heating demand for 449 KWh/day (42 litres of heating oil). The heat demand pattern for each development option is shown in Table 6.4.

Table 6.4 Heat Demand from the AD Plant

Development Option	Heat Demand (% of heat generated)
Individual High Risk Farm	45%
On-Farm treatment	45%
Farm based community plant	15%
Dairy based community plant	100%

- *Digestate (liquid biofertiliser),* The second output of the AD plant is digestate. Digestate provides a valuable fertiliser that can be applied directly to the fields with a reduced risk of bathing water FIO pollution. We have modelled the value of the digestate as the enhanced value of digestate compared with the application of slurry and inorganic fertiliser that would have been applied to the field if there was no AD facility. The enhanced value is achieved through the chemical composition of the digestate and the efficiency with which it can be applied to the field. We estimate that the enhanced value of digestate is £1.17/tonne (based on the difference in the nitrogen, potassium and phosphate composition of digestate versus slurry and the cost of the inorganic fertiliser).

- *Electricity Generation,* If an engine is added to the configuration of the AD plant additional revenue can be generated from the sale of electricity, renewable obligation certificates (ROCs) and climate change levy exemption certificates (LECs). The value of electricity generation will be greater where the electricity is consumed on site compared to where it is exported off site, due to the difference between the retail and wholesale price of electricity and different power purchase agreement and consolidation charges applied.

  Where electricity is consumed on site the estimated value of electricity is £89.54 / MWh generated and £60.29 / MWh for electricity exported off-site. The calculations used to generate these figure are shown in Table A3.6.

  The amount of electricity used on site and exported is determined by the number of cattle held on the farm. Energy consumption figures used in the BIFFA's mass balance of agricultural waste, this indicates that an average dairy farm would consume 0.2 MWh/yr per head of livestock. It is assumed that any remaining electricity is surplus to requirements and exported to the grid. The exception to this is the community treatment based at a dairy. In this instance it is assumed that all electricity can be used on site.An alternative development option is to replace the engine with a fuel cell, although this has not been formally considered within this project, the increased electricity output would have a significant impact on the project economics.

- *Solid Biofertiliser,* An additional process that can be added to the configuration of the AD plant is a separator which separates the digestate into its solid and liquid components. The liquid biofertiliser can be returned to the field, whilst the solid biofertiliser can be sold to the market. As solid biofertiliser and compost have similar components we assume that solid biofertiliser can be sold as compost, where this market exists. We have not modelled a separator if there is no market for compost, as the additional benefits of solid biofertiliser compared with liquid biofertiliser require further analysis. The market price of compost and the expected sensitivities are given in the following section on aerobic composting.

For anaerobic digestion we have applied the following value ranges (Table 6.5).

Table 6.5 Anaerobic digestion sensitivities

	Low	Central	High
Retail price for Fuel oil £/MWh	£20.00	£25.19	£30.00
Retail price for electricity £/MWh (exc. standing charges)	£36.99	£49.32	£61.66
Wholesale price for electricity £/MWh	£30.07	£40.09	£50.11
Market price for ROCs £/MWh	£30.00	£46.00	£60.00
Enhanced value of liquid biofertiliser £/t.	£0.50	£1.17	£1.50

Aerobic Composting

From composting the only potential revenue stream is the value of compost. The model assumes two possible scenarios for the value of compost; the value of compost when used on farm as a fertiliser – the enhanced value of compost - and the value of compost sold to the market.

The model assumes that all FYM arisings would normally be applied directly to the field, thus when compost is used on the farm the value of the compost is the value of the net benefit of using compost over FYM and hence reducing the need for inorganic fertiliser. We have estimated that the enhanced value of compost is £1.32/tonne (based on the difference in the nitrogen, potassium and phosphate composition of digestate versus slurry and the cost of the inorganic fertiliser).

When there is a market for compost and an AD plant on the farm exists, the model assumes that the farm's fertiliser requirements can be met through the liquid biofertiliser generated by the AD plant and that all the compost generated will be surplus to the requirements of the farm (i.e. can be sold with no additional inorganic fertiliser purchase required). If there is no AD plant on site then the model assumes that 50% of the compost generated will be used on the farm and the remainder can be sold to the market. Market prices for graded and contaminant free compost in July and August 2005 are between £5 and £10 a tonne so we have assumed a central price of 7.50 £/t[8].

For composting we have applied the following ranges (Table 6.6).

Table 6.6 Composting sensitivities

	Low	Central	High
Enhanced Value of Compost (£/t)	£0.99	£1.32	£1.65
Financial gain from selling compost (£/t)	£5.00	£7.50	£10.00

8 Compost prices have been provided by Lets Recycle.com July 2005- http://www.letsrecycle.com/prices/compostingPrices.jsp

Zero Grazing

Zero grazing increases the amount of time that the livestock are housed and results in an increase in the volume of slurry and FYM that can be collected during the summer months (when cattle are normally grazing). The volume of slurry collected during the summer months reduces FIO contamination and improves the utilisation rate of the AD and composting facilities. In addition to higher slurry volumes, there is an increased yield generated from zero grazing with greater milk production volumes and increased livestock weight.

The value of increased slurry and FYM collection is captured under revenue streams generated by the anaerobic digestion and composting treatment facilities. There may be an additional benefit from reduced fertiliser consumption as manure that is collected centrally can be spread across the farm more effectively than manure deposited directly to the field; however, for this study no net change in fertiliser consumption is assumed.

It is also assumed that zero grazing brings about a 4% increase in the milk yield and a 15% increase in the livestock weight (beefstock are assumed to be slaughtered at 30 months)[9]. These increases in yield are equivalent to a 42 £/yr increase in the annual income from a dairy cow and 32 £/yr increase in the value of beefstock.

A final income stream from zero grazing is the value of land release. When zero grazing is implemented the land which would have been used to graze animals during the summer months becomes available for alternative uses. Most of the land will probably be used for growing grass to be used as feed for the housed cattle, whilst the remainder can be set to alternative farming practices e.g. growing energy crops or set aside as a part of a land release scheme. We expect moving to zero grazing will allow 23% of the existing farmland to be dedicated to a land-release scheme; the remaining 77% will be required for growing grass (Morrison, V., 2003). There are a number of schemes that encourage farmers to set aside land for environmental enhancements. The Rural Stewardship Scheme and Land Management Contract Menu Scheme are compatible with the Single Farm Payment, i.e. producers will be paid the Single Farm Payment and receive a top up for the agri-environment option. The top up is based on production/income lost and the rates have yet to be finalised but are likely to be in the range from £150/ha (management of extensive mown grassland for birds) to £250/ha (creation of wetland). We have assumed the value of these subsidies is £150/ha, a value that is consistent with the expected land rental value.

For each income stream under zero grazing we have assessed the following potential ranges (Table 6.7).

Table 6.7 Zero grazing sensitivities

	Low	Central	High
Milk Yield (% increase)	2%	4%	6%
Beef Yield (% increase)	10%	15%	20%
Income from land release (£/ha)	£100	£150	£200

6.5.1 Scenarios

In the previous sections we have identified the costs and the benefits for AD and composting facilities within the Sandyhills catchment area. These costs and

9 Personal communication with Steve Cooke and Jimmy Goldie (Scottish Agricultural College) and Northern Ireland farm business data; http://www.dardni.gov.uk/econs/econ0039.htm

benefits have been combined with the technical opportunities to develop a set of four development scenarios.

Each of these development scenarios introduce new revenue streams. In the first scenario there is only an AD & composting facility. We then introduce a market for the compost generated and CHP unit is added to the AD facility to generate electricity. The third scenario we consider increasing the utilisation of the AD and composting facility by adding energy crops and then we introduce a separator to the AD facility in the final development scenario. These development scenarios are described in Table 6.8, each of the four scenarios described are applied to normal and zero grazing.

Table 6.8 Scenario table for normal and zero grazing

	Treatment (AD & Composting Only)	Treatment with CHP and a market for compost	Treatment with CHP, energy crops and a market for compost	Treatment with CHP, energy crops, separator and a market for compost
Composter	**Yes**	**Yes**	**Yes**	**Yes**
Anaerobic Digester	**Yes**	**Yes**	**Yes**	**Yes**
CHP Included	No	**Yes**	**Yes**	**Yes**
Separator included	No	No	No	**Yes**
Additional Energy Crops	No	No	**Yes**	**Yes**
Market for Compost	No	**Yes**	**Yes**	**Yes**

Each of these scenarios can be calculated with the four catchment area development options (Single high risk farm, On-farm treatment, Farm based community treatment, Dairy based community treatment) identified in the previous section to generate a single results table.

6.6 Results for the Catchment Area

The NPV of the direct economic costs and benefits associated with mitigating FIO run-off under different development options under the normal and zero grazing compliance options are presented below.

The NPV of each development option is the discounted value of future income streams over the lifetime of the project taking into account the initial capital expenditure. We have assumed a 10% discount rate as the cost of borrowing for the farm (the actual value would be expected to range between 7.5% for an agricultural mortgage and 14% for a business charge card) and a 15 year project life time. A positive NPV indicates that the economic benefits are greater than the economic costs and represents a good investment for the farmers. Where a project has a positive NPV, an expected payback is also provided (the number of years it takes to payback the initial capital cost). A project can have a positive NPV but a long payback, which would suggest that the project is unlikely to be implemented. Many private businesses use payback criteria of between 2 and 3 years.

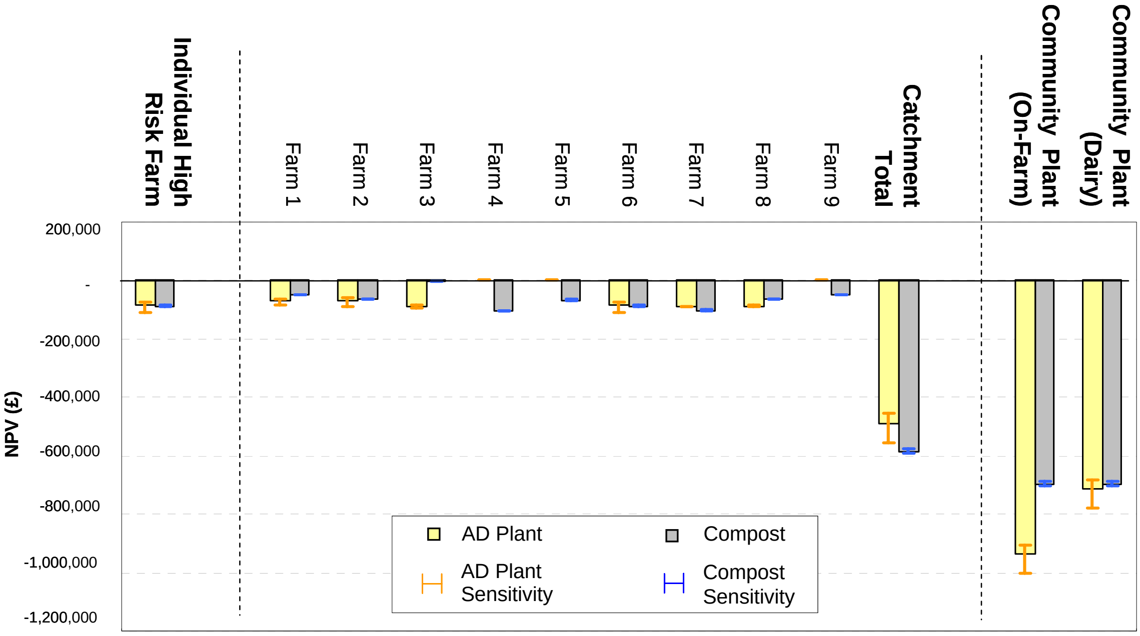
6.6.1 Normal Grazing

The NPV of each scenario is shown in the following graphs and detailed results tables are provided in the annex. These results give the NPV of treating the FYM and slurry arisings in the Sandyhills catchment area. Broader social costs and benefits that may result from the treatment of FIO are discussed in the next section.

Normal Grazing – Treatment (AD and composting only)

Under this treatment scenario the AD and composting is implemented but there is no CHP unit attached to the AD plant. This would minimise the initial capital expenditure, however, it would also prevent income being generated from electricity. Where compost is produced, it is assumed that it is used on the farm and not sold to market. The results are given in Figure 6.1 and Table A3.7.

Figure 6.1 Normal Grazing – AD and composting only



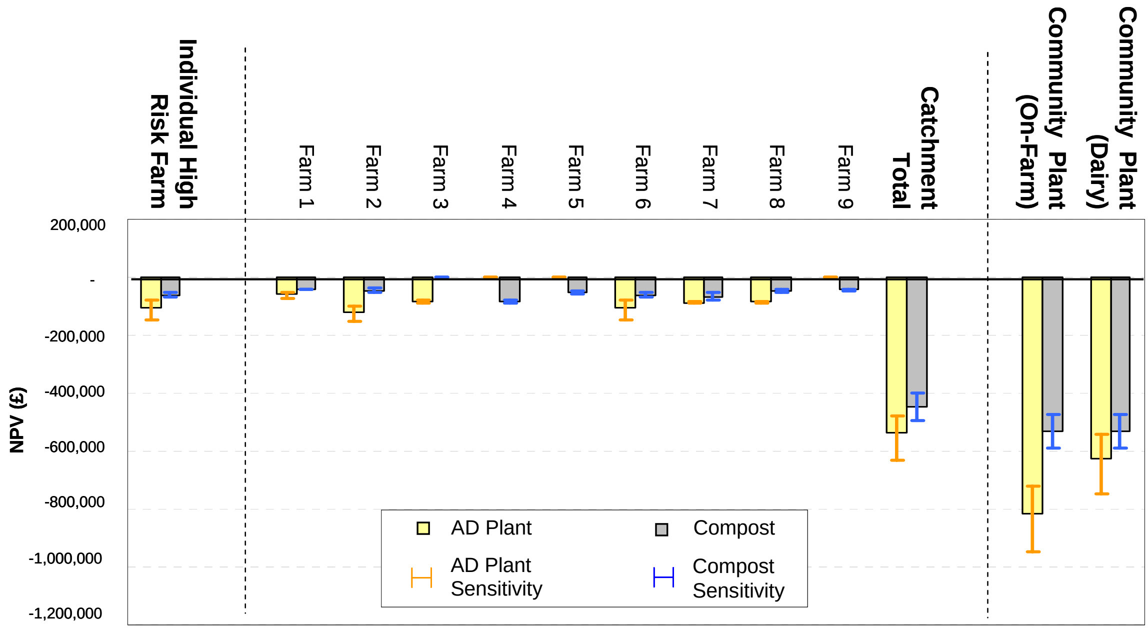
Installing an AD plant and a composting facility without a CHP unit or market for compost has an overwhelmingly negative net present value, with a NPV to the catchment area of £1.1m if all farms are treated (£-0.6m compost and £-0.5 AD). Under a community plant the NPV is even lower at -£1.6m for the on-farm community plant and -£1.4m community plant located next to a demand for heat (a dairy). The NPV of the community plant is lower than the on-farm treatment options due to the increased cost of transport, biohazard control and environmental and planning licences. The difference between the on-farm and dairy community plant depends on the quantity of heat that can be consumed.

High and low sensitivities on the AD plant can then either reduce the NPV by £0.06m or increase the NPV by £0.03m according to the expected enhanced value of the liquid biofertiliser and the value of the heating oil. The sensitivities for compost depend on the enhanced value of compost as a fertiliser for the farm and change the NPV by approximately £0.01m.

Normal Grazing – Treatment with CHP and a market for compost

The second scenario assumes that a CHP unit is added onto the AD plant to generate electricity and that the compost material can be sold to market. This increases the potential revenue of each AD plant and compost facility (Figure 6.2 and Table A3.8).

Figure 6.2 Normal Grazing – Treatment with CHP and market for compost



Introducing a CHP unit and a market for compost increases the expected net present value of each treatment option, however they are still negative (ie a net cost). For on farm treatment across the catchment the total NPV has been improved by approximately £0.9m, whilst for the community treatment the total NPV has been improved by approximately £0.29m for the on-farm community plant and £0.26m for the dairy based community plant. This improvement in the NPV is due to the export of compost to the market and the conversion of surplus heat to electricity.

For both composting and AD plants, however, there is still a total cost to the catchment area with an NPV of -£1m (-£0.5m AD and -£0.4m compost) if all farms are treated individually in the catchment area. For the community plant there is a NPV of -£1.3m (-£0.8 AD and -£0.5 compost) if the community plant is located on farm and -£1.2m (-£0.6 AD and -£0.5 compost) if the community plant is located next to a source of electricity and heat demand (community plants are expected to have a lower NPV due to the cost of transport and environmental licensing). High and low sensitivities on the total cost of treatment can vary the NPV by up to +/- £0.18m depending on the market value of compost and the expected fuel and electricity prices.

Although exporting compost has improved the NPV, composting is still considered financially unviable. As there is some uncertainty surrounding the market price for compost and a farmer in the Sandyhills catchment has found a market that is willing to pay £30 per tonne, we have included an additional sensitivity analysis to examine the price required to generate a positive NPV is given in Table 6.9.

Table 6.9 Market price of compost

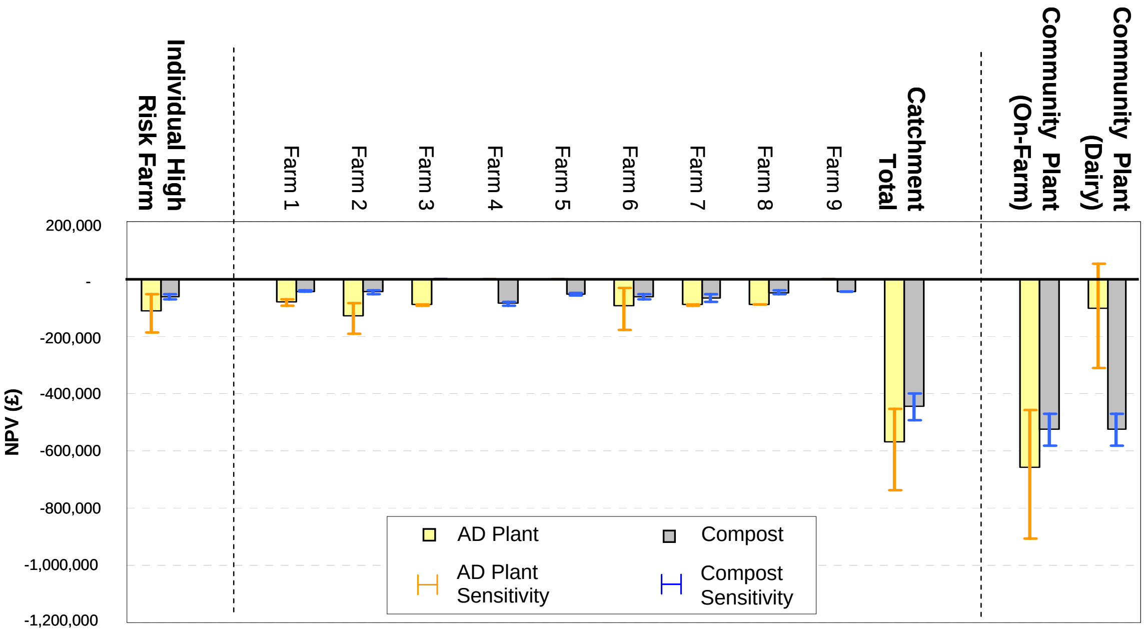
Market price of compost (£/t)	Individual High Risk Farm		Individual Farm Catchment Total		Community treatment (On-Farm & Dairy)	
	NPV	Payback (Yrs)	NPV	Payback (Yrs)	NPV	Payback (Yrs)
£7.50	-£62,000	n/a	-£446,000	n/a	-£531,000	n/a
£15	-£36,000	n/a	-£306,000	n/a	-£359,000	n/a
£30	£15,000	6	-£27,000	n/a	-£15,000	n/a

Table 6.9 shows that a minimum price of 30 £/t of compost has to be achieved for the composting unit to have a positive NPV at an individual high risk farm. For individual farms across the catchment area and the community treatment plant, however, the NPV of composting still negative (due to the greater capital costs and higher unit operating costs). Whilst a compost price of 30 £/t has been reported it should be noted that as compost supplies are increased, the market price would be expected to fall unless additional sources of demand can be accessed.

Normal Grazing – Treatment with CHP, energy crops and a market for compost

In this scenario we keep the assumption that there is a market for compost and so the NPV of compost remains unchanged for the on-farm treatment options[10]. In addition the model assumes that the farmer grows energy crops. Energy crops significantly increases the utilisation of the AD plant by increasing the amount of material that can be input into the AD plant during the summer months. As a result there is an increase in the amount of electricity and heat that can be generated (Figure 6.3 and Table A3.9).

Figure 6.3 Normal Grazing – Treatment, CHP, energy crops & market for compost



Introducing energy crops to the AD plant, has increased the NPV of AD as it increases the utilisation of the plant and increases the amount of electricity and heat that can be generated. The NPV of the AD plant for on farm treatment across the catchment area has increased by £0.05m compared with the original scenario,

10 There is a minor change in the cost of community treatment due to the method of allocating generic community treatment costs to AD and composting.

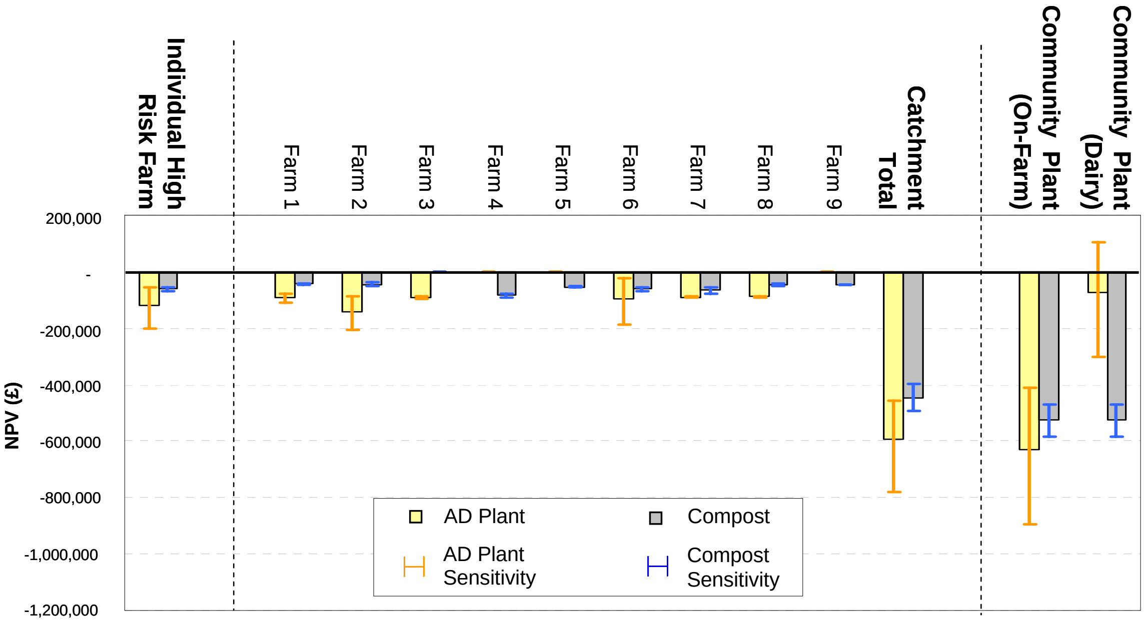
treatment (AD and composting only), however, the AD plant still has an NPV of -£0.5m.

For the community treatment plants, however, the NPV improves more significantly. The most significant improvement in the NPV occurs when the community treatment facility is located close to a source of heat and electricity demand such as a dairy. This has improved the NPV to £-0.1m and there is a potential for a positive NPV under the high income sensitivity. This NPV, however, does not include potential additional costs of connecting the CHP unit to the source of heat demand.

Normal Grazing – Treatment with CHP, energy crops, separator and a market for compost

In the final normal grazing scenario we keep the assumption that there is a market for compost and we assume that a separator is added to the AD facility so that a proportion of the digestate can be converted into a compost material to create an additional potential revenue stream for the AD plant. The NPV of the compost facility remains unchanged from the previous scenarios. (Figure 6.4 and Table A3.10).

Figure 6.4 Normal Grazing – Treatment, CHP, energy crops, separator & market for compost



The impact of including a separator on AD plant depends on the treatment facility being considered. For the individual high risk farm and on farm treatment across the catchment area, the NPV of the AD plant deteriorates slightly as a result of the additional capital expenditure. For the community facilities, however, the NPV of the AD plant increases by approximately £0.03m compared with the previous scenario.

6.6.2 Zero Grazing

Zero grazing is a farm management practice whereby cattle are housed throughout the year. Moving to zero grazing, therefore, increases the amount of FYM and slurry that is treated by the AD and composting facility and increases some revenues. However, zero grazing also increases the farms' annual costs. As zero grazing was not the primary focus of the study, there is considerable uncertainty associated with the cost and benefits of zero grazing management practices in the

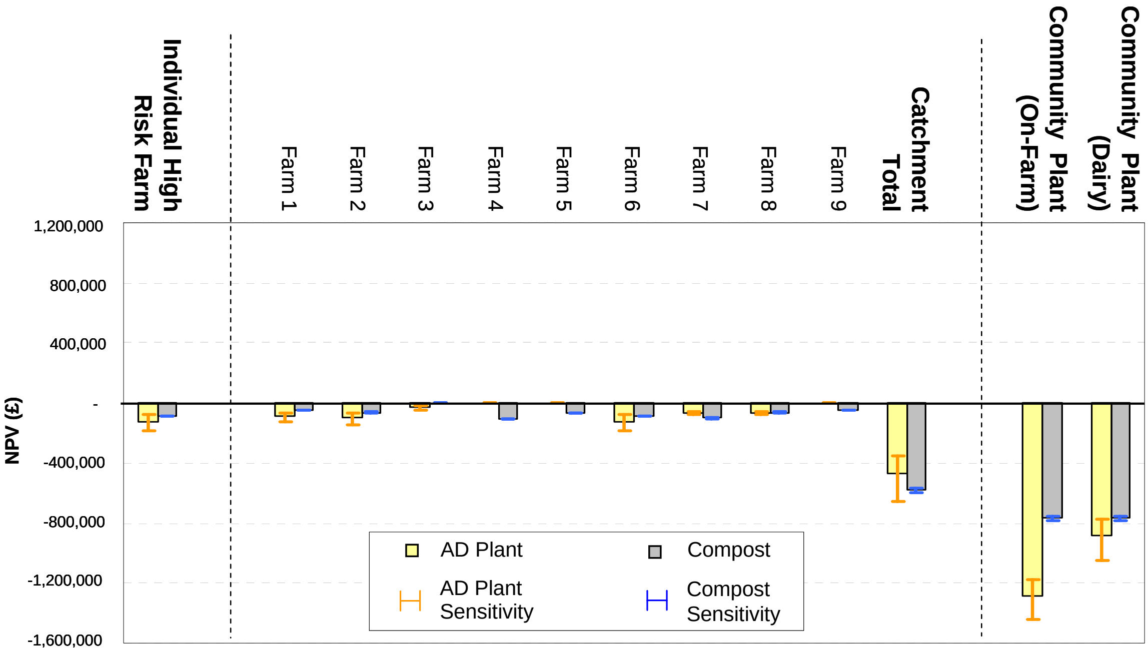
Sandyhills and Saltcoats catchment area. In addition zero grazing is not a practice widely used in the UK, so little substantive data on the precise costs of zero grazing is readily available.

As with normal grazing we have provided the NPV of each scenario as a graph and a table in Annex 3.

Zero Grazing – Treatment (AD and composting only)

Under this treatment scenario it is assumed that the AD and composting is implemented but there is no CHP unit attached to the AD plant. Where compost is produced, it is used on the farm and not sold to market. The results are given in Figure 6.5 and Table A3.11.

Figure 6.5 Zero Grazing – Treatment (AD and composting only)



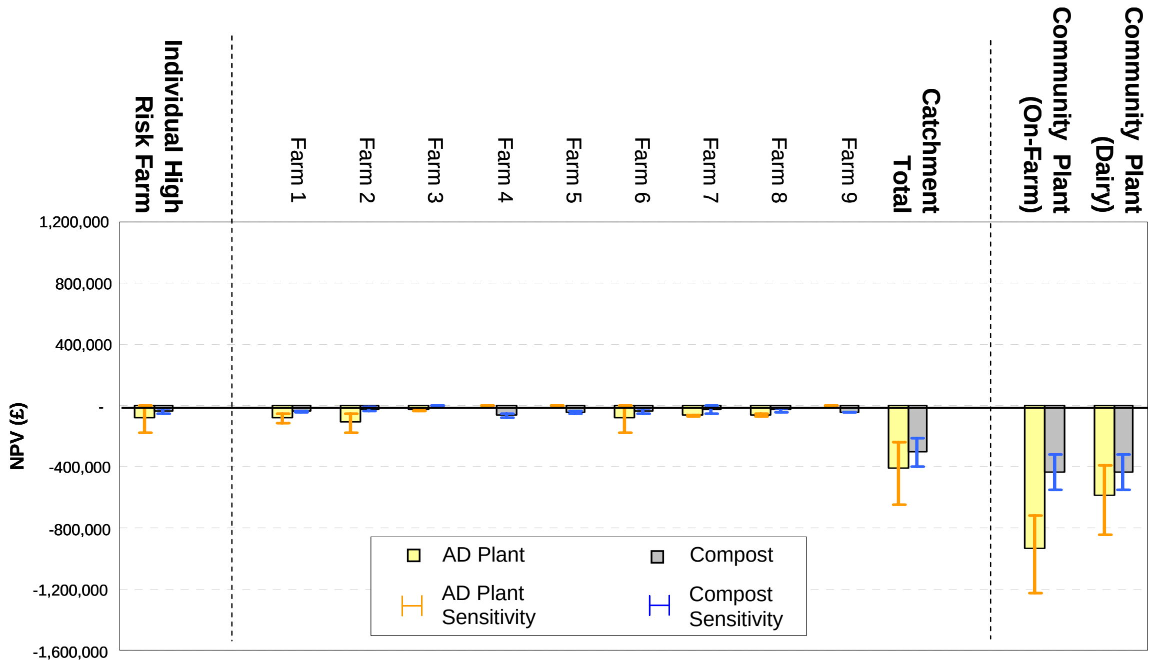
Installing an AD plant and a composting facility treatment facility without a CHP unit or market for compost and with zero grazing has a negative net present value. The NPV for treating the arisings on-farm across the catchment area is -£1.1m (-£0.5m AD and -£0.6m compost). If a community plant is installed the NPV is lower with an NPV of -£2.0m (-£1.2m AD and -£0.8m compost) if the community plant is located on-farm and -£1.6m (-£0.9m AD and -£0.8m compost) if the community plant is located next to a demand for heat (such as a dairy). High and low sensitivities on the AD plant can either reduce the NPV by -£0.2m or improve the NPV by £0.1m according to the expected value of the liquid biofertiliser and the value of the heating oil.

Comparing the zero grazing with the normal grazing treatment (AD and composting only) scenario (table A3.11 with table A3.7), shows there is little change in the NPV for the single high risk farm and the on-farm treatment between the two scenarios. With the on-farm treatment across the catchment area the NPV is improved by £0.02m under zero grazing due to increased revenue from improved beef and milk yields. However, with the community facility the increased revenue is negated by increased transport costs, the NPV under zero grazing is reduced by £0.4m for the community plant located on a farm and £0.2m for the community plant located on a dairy compared with normal grazing.

Zero Grazing – Treatment with CHP and a market for compost

The second scenario assumes that a CHP unit is added onto the AD plant to generate electricity and that the compost material can be sold to market. (Figure 6.6 and Table A3.12).

Figure 6.6 Zero Grazing – Treatment with CHP and market for compost



Introducing a CHP unit and a market for compost considerably reduces the expected cost of treatment compared with the treatment only scenario. For on farm treatment across the catchment area, the total NPV has been improved by approximately £0.3m with the NPV of the AD plant improving by £0.06m and the composting facility by £0.2m. For the community treatment the improvement in the NPV is more significant with the total NPV for community plant located on a farm now -£1.4m and -£1.0m when located by a diary.

These improvements in NPV under zero grazing are more significant than the improvements experienced under normal grazing option as the AD and composting units have a higher utilisation under the zero grazing option when slurry and FYM is collected through-out the year.

For the composting facilities, however, whilst the NPV is still negative increasing the FYM input under zero grazing increases the compost output and only slightly increases the annual cost of composting. As a result, the NPV of the composting facility is more sensitive to the market price of compost than under the normal grazing scenario, Table 6.10.

Table 6.10 Market price of compost sensitivities

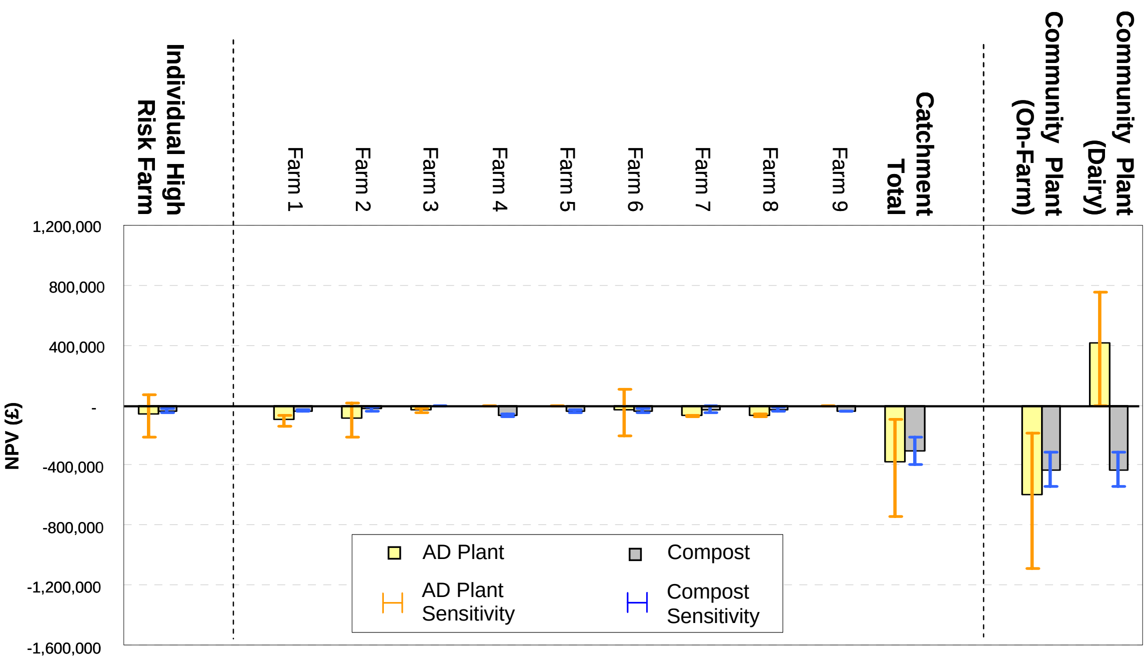
Market price of compost (£/t)	Individual High Risk Farm		Individual Farm Catchment Total		Community treatment (On-Farm & Dairy)	
	NPV	Payback (Yrs)	NPV	Payback (Yrs)	NPV	Payback (Yrs)
£7.50	-£36,000	n/a	-£306,000	n/a	-£432,000	n/a
£15	£15,000	6	-£27,000	n/a	-£87,000	n/a
£30	£118,000	3	£530,000	8	£600,000	3

Table 6.10 shows that an expected compost price of 30 £/t achieves a positive NPV and a 2 or 3 year payback period for large farms and community facilities. Although a positive NPV is also achieved at 15 £/t on large farms, the payback period is greater than 5 years and it is unlikely that the investment would take place through private investment.

Zero Grazing – Treatment with CHP, energy crops and a market for compost

In this scenario we maintain the assumption that there is a market for compost (so the NPV of compost facilities remains unchanged). In addition, it is assumed that the farmer grows energy crops which can be added to the slurry to improve the performance of the AD plant (Figure 6.7 and Table A3.13).

Figure 6.7 Zero Grazing – Treatment, CHP, energy crops & Market for compost



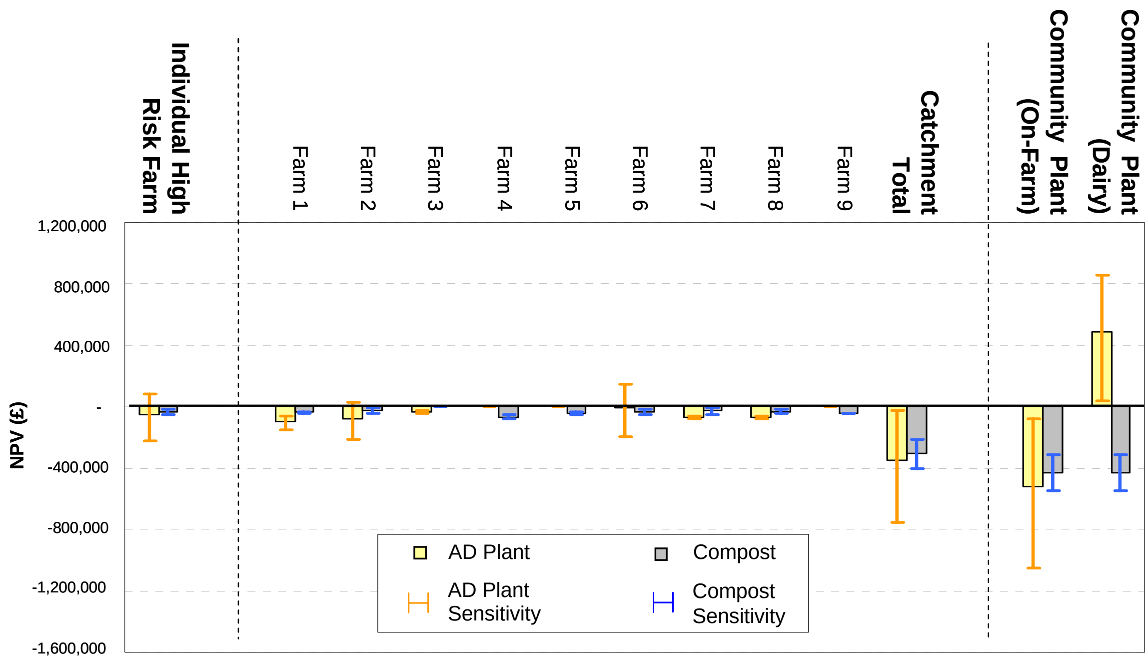
Introducing energy crops to the AD facility increases the utilisation of the AD plant so that the AD facility on the individual high risk farm has a potentially positive NPV under the high income sensitivity (although this is only £0.07m). The total cost of on-farm treatment across the catchment area, however, still has a negative NPV of -£0.7m as many of the small farms are not cost effective under any revenue scenarios.

The most noticeable change is with the community treatment facility. Where the community AD plant is located next to a source of heat and electricity demand (the dairy) the AD plant is expected to have a positive NPV of £0.4m with an expected payback of 5 years. This NPV may which might vary between an NPV of -£0.01m and £0.7m (creating a 3 year payback) under the low and high income sensitivities and can generate sufficient revenue to subsidise the composting facility.

Zero Grazing – Treatment with CHP, energy crops, separator and a market for compost

In the final scenario we maintain the assumption that there is a market for compost and assume that a separator is added to the AD facility generate an additional revenue form solid biofertiliser. (Figure 6.8 and Table A3.14).

Figure 6.8 Zero Grazing – Treatment, CHP, energy crops, separator & market for compost



As with the CHP and energy crop development option the NPV of the anaerobic digester is positive, partly due to the introduction of a separator. Overall the NPV improves by £0.01m for the single high risk farm, the NPV of the total catchment area for on-farm treatment is improved by £0.3m and the NPV of both community treatment plants are improved by £0.8m. This improvement in NPV is sufficient to allow the community treatment plant located next to a dairy to subsidise the composting facility, and generate a total NPV for composting and AD plant of £0.06m.

6.6.3 Summary – Zero and Normal Grazing NPVs

Combining the results of the normal and zero grazing options, Table 6.11, it is clear there is only one development scenario that generates a positive NPV – community treatment (dairy based). This development option requires zero grazing and the heat and the electricity output of the CHP to be fully utilised and a separator installed.

Table 6.11 Summary Results for Normal and Zero Grazing at 10% Discount Rate. (NPV £)

	Normal Grazing				Zero Grazing			
	Treatment (AD & Composting Only)	Treatment with CHP and a market for compost	Treatment with CHP, energy crops and a market for compost	Treatment with CHP, energy crops, separator and a market for compost	Treatment (AD & Composting Only)	Treatment with CHP and a market for compost	Treatment with CHP, energy crops and a market for compost	Treatment with CHP, energy crops, separator and a market for compost
Individual High Risk Farm	-£172,000	-£166,000	-£174,000	-£183,000	-£209,000	-£114,000	-£96,000	-£88,000
On-Farm treatment (catchment total)	-£1,073,000	-£984,000	-£1,017,000	-£1,041,000	-£1,054,000	-£718,000	-£682,000	-£653,000
Community Plant (On-Farm)	-£1,634,000	-£1,344,000	-£1,186,000	-£1,158,000	-£2,048,000	-£1,373,000	-£1,027,000	-£952,000
Community Plant (dairy based)	-£1,411,000	-£1,156,000	-£631,000	-£603,000	-£1,646,000	-£1,022,000	-£16,000	**£59,000**

With normal grazing these results show that identifying a single high risk farm and installing AD and composting equipment on the farm, with a CHP Unit, energy crops and a market for compost is the most cost effective development option. However, as this still has a negative NPV and would not be expected to make a financial gain over the lifetime of the facility.

If all the slurry and FYM arisings in the catchment area require treatment, then a community treatment (dairy based) is the most cost effective option, where the AD plant is located next to a source of onsite demand for the electricity and the surplus heat generated. However, on farm treatment is more cost effective than a community plant located on a farm where the demand for heat and onsite electricity consumption is limited. The reason for this is that in the Sandyhills catchment area, the additional costs associated with community treatment outweigh the expected economies of scale of building a single facility that can treat material from across the catchment area.

Under the zero grazing scenario it is possible to develop a treatment scenario that generates a positive NPV by installing a community treatment facility next to a dairy, this generates total NPV of £59,000 for treating both the FYM and slurry arisings.

However, it is important to note that in these scenarios we have assumed that slurry and FYM are treated in a similar manner either at a community facility or on farm. A more favourable option would be to combine the positive economic result for managing slurry at a community AD facility close to a source of heat demand, and the least expensive option for managing FYM using on-farm composting.

6.7 Social Costs and Benefits

6.7.1 Social Discount Rate

The analysis provided in the previous section was completed with a 10% discount rate, a rate which is representative of commercial investment appraisal. This answers the question of whether the farmer would choose to invest in either an AD plant or composting facility based on the expected revenues and costs.

As the commercial investment appraisal is generally negative, an alternative consideration is whether a positive investment appraisal is generated by a social discount rate (determined by the cost of government borrowing). We have repeated the analysis in the previous section to appraise each development scenario using the real social discount rate of 3.5%. These results are presented in Table 6.12.

Table 6.12 Summary Results at a 3.5% discount rate for Normal and Zero Grazing.

	Normal Grazing				Zero Grazing			
	Treatment (AD & Composting Only)	Treatment with CHP and a market for compost	Treatment with CHP, energy crops and a market for compost	Treatment with CHP, energy crops, separator and a market for compost	Treatment (AD & Composting Only)	Treatment with CHP and a market for compost	Treatment with CHP, energy crops and a market for compost	Treatment with CHP, energy crops, separator and a market for compost
Individual High Risk Farm	-£151,000	-£113,000	-£109,000	-£112,000	-£208,000	-£35,000	**£8,000**	**£31,000**
On-Farm treatment (catchment total)	-£1,066,000	-£872,000	-£891,000	-£897,000	-£1,038,000	-£470,000	-£385,000	-£310,000
Community plant (On-Farm)	-£2,014,000	-£1,529,000	-£1,273,000	-£1,220,000	-£2,640,000	-£1,572,000	-£1,033,000	-£909,000
Community plant (dairy based)	-£1,676,000	-£1,244,000	-£432,000	-£380,000	-£2,032,000	-£1,040,000	**£498,000**	**£623,000**

Reducing the discount rate from a commercial to a social discount rate has a significant impact on the NPV of each scenario. For development scenarios with a annual income that is positive (i.e. their revenues are greater than their operating costs), the social discount rate improves their NPVs. Whilst development scenarios which have an annual negative annual income (i.e. their revenues are less than their operating costs) then reducing the discount rate reduces their NPV as future annual losses are given a greater emphasis with a low discount rate.

As a result the NPV of the first development scenario, ‘treatment (AD & composting only)’, deteriorates as the discount rate is changed from 10% to 3.5%, whilst the NPV of third and fourth scenarios improves, ‘treatment with CHP, energy crops and a market for compost’ and ‘treatment with CHP, energy crops, separator and market for compost’. This improvement is most significant with the zero grazing and is sufficient to give the single high risk farm development scenario a positive NPV.

6.7.2 Grants & Subsidies

The effectiveness of grants and subsidies is influenced by whether there is a net annual operating cost (whether the annual expenditure is greater than the annual income). If there is a net annual operating cost, an annual incentive would be required for the farmer to maintain the operation of the treatment facility. If there is an annual operating income, then the farmer would be expected to continue the operation of the treatment if grants were available to reduce the initial capital expenditure.

In the following section we first assess which scenarios make an annual operating profit and, for those scenarios, we then assess the capital grants that would be required to give them a positive NPV. We have not assessed the combination of grants and subsidies that would be required to maintain the operation of facilities that generate an annual operating cost.

Whether the annual operating cost is positive or negative is given under each of the development scenario is given in Table 6.13.

Table 6.13 Annual operating incomes

		Normal Grazing				Zero Grazing			
		Treatment (AD & Composting Only)	Treatment with CHP and a market for compost	Treatment with CHP, energy crops and a market for compost	Treatment with CHP, energy crops, separator and a market for compost	Treatment (AD & Composting Only)	Treatment with CHP and a market for compost	Treatment with CHP, energy crops and a market for compost	Treatment with CHP, energy crops, separator and a market for compost
Individual High Risk Farm	AD Facility	£7,000	£13,000	£16,000	£17,000	£2,000	£16,000	£22,000	£26,000
	Composting Facility	-£2,000	£1,000	£1,000	£1,000	-£2,000	£4,000	£4,000	£4,000
On-Farm treatment (catchment total)	AD Facility	£17,000	£26,000	£30,000	£34,000	£20,000	£43,000	£55,000	£67,000
	Composting Facility	-£16,000	£3,000	£3,000	£3,000	-£15,000	£21,000	£21,000	£21,000
Community Plant (On-Farm)	AD Facility	-£61,000	-£33,000	-£9,000	-£2,000	-£106,000	-£49,000	£0	£12,000
	Composting Facility	-£36,000	-£14,000	-£14,000	-£14,000	-£45,000	-£2,000	-£1,000	-£1,000
Community Plant (dairy based)	AD Facility	-£32,000	-£8,000	£64,000	£71,000	-£54,000	-£3,000	£133,000	£145,000
	Composting Facility	-£36,000	-£14,000	-£14,000	-£14,000	-£45,000	-£2,000	-£1,000	-£1,000

From Table 6.13 a large number of scenarios have negative annual operating incomes. These scenarios would probably require an annual subsidy to continue in operation.

In general composting facilities have a positive annual income when there is a market for compost and when the compost facility is located on the farm. With community facilities the additional annual costs of transport and licensing generates a negative annual income for composting under both the normal grazing scenario and zero grazing scenarios.

A similar benefit can be seen with the AD facility. In most instances this has a positive annual operating cost when installed on farm. When the AD facility is installed as a community plant the annual income is typically negative unless there is a demand for the heat and electricity. Where there is a demand for the heat and electricity generated from a community AD plant at a dairy; the AD facility generates an annual income of between £64k (with normal grazing with CHP and energy crops) and £145k a year (under the zero grazing scenario with CHP, energy crops and a separator).

Where a development option has a negative annual income the plant will require an annual subsidy to maintain its operation and may require an additional capital grant to generate a positive NPV. However, if a development option has a positive annual income but a negative NPV, then the capital costs associated with that development option are greater than the discounted value of future income. These projects may benefit from a capital grant.

For development scenarios that have a positive annual income, we considered three different capital grant assumptions (25%, 50% and 75% of capital costs) to determine the capital grant required to generate a positive NPV project. Table 6.14

shows the net present value of investment with a 25% capital grant (50% and 75% capital grant are given in the appendix, Tables A3.15 and A3.16). These tables do not show results for scenarios with a negative annual cost where a capital grant alone would be insufficient to ensure the continued operation of the plant.

Table 6.14 Net Present Value with 25% Capital Grant with a 10% discount rate

		Normal Grazing				Zero Grazing			
		Treatment (AD & Composting Only)	Treatment with CHP and a market for compost	Treatment with CHP, energy crops and a market for compost	Treatment with CHP, energy crops, separator and a market for compost	Treatment (AD & Composting Only)	Treatment with CHP and a market for compost	Treatment with CHP, energy crops and a market for compost	Treatment with CHP, energy crops, separator and a market for compost
Individual High Risk Farm	AD Facility	-£49,000	-£54,000	-£54,000	-£58,000	-£88,000	-£28,000	-£3,000	£11,000
	Composting Facility		-£45,000	-£45,000	-£45,000		-£19,000	-£19,000	-£19,000
On-Farm treatment (catchment total)	AD Facility	-£334,000	-£354,000	-£372,000	-£381,000	-£317,000	-£228,000	-£177,000	-£133,000
	Composting Facility		-£330,000	-£330,000	-£330,000		-£190,000	-£190,000	-£190,000
Community Plant (On-Farm)	AD Facility							-£447,000	-£367,000
	Composting Facility								
Community Plant (dairy based)	AD Facility			£44,000	£77,000			£564,000	£644,000
	Composting Facility								

Table 6.14 shows that for a large single high risk farm under normal grazing practices a 25% grant is sufficient to make an AD facility cost effective if energy crops are also added to the digester and a separator under a zero grazing scenario. Under the 25% capital grant the AD facility applied to a single high risk farm would require a capital grant of approximately £60k (the capital grant requirements for a 25% capital grant is given in Annex 2, Table A3.17) and would generate a payback of approximately 11 years. The community AD facility is also cost effective with a 25% capital grant (equivalent to a capital grant of £153k) with a payback time of 7 years. The payback period of the community AD facility would be reduced to 3 years under zero grazing for the same capital grant.

The compost facilities are not cost effective with a 25% capital grant, however under zero grazing with a 50% capital grant on farm composting facilities are cost effective (shown in annex 2). This requires a capital grant of approximately £35k for the single high risk farm and £232k for on-farm treatment across the catchment area. It should be noted that, as the catchment area consists of 9 high risk farms, the aggregated NPV is positive due to the presence of large farms with better economies of scale; however, smaller farms may not generate a positive NPV.

Where scenarios generate a negative net annual cost and a negative NPV a combination of initial capital grant and ongoing subsidy or grant would be required to maintain the operation of the treatment facility.

A commitment to increasingly embed the ‘polluter pays principle’ into policies has been stated within Scotland’s Sustainable Development strategy published in December 2005. The Environmental Liability Directive will be implemented in 2007 and will oblige operators in specified circumstances who risk or cause damage to land, water or biodiversity to avert the risk or pay to remedy the damage caused.

This will need to be addressed in future projects when assessing the economics of agricultural based AD or composting technologies and potential grant aid systems.

6.7.3 Cost of infraction proceedings

Costing the risk of potential infraction penalties is problematic and does not sit easily with an economic analysis of "probable annual cost" of a bathing waters infraction before and after adopting any particular treatment option.

The maximum cost resulting from a breach of bathing water rules has a maximum penalty of €18 million per day. However, the maximum penalty is rarely applied and in recent infraction proceedings, Spain was charged €0.6 million per year for each percentage of bathing waters judged to be in non compliance. It is therefore considered unlikely that the maximum penalty of €18 million would be applied. As bathing waters infraction depends on a number of sources of FIO pollution that combine in a non-linear fashion, we excluded the cost of infraction proceedings from this model. We note, however, that there may be an additional economic cost associated with bathing waters infraction.

6.7.4 Increased Amenity

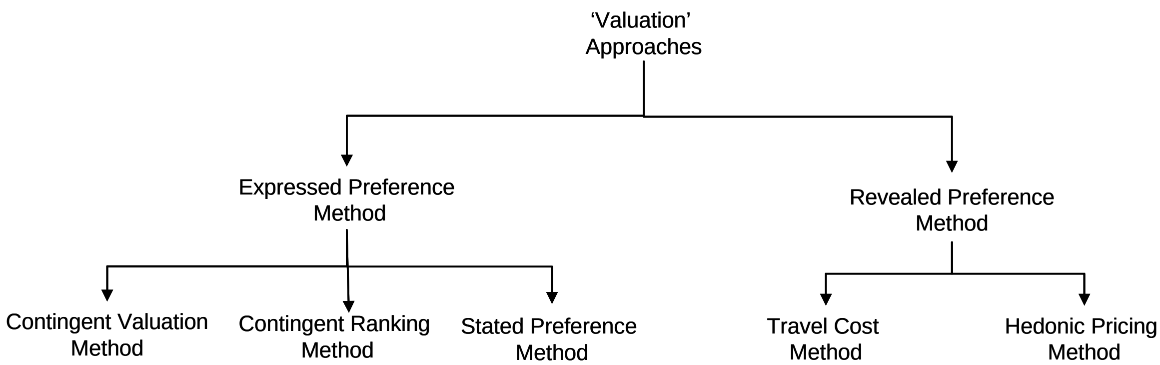
The bathing waters at Sandyhills and Saltcoats are natural assets and used by bathers. There are health and non-health benefits and attributes of value to society associated with clean bathing, including space for recreation, visual appeal and habitats for biodiversity.

Compliant Bathing Water Valuation Methods

Some common valuation methods used to value non-market and environmental goods and services and to assess the specific value of the bathing waters in question are introduced below. These values capture the extent to which society is willing to pay for a good or a service, such as clean air and water, and hence the loss in value if society were deprived of the asset.

There are a range of methods to determine the financial value of and environmental goods. Figure 6.9 presents an overview of the different valuation approaches. These can be grouped into expressed preference methods and revealed preference methods.

Figure 6.9 Overview of Valuation approaches



Source: adapted from Bateman (2001)[11]

11 Bateman, I, Day, B, Lake, I, Lovett, A (2001). The Effect of Road Traffic on Residential Property Values: A Literature Review and Hedonic Pricing Study.

Expressed preference methods are based on direct interaction with a representative number of people to understand individuals' or households' preferences. This can be done via questionnaires, surveys or focus group sessions. Revealed preference techniques try to elucidate values for environmental attributes via traded markets related to the asset in question, typically these include travel costs and housing markets. The five most common techniques are described below;

- *Contingent valuation methodology* The contingent valuation methodology is a survey-based technique where individuals are asked to state their maximum Willingness to Pay (WTP) for an environmental good or benefit or how much they are Willing to Accept (WTA) in compensation for deprival of the asset. WTA studies often generate higher valuations than WTP studies (although in theory they should not) because the public want to be paid more for the deprival of something that had previously used, than to pay for the asset they currently use.

- *Contingent Ranking and Stated Preference Methods.* These are often referred to as choice experiments. Economists use choice experiments to determine individuals' preferences for the attributes of a good or service. If one of these attributes is price, then the respondents' willingness to pay for the other attributes can often be inferred.

- *Travel cost method* The minimum willingness to pay to enjoy the services of non-market good such as green spaces can be measured by estimating the costs of travelling to them, in addition to any other costs incurred in consuming these services. On the basis of questionnaire surveys, data is collected on the number of visits and cost of accessing the site.

- *Hedonic pricing method*. Hedonic pricing refers to the theory that the marginal value of a good is based on a wide range of attributes the good possesses. The hedonic price method is based on the fact that house prices can reflect differing local environmental attributes. If these price effects can be isolated and the value of the environmental attribute in question can be estimated.

One key point on these methods is that a value derived in one region may not correlate another region, as geographical and economic features will vary considerably between regions. The value attributed to a beach will depend on the number of alternative beaches in the region and the proximity to transport links and type of leisure activities involved.

Sandyhills and Saltcoats Valuation – Health based

To determine the societal value of the bathing water and beaches at Sandyhills and Saltcoats, ideally a location specific valuation exercise is required. The most appropriate method would be a contingent valuation through a survey or focus group session with residents and visitors. Such an exercise is outside the scope of this project. However, we can, to a limited extent, make use of previous valuation studies on bathing water quality.

The Environment Agency published guidance on determining the benefits of bathing water improvements in 2003 (Environment Agency, 2003). The guidance is based on two primary studies by Georgiou et al (2000) and Eftec (2002). The Georgiou study applied contingent valuation methodologies to assess the Willingness To Pay (WTP) for maintaining or achieving bathing water standards at two beaches in East Anglia. The Eftec study is based on a national survey and determines the WTP for bathing water improvements at beaches across England and Wales. Both studies focused only on reducing health risks associated with the microbiological quality of bathing waters in the context of the Bathing Water Directive. (No similar Scottish studies have been identified).

Table 6.15 summarises the value per beach per annum derived from these studies, focussing purely on health effects – i.e. a reduction in the risk of contracting gastroenteritis (Risk Policy Analysts, 2003). The figures represent an improvement in risk of 2%, i.e. from a risk of between 7% to 5%. The Environment Agency recommends the use of the Eftec value as the best estimate of potential benefits from improvements to bathing waters (we are not aware of any guidance provided by SEPA). As a sensitivity check it is proposed that the Georgiou values be used.

When using the Georgiou values, the number of alternative sites needs to be identified within 130 km for large resort (65 km in Wales), 50 km for small resorts (25 km in Wales) and 30 km for small beaches (15 km in Wales). The value then needs to be divided by the number of alternative sites plus one to arrive at the correct value. This calculation attempts to take account of the scarcity value of a good quality beach. When using the Georgiou approach we would recommend using the value for Wales in the context of the Sandyhills and Saltcoats beaches as we consider the Welsh beaches to be more representative of Scottish beaches in terms of their physical attributes and visitor profiles.

Table 6.15 Values for Bathing Benefits (2001 prices) (Environment Agency 2003)

Type	Value per beach p.a. (Eftec 2002) **	Value per beach p.a. (Georgiou 2000)*
Large Resort (long beach, entertainment and facilities available)	£646,000	£13,000,000 (England)
		£2,400,000 (Wales)
Small Resort (good access, some beach facilities available, village/ small town)	£96,000	£1,900,000 (England)
		£360,000 (Wales)
Small beach: little access, valued for peace and quiet	£48,000	£680,000 (England)
		£130,000 (Wales)

* The value in this column has to be divided by the number of alternative sites plus one.
** For each value the range is of the order of +/- 30%

Using these values we would draw the following values for estimates of the value of improved bathing water quality at the Sandyhills and Saltcoats beaches (Table 6.16). These figures represent annual values. To determine the present day value of the beach we have discounted these future benefits at the Treasury's real social discount rate of 3.5% over a 15 year lifetime, the same lifetime assumed for an AD and composting facility. These present day values are shown in Table 6.17.

Table 6.16 Valuation Summary – (2001 prices)

Type		Sandyhills £/yr	Saltcoats £/yr
Eftec	Low (-30%)	£67,200	£452,200
	Mid	**£96,000**	**£646,000**
	High (+30%)	£124,800	£839,800
Georgiou[12]	Low	£50,400	£420,000
	Mid	**£72,000**	**£600,000**
	High	£93,600	£780,000

12 There are 4 similar beaches within a 25 km radius of Sandyhills, including Southerness, Rockcliff, Brighouse Bay, Carrick Bay. A total of 9 beaches in the vicinity of Saltcoats were identified, of which 3 are comparable sites (large beaches), including Girvan, Ayr, Troon.

Table 6.17 Valuation Summary – Present Value (2001 prices)

Type		Sandyhills	Saltcoats
Eftec	Low (-30%)	£774,000	£5,208,000
	Mid	£1,106,000	£7,440,000
	High (+30%)	£1,437,000	£9,672,000
Georgiou	Low	£580,000	£4,837,000
	Mid	£829,000	£6,910,000
	High	£1,078,000	£8,984,000

It is important to note that there are a number of limitations to the applicability of these values to the Sandyhills and Saltcoats beaches in the context of this study. In particular:

- The values in Tables 6.16 and 6.17 only include benefits associated with improvements in health. There are other knock-on benefits in terms of recreational fisheries, shell fisheries, biodiversity and non-use values, which these values do not take into account.
- The Eftec values are averages and not marginal values, i.e. they have been calculated by determining the total value of bathing beaches in the UK and dividing this by the number of bathing beaches. They therefore do not reflect the incremental value of improving individual beaches. The Georgiou figures attempt to take this marginal impact into account.
- The values are based on beaches in England & Wales where population density, visitor profiles and level of beach and bathing activity may differ considerably from those in Scotland.

In view of these uncertainties it would be misleading to use the benefit values shown here in the context of a cost benefit analysis comparing costs and benefits of improving bathing water quality at the Saltcoats and Sandyhills beaches. They are best used to illustrate the very broad orders of magnitude that might exist solely for the health benefits of improved bathing water quality for a typical beach. How representative the beaches in question are in relation to those used in the Eftec study has not been assessed.

6.7.5 Change in Employment

While the loss of the beach would have an impact at the local level, at the national level this would simply become an issue of displacement as any loss of tourist revenue would be displaced by income generated from alternative uses of the resources that are currently employed in the tourist industry. We have therefore not considered the impact on changes in employment.

6.8 Conclusions

The economic assessment has established the economic costs and benefits of minimising FIO pollution from agricultural sources to bathing waters. The economic assessment has focused on the Sandyhills catchment, as the majority of pilot facilities were installed there, but the conclusions are also applicable to Saltcoats catchment area.

In order to comply with the Bathing Water Directive in the Sandyhills catchment area, the slurry and FYM arisings collected during the winter months have to be treated in an AD and composting facility. For the Saltcoats catchment area zero grazing is required along with the treatment of all slurry and FYM arisings. In this project we have studied the impact of two small rural catchment areas, and found that zero grazing was required to comply with the bathing water directive in one of them. Further analysis would be required to expand these results beyond the Sandyhills and Saltcoats catchment areas. Zero grazing has emerged as an important method of complying with the bathing water directive during the course of this project and would be required to comply with the bathing water directive in the Saltcoats catchment area but not the Sandyhills catchment area.

From the economic analysis we can conclude that;

- Zero grazing improves the economics of AD and composting as it allows greater quantities of slurry to be collected during the summer months thereby improving the utilisation of treatment equipment. The wider social costs and benefits of zero grazing have not been assessed in this study.

- Due to poor returns, farmers are unlikely to invest in either an on-farm composting or an on-farm AD facility without an additional economic incentive under both the normal and zero grazing scenarios.

- The expected returns to the farmer are sensitive to the amount of electricity generated. Increasing the amount of electricity generated by introducing an alternative technology, such as fuel cells, would increase the returns to the farmer. However, a full assessment of the associated costs and operating characteristics of fuel cells would be required to determine whether this improves the project economics.

- The lowest cost development scenario is a community AD facility with a CHP unit along with energy crops and zero grazing when located next to an onsite demand for the heat and electricity output (such as a dairy). This generates a small positive NPV of £59,000 at 10% discount rate and hence could possibly attract a private developer, although the developer would need to consider all the risks of the project as well as the base case financial appraisal. All other development scenarios require a capital grant to generate a positive NPV.

- Composting is not cost effective under any development scenarios if current market prices of £7.5/t are expected for composting. Under high compost prices of £30/t a composting facility is cost effective for a large farm with normal grazing, however, the payback period is around 6 years. With zero grazing the payback is improved to 3 years and the community composting facilities are also cost effective.

- Introducing a social discount rate, at 3.5%, improves the NPV of development options that have a positive annual income and makes AD treatment on single high risk farms cost effective but with a long payback period. The most cost effective project remains community treatment close to a dairy with zero grazing, energy crops and a separator.

- Projects with a negative annual income will require support payments to maintain their operation and may require a capital grant to give them a positive NPV. Projects with a positive annual income will require a capital grant. The subsidy and grant requirement of each treatment plant under different development options has been summarised in Table 6.18.

Table 6.18 Support Payments and Capital Grant Requirements at 10% Discount Rate

		Normal Grazing				Zero Grazing			
		Treatment (AD & Composting Only)	Treatment with CHP and a market for compost	Treatment with CHP, energy crops and a market for compost	Treatment with CHP, energy crops, separator and a market for compost	Treatment (AD & Composting Only)	Treatment with CHP and a market for compost	Treatment with CHP, energy crops and a market for compost	Treatment with CHP, energy crops, separator and a market for compost
Individual High Risk Farm	AD Facility	75% CG	75% CG	50% CG	50% CG	>75% CG	50% CG	50% CG	25% CG
	Composting Facility	SP&CG	>75% CG	>75% CG	>75% CG	SP&CG	75% CG	75% CG	75% CG
On-Farm treatment (catchment total)	AD Facility	>75% CG	75% CG	75% CG	75% CG	>75% CG	75% CG	50% CG	50% CG
	Composting Facility	SP&CG	>75% CG	>75% CG	>75% CG	SP&CG	75% CG	75% CG	75% CG
Community Plant (On-Farm)	AD Facility	SP&CG	SP&CG	SP&CG	SP&CG	SP&CG	SP&CG	>75% CG	>75% CG
	Composting Facility	SP&CG	SP&CG	SP&CG	SP&CG	SP&CG	SP&CG	SP&CG	SP&CG
Community Plant (dairy based)	AD Facility	SP&CG	SP&CG	25% CG	25% CG	SP&CG	SP&CG	Positive NPV	Positive NPV
	Composting Facility	SP&CG	SP&CG	SP&CG	SP&CG	SP&CG	SP&CG	SP&CG	SP&CG

SP: Support Payments
CG: Capital Grant

- The analysis of the health benefits from an improvement in the bathing water quality in Sandyhills indicated a positive value of the order of £0.8m to £1.4m. These figures, however, are highly uncertain in the context of Sandyhills as they are based on beaches in England and Wales and only take account of the health benefits, ignoring the other potential societal benefits. They should not be used in a direct cost benefit comparison with the costs of controlling FIO run off.

- The expected present value for controlling FIO pollution by implementing a AD and composting facilities for the Sandyhills catchment area with normal grazing and a 3.5% discount rate is -£0.9m and -£1.2m.

The judgement of whether financial support should be provided to farmers to implement FIO controls is not easily reduced to simple cost benefit analysis. The increased adoption and implementation of the “polluter pays principle“ in Scottish legislation and policies may affect the viability of grant aid or support payment systems. Whilst this study has provided detailed costs for options for controlling FIO run off, there is far less certainty on the value of the social benefits. Whilst we would not recommend taking such a decision purely on the basis of the health benefits provided through the figures shown above, it should be noted however that the benefit figures from the Eftec study exclude non health benefits; hence the full social benefit of the beach could be higher than the range shown. If the decision on whether on farm controls is to be based on a cost benefit approach then further research is required on the value of the social benefits of the Sandyhills and Saltcoats beaches.

7. SUSTAINABILITY APPRAISAL

An appraisal of the legislation and sustainability benefits of the biogas and composting plants is an essential and final part of the research programme of this pilot project. A sustainability appraisal requires that legislative, environmental, economic and social aspects are all taken into account. There are various ways this can be set out, but it is important to give approximately equal consideration to each broad heading. The appraisal will consider the results of the research against the initial objectives using a framework of questions relating to key and supporting indicators, called a sustainability appraisal matrix.

The process was iterative and the initial appraisal was applied at the farm scale. During the process it became obvious that it would be necessary to widen out consideration of the impacts to take into account not only the benefit of the project to the catchments but also more widely, in effect the benefits to the nation.

7.1 Legislative Drivers and Constraints

7.1.1 Drivers

The key legislative driver in the context of this study is the European Bathing Water Directive (76/160/EEC). It sets the standards for bathing in coastal or inland waters where (a) bathing is authorised or (b) where it is established that bathing has traditionally occurred. Sampling of Scotland's designated bathing waters is carried out by SEPA to establish if the water quality is meeting European standards to protect public health. Several have failed in the last few years including the Saltcoats and Sandyhills bathing waters. The text of a new revised EU bathing water directive has recently been agreed and is due to enter into force in 2006. It represents a significant tightening of the standards relating to faecal pollution and will have significant implications for designated bathing water compliance in areas prone to diffuse agricultural pollution. This may therefore lead to a greater level of reported failure.

The provisions of the EC Nitrates Directive (91/676/EEC) and the current EC Groundwater Directive (80/68/EEC) and future proposed groundwater directives (COM(2003)550) are also very relevant with respect to run off from farm slurry and FYM. Groundwater in Scotland is not usually at risk of FIO pollution because the hydrogeology is such that there are few major aquifers, but minor and near surface aquifers are important sources of private water supply and could be at risk. The principal pollutant of concern, in addition to FIO, is nitrogen. There are no areas designated as Nitrate Vulnerable Zones (NVZ) under the Nitrates Directive in the project catchments. Additional drivers are discussed below.

The reform of the Common Agricultural Policy (CAP), agreed in 2003, requires that all farmers in receipt of the Single Farm Payment should meet the requirements of Cross Compliance. This means compliance with a series of 18 Statutory Management Requirements covering the environment, public, animal and plant health and animal welfare. The second part of Cross Compliance deals with revised Good Agricultural and Environmental Condition (GAEC) measures. The minimum requirements for GAEC measures are defined by Member States and relate to soil erosion, soil organic matter, soil structure and the minimum level of maintenance and protection of habitats.

Relevant Codes of Practice on soil protection, air and water will increasingly put pressure on farmers to control diffuse pollution; the various agri-environment schemes are also relevant tools and drivers in this category.

Government Policy on the benefits and take-up of renewable energy and the Renewables Obligations Orders/Regulations seek to maximise generation and use of renewable energy such as biogas. The Renewables Obligation Scotland (ROS) requires electricity suppliers to source some of their generation from renewable sources. This was set at 3% for 2002/2003 and 10.4% for 2010/2011. This scheme has proven to be very successful in creating commercially viable projects and increasing the demand for renewable generation. Small generators can currently aggregate their output over an annual basis and further steps are being considered which will make it easier for small generators to gain access to ROCs.

The European Emissions Trading Scheme (ETS) does not yet facilitate the trade of methane emissions, despite methane (CH_4) being a much more damaging 'greenhouse' gas than carbon dioxide (CO_2) when released to atmosphere. There is a wide lobby to have methane included in the trading scheme. This could add greatly to the financial profitability of biogas plants because methane generated during AD is combusted producing heat, water vapour and CO_2 rather than being released to the atmosphere.

If the drive towards greater accountability of the greenhouse gas cost and environmental sustainability of agriculture continues, the ability of AD plants and composting facilities to reduce the need for artificial fertiliser use should be highlighted. Production methods for artificial fertilisers are very energy intensive. By decreasing the need for energy intensive fertiliser, the overall carbon cost of agriculture on farms will be reduced.

Different taxation and pricing and support mechanisms are in place across Europe and are critical to the development of the economics of AD plants. The liberalisation of energy markets and likelihood of further diversification and decentralisation of energy generation will favour biogas based energy systems. Economic instruments to support mechanisms that provide benefits to sustainable energy, waste and agricultural development are not yet in place in the UK. A cross-sector approach may be necessary to correctly evaluate and financially value the multi-disciplinary nature and benefits of AD plants. As demonstrated by the Danish example below, some European countries have economic instruments in place that work to support such technologies.

In Denmark, approximately 4% of animal manure produced nationally goes to AD plants. The resulting biogas is used to fuel district heating schemes where possible. A Danish policy of promoting district heating systems fuelled by natural gas and biogas has helped provide a stable market for the biogas produced. Denmark has many large centralised plants that deal with the co-digestion of organic waste, domestic or industrial waste (75% slurry/manure - 25% organic wastes typical).Current policy in Denmark has created high energy and environment taxes on fossil fuels which favours the selection of houses heated with district energy from biogas.

7.1.2 Constraints

The legislative constraints associated with AC or AD technologies are considered below.

Waste Regulations

The Waste (Scotland) Regulations 2005 came into force on 21 January 2005 and bring agricultural waste into the existing Waste Management Licensing (and associated exemption) system. The driver for the introduction of these new Regulations was to bring current waste legislation in line with the EU Waste

Framework Directive (75/442/EEC, as amended). Where a farmer produces manure which is certain to be used by himself or another farmer as a fertiliser or soil conditioner (i.e. the use is beneficial to the land) and in accordance with good practice (in Scotland, as advised in the PEPFAA code and the 4 Point Plan) these materials are not considered wastes, even under the new legislation. Where, however, manure is used (1) in excess quantities - i.e. beyond those which are agriculturally beneficial, or (2) otherwise than in accordance with good practice, or (3), produced in quantities beyond those for which the farmer knows a use may be found, it will be considered a waste and waste legislation will apply.

Also where a farmer has manure/slurry transferred from the farm on which it is produced for use by a third party, it falls outwith the category of beneficial use.

Against this background, the decision as to whether an exclusion from the regulatory regime would apply to either a community composting plant, or a farm composting operation that is dependant on the import of off site waste, would be a matter of fact and law in each individual case, and would have to be discussed with SEPA. In addition the compost being produced on the project compost facilities may qualify as ‘off specification compost’ (i.e. not meeting industry standards such as BSI PAS100) under these Regulations and therefore may be suitable for spreading on land other than agricultural land i.e.:

- operational land of a railway, light railway or the British Waterways Board;
- land which is a forest, woodland, park, garden, verge, landscaped area, sports ground, recreation ground, churchyard or cemetery; or,
- where the land in question is not used for agriculture and such treatment results in ecological improvement.

However, such spreading may require to be carried out under exemption or waste management licence.

As there is currently no real market for digestate material it may not be possible to sell this product to the larger non-agricultural market outlined above. This may serve as a disadvantage to AD plants if competing against compost facilities for market of the treated products.

Animal By-Products and Biowaste

Biogas and composting plants are recognised treatment methods under Animal By-Products (ABP) legislation. As such, these technologies are increasing in popularity as a means for organic waste treatment, especially due to increased diversions of organic waste from landfill. The EU is currently working on a thematic strategy for soil which could provide more comprehensive guidelines relating to catering waste and highlight the value of recapture of nutrients from organic waste, and subsequent recycling of nutrients to agricultural land. A consultation was conducted in late 2005, and the directive is expected to be implemented during 2006. The development of the proposed Biowaste Directive has stalled, but changes will be made to the Waste Framework Directive that will allow and encourage member states to adapt a life cycle approach to biodegradable waste management. The EU has also indicated that a product standard system is being developed for compost and AD treated biowaste. This will, if implemented, create a very strong driver for compost and AD treatment of biological waste.

ABP implications

Animal manures and slurries fall under the EU Animal By-Products Regulation (EC No1774/2002) and they are categorised as Category 2 animal waste by-products. This legislation has been transposed in Scotland by virtue of the Animal By-products (Scotland) Regulations (ABPR) 2003. This legislation imposes certain standards for composting and AD treatment of animal by-products, including catering waste, and imposes restrictions on the application to land of the treated product. However there is currently no requirement under the regulations to treat animal manure to these standards. This legislation will potentially apply to both the small, on-farm scale systems and community based systems, (but only if animal by-products other than farm manures are being treated).

The EU Directive also imposes restrictions (Article 7) on the transport of manures and slurries from farm to farm and within farms, but offers dispensation for Member States to opt out of this for transport within the Member State. The UK has opted to dispense with Article 7 for movements of manures and slurries within the UK, so transport of these materials between farms is not restricted, save where it may be necessary to restrict movements due to risk of spreading a serious transmissible disease i.e. Foot and Mouth Disease. The treatment, and application to land, of digestate or compost composed of manure and slurry only, is concurrent with that of untreated slurry or manure (again, subject to risk of transmissible disease period restrictions). It is not subject to required treatment standards, application restrictions or required periods of non-grazing. It should be noted though, that other legislation may impinge on land application of composted or digested manure (i.e. Nitrate Vulnerable Zones) and current agricultural guidelines such as the PEPFAA may advise restrictions to application and periods of non-grazing.

If any other material (i.e. not slurry or manures) is included in an a farm scale composting or AD system then the process and the use of the compost and/or digestate will be subject to the terms set forth in the EU ABP regulation.

Community Scale Plants

The same ABP rules apply to community scale plants if the feedstock materials consist only of slurries and manures. However, the installation of a community plant would possibly open up avenues to take in feedstock that would generate gate fees (i.e. dairy waste or catering waste). If animal by-product wastes other than manures or slurries are to be treated in a community plant, then the following further requirements would need to be achieved:

- State Veterinary Service recommendation and Scottish Minister approval of the plant;

- implementation of a HACCP (hazard analysis and critical control points) procedure, a regular monitoring and microbiological testing procedure;

- comply with the hygiene and clean area requirements of the regulations and a maintained separation between clean and dirty areas;

- keep records of incoming and out going wastes and products;

- implement processing standards that meet the minimum treatment requirements for composting and AD in Tables 7.1 and 7.2 below;

- comply with the microbiological standards as detailed in the regulations;

- ensure the restrictions on grazing of land i.e.
    - 8 weeks in the case of pigs; or
    - 3 weeks in the case of other farmed animals

The EU Animal By-products regulation requires that

Category 3 material (catering waste) used as raw material in an enclosed biogas plant equipped with a pasteurisation/hygienisation unit must be submitted to the following minimum requirements:

(a) maximum particle size before entering the unit: 12 mm;

(b) minimum temperature in all material in the unit: 70 °C; and

(c) minimum time in the unit without interruption: 60 minutes.

However, category 3 milk, colostrums and milk products may be used without pasteurisation/hygienisation as raw material in a biogas plant, if the competent authority does not consider them to present a risk of spreading any serious transmissible disease.

Category 3 material used as raw material in an enclosed composting plant must be submitted to the following minimum requirements:

(a) maximum particle size before entering the composting reactor: 12 mm;

(b) minimum temperature in all material in the reactor: 70 °C; and

(c) minimum time in the reactor at 70 °C (all material): 60 minutes.

The EU regulation allows the adoption of national standards; "..the competent authority may, when catering waste is the only animal by-product used as raw material in a biogas or composting plant, authorise the use of specific requirements … provided that they guarantee an equivalent effect regarding the reduction of pathogens. Those specific requirements may also apply to catering waste when it is mixed with manure, digestive tract content separated from the digestive tract, milk and colostrum provided that the resulting material is considered as if it were from catering waste.

Where manure, digestive tract content separated from the digestive tract, milk and colostrum are the only material of animal origin being treated in a biogas or composting plant, the competent authority may authorise the use of specific requirements other than those specified in this (regulation)"

Tables 7.1 and 7.2 below contain the treatment standards required for ABPR approval for treatment of catering waste under Scottish legislation - these are designed to ensure that composting and AD treatment systems achieve sufficient material degradation and pathogen kill by reaching either of two (A or B) time/temperature and particle size process options.

Table 7.1 Minimum Requirements for Composting under ABPR

System	Composting in a closed reactor (A)	Composting in a closed reactor (B)	Composting in housed windrows
Maximum particle size	40 cm	6 cm	40 cm
Minimum temperature	60°C	70°C	60°C
Minimum time spent at the minimum temperature	2 days	1 hour	8 days (during which the windrow shall be turned at least 3 times at no less than 2 day intervals)

Table 7.2 Minimum Requirements for Anaerobic Digestion under ABPR

System	Biogas in a closed reactor (A)	Biogas in a closed reactor (B)
Maximum particle size	5 cm	6 cm
Minimum temperature	57°C	70°C
Minimum time spent at the minimum temperature	5 hours	1 hour

Waste Management Licensing

The digested products-liquor and digestate from AD treatment are also exempt from waste management licensing as detailed in The Waste Management Licensing Amendment (Scotland) Regulations 2003, and are listed with the relevant European Waste Catalogue Codes as follows (Table 7.3)

Table 7.3 European Waste Categories

Wastes from anaerobic treatment of waste (19 06)	
19 06 03	Liquor from anaerobic treatment of municipal waste
19 06 04	Digestate from anaerobic treatment of municipal waste
19 06 05	Liquor from anaerobic treatment of animal and vegetable waste
19 06 06	Digestate from anaerobic treatment of animal and vegetable waste

The composting of farmyard animal excreta and waste ("Animal faeces, urine and manure including solid bedding material") is exempt from waste management licensing in Scotland and will require registration with SEPA, but there is no registration fee associated with this activity. The limit on this activity is set at 400 t for open windrow composting on an impermeable pavement with sealed drainage. This exemption applies by virtue of the 2004 amendment to the 1994 Regulations.

Again, these limits may act as a key constraint for community or larger scale compost facility.

The Integrated Pollution Prevention and Control Regulations 2000 should not apply to farm or community based agricultural composting or AD plants, as the materials being processed are not hazardous (but this may occur if large pig and poultry manures and slurries were involved), nor are the installations likely to require more than 50MW of thermal input. In circumstances where 50MW input exists, a permit will be required.

7.2 Process Benefits

7.2.1 FIO Kill and Bathing Water Quality

The key environmental benefits, with respect to this pilot project, are FIO kill and the potential improvement to bathing water quality. The assessment (chapter 4) has shown that both AC and AD technologies lead to a reduction in the microbial load of animal manures and slurries:

- The $\log_{10}$ reduction achieved through mesophilic AD reached 4.5 for total coliforms; 4.3 for *E. coli*; and 1.4 for Enterococci. However, a lower kill efficiency was observed during plant commissioning;

- AD combined with pasteurisation leads to a virtual eradication of FIO in the treated manures ($\log_{10}$ of the order of 5 or 6); and,

- The $\log_{10}$ reduction achieved through composting reached a maximum of 5.7 for total coliforms and *E. coli*, and 3.1 for Enterococci. However, this kill efficiency was not consistent and, for instance, if the feedstock FYM was water logged or not turned properly, very much lower faecal kill was observed.

The associated risk assessment (Chapter 5) has shown that treatment of slurry and FYM across all high risk farms in the catchments will reduce the catchment source of agricultural FIO under event conditions by 57 to 65 % and hence reduce the risk of non-compliance of bathing water failure. However, a residual risk remains due to run-off and other routes of FIO migration into watercourses from livestock at pasture. In catchments where poor microbial bathing water quality is due to agricultural sources, zero grazing with treatment of manures before return to the land could reduce the risk by >99%. This does, however, assume that there are no losses of FIO from farm steadings. If these are not fully controlled zero grazing may simply replace diffuse FIO sources from livestock at pasture with point source pollution.

7.2.2 Nutrients and Diffuse Pollution

The monitoring results showed that both AD, composting and storage can affect the total concentrations and form of nutrients in FYM and manure. In particular the following points were concluded in chapter 4:

- A reduction in the concentration of total nitrogen, nitrate and ammonium was measured in the AD plants, although this may be related to difficulties in sampling stored digestate and to post-storage dilution;

- Changes in the concentration of other nutrients (e.g. phosphorus, potassium and chloride) occurred during AD treatment, but these were not consistent;

- Composting led to a decrease in total nitrogen concentration, potentially lost through the volatilisation of ammonia;
- Ammonia concentrations in the compost were lower compared with FYM. Ammonia was probably lost through volatilisation and also conversion to nitrate by denitrifying bacteria; and,
- Increases in nitrate, potassium and phosphorus concentrations occurred through the reduction in the composting biomass. Nitrate will also have increased through conversion from ammonia.

The results given from the MANNER analysis (Chapter 5) show that both composting and AD treatments can lead to a significant reduction in the amount of nitrate leached following land spread.

The processes change the form of nitrogen compounds to more plant available compounds. MANNER has shown that there is an increase in the amount of plant available N following treatment, especially with composting treatment.

The benefits of theses findings to the agricultural community are discussed further in Section 7.3.3. Ammonia emissions are dealt with in Section 7.3.1

7.2.3 Energy

Although the pilot project is mainly concerned with diffuse pollution from agriculture it is an important objective that the plants should utilise the renewable energy produced.

The AD plant process is an exoergic process i.e. a net producer of energy through the ability to generate heat and electricity from methane. This provides a sustainable contribution to the recovery of energy from agricultural practices and the organic fraction of animal wastes. Composting on the scale implemented in this project is an endoergic process, i.e. a net consumer of energy, albeit only in a minor fashion. Heat is produced during the composting process by bacterial activity and decomposition of waste, but energy in the form of tractor fuel is consumed for compost turning and the heat produced during the composting process is lost during each turning.

The biogas produced typically consists of 60% methane (CH_4), with the remainder as CO_2 and small amounts of other gases. The methane can be used to fuel a Combined Heat and Power (CHP) system for electricity and heat generation, or used in conventional gas boilers or engines for separate heat or electricity generation. Under natural decomposition of slurry, some CH_4 would be released to the atmosphere, so AD not only displaces conventional generation it also helps to reduce natural greenhouse gas emissions provided that the plant does not vent any CH_4 to atmosphere. Electricity generated from AD and biogas combustion can be sold and would normally be eligible for Renewables Obligation Certificates under the Renewables Obligation schemes, which therefore helps to improve financial viability of AD plants if there is sufficient energy generated to export.

7.2.4 Biogas Production

All the pilot AD plants are producing biogas available for energy generation. Each AD plant is fitted with an electricity meter to monitor the consumption by the plant itself. Specific gas yield from the process, given slurry characteristics and process parameters, are yet to be fully assessed. Approximately one third of the thermal energy available is used for internal process heat.

The yield of biogas, in terms of m^3 CH_4 per kg organic dry matter, varies significantly from farm to farm, but cannot be quantified until winter 2005-2006 when a full year of production can be assessed. This may be as a result of different animal types or different diets. Maximum FIO reduction in an AD plant can require a pasteurisation or thermophilic process which would reduce the maximum amount of renewable energy available for non- process heat and electricity.

The dilution of slurry with washing water, drinking water and rainwater significantly reduces the effectiveness of the AD plants with respect to the production of energy. The dry matter content of the slurry has been found to be in the range of 4% to 7.5%, compared with the anticipated figure of 9.5%. A benefit of reduced water ingress is increased effective storage capacity for both slurry and digestate; farms without AD plants tend not to minimise water ingress as this would make the slurry difficult to spread, whereas digestate is easier to spread since it is thinner.

There are increasing numbers of potential uses of biogas both for small and large scale benefit. A list of such uses is given below, in the order of increasingly advanced and experimental technology (Nielsen and Al Seadi 2003):

- Conversion by conventional boilers for heating at the plant (domestic, district, industrial);
- CHP generation;
- Biogas and natural gas combination and integration in the national gas grid;
- Biogas upgraded and used as vehicle fuel; and,
- Biogas utilisation for hydrogen production and fuel cells.

Utilisation of biogas in a boiler at a mesophilic plant can have a conversion efficiency of 85% for heat generation. For a mesophilic plant approximately 30% of each kWh heat produced will be needed for process heat with remainder available to the farmer for personal or farm use. For a thermophilic process or a process with pasteurisation, approximately 45% of heat generated will be needed for process heat and so the amount of available heat may reduce. It must be noted that these values are based on the assumption that thermophilic digestion does not alter the biogas yield rate. An examination of the effects of thermophilic processes on such feedstock is outside the scope of this study.

For optimum utilisation, electricity generation with export of surplus to the grid would allow all the gas to be used and link in to the main environmental economic instrument for utilisation of renewable energy - the ROC (Renewables Obligation Certificates) system. However, the problems of single phase electricity supplies, e.g. the four farms in Sandyhills, and access to the grid in either catchment for small renewable energy sources, may make this route non feasible at present.

7.3 Environmental Benefits

7.3.1 Ammonia Emissions

Ammonia is a soluble, odorous and reactive gas and dissolves readily to react with other chemicals to form ammonia-containing compounds. Agriculture accounts for approximately 80% of ammonia emissions in the UK and according to national data[1] approximately 48% of total ammonia emissions from agriculture occur during land spreading of raw slurries and manures.

There is a 2010 emissions ceiling for ammonia under the terms of the EU National Emissions Directive (2001/81/EC). Ammonia contains nitrogen (N) and is deposited from the atmosphere onto soils and plants. This atmospheric deposition may:

- damage plant communities and species that have evolved on nutrient-poor habitats (such as heathlands, upland bogs and some forests) by increasing the amount of N in the soil;
- alter or reduce biodiversity in some areas;
- lead to increases in nitrate content with increased nitrate leaching to water courses following the nitrification of ammonia to nitrate; and,
- increase soil acidity due to the nitrification of ammonia to nitrate, which can causes toxic elements, e.g. aluminium, to become more available to plants while other elements essential to plant growth will become less available. Increased leaching of toxic elements into water courses is a potential problem in areas of high ammonia deposition.

The treatment of FYM and slurry by compost facilities and AD plants may affect the ammonia volumes released in comparison to handling untreated materials. To assess the net change in overall ammonia release, it is necessary to analyse the staged process of slurry and FYM handling – before, during and after treatment. In the pre treatment scenarios of FYM and slurry, ammonia release is possible during the collection, storage and spreading to land of material. In the post treatment scenarios ammonia release is possible during the collection, treatment, storage and spreading to land of material.

This project has used MANNER to assess the potential ammonia released during land spreading of untreated and treated slurry and FYM. A reduction in the amount of ammonia volatilised has been calculated from the treatment of slurry by AD and the treatment of FYM by composting. In the Sandyhills farms total ammonia volatilised from slurry spreading is 1,682 kg N per year, and reduces to 560 kg N per year once treated by AD. In the Saltcoats catchment FYM spreading releases 750 kg N per year, whereas compost spreading only reduces 136 kg N per year.

As described by Fukumoto et al. (2003), during windrow composting the temperature is generated by intense microbiological activity and the degradation of organic compounds generates and facilitates large ammonia emissions. This report found that ammonia emissions decreased after composting for 35 days. The higher the number of turns made to each windrow, the greater the emission rate of ammonia (MAFF Project Report, 2000) since the turning effect increases the exposure of the material surface to the air, facilitating ammonia emission. Thus, if the compost facilities are operated to incorporate frequent turning, ammonia will be released

1 Ammonia in the UK- DEFRA publication 2002 www.defra.gov.uk

from the composting windrows. The smell of ammonia gas is a common feature in large scale composting plants. In comparison, normal FYM storage methods involve little, if any, turning so the ammonia is stored within the material until disturbed through transport and spreading. Therefore it is reasonable to estimate that the period of major ammonia release has changed from occurring during the land spreading stage to the compost turning stage. The composting process itself will lend to an increase rate of microbial activity, with the turning providing more rapid and thorough degradation so increased values of ammonia generation are anticipated in comparison with normal FYM storage. This would explain the reduced MANNER ammonia volatilisation values from FYM to compost; most of the ammonia has already been released before land spreading occurs.

Anaerobic digestion is regarded as not having a significant increasing effect on ammonia concentrations (Wulf, Vandre et Clemens, 2002), as most of the microbiological activity is conducted by anaerobic methanogenic bacteria with methane as the main gas produced. The storage of the AD digestate in open tanks before spreading, however, may lead to ammonia release. With an open tank any remaining organic material within the digestate could degrade aerobically with the release of ammonia. The length of storage time will influence the amount of ammonia released. This would help account for the amount of loss in volatilisation between slurry and digestate values.

The remit of this project did not incorporate detailed monitoring of compost or AD process variables or gaseous emission values so it has not been possible to accurately assess the total net change in ammonia. It is anticipated though that there is no significant change in ammonia release over the whole slurry and manure life cycle, only a displacement of the period of release.

One of the most important methods for controlling the release of ammonia from raw slurries and manures, compost or digestate is the method of spreading. It has been found that the main spreading technique used on these farms is that of broadcast spreading which is the method that releases the greatest quantity of ammonia. Trailing hoses or injection spreading would help reduce ammonia emissions through faster incorporation of ammonia to soil in comparison with broadcast spreading (ADAS, 2001).

The ammonia assessment findings are summarised below;

- It has not been possible to monitor the amount of ammonia volatilised during AD and composting process or during storage of the treated material;
- Previous studies have shown that composting leads to large volumes of ammonia emissions, with AD treatment having little effect on ammonia release;
- The amount of ammonia volatilised during land spreading of material has been modelled by MANNER and was found to reduce when slurry is treated by AD and FYM treated by composting;
- Over the lifecycle of ammonia generation and volatilisation, it is expected that the total volume of gaseous releases of ammonia has not changed significantly, but that the period of release has shifted from land spreading to release during treatment and storage; and
- Improved spreading and soil incorporation methods will be important tools in the reduction of ammonia release.

7.3.2 Greenhouse Gases

The Greenhouse gas implications of the two technologies focus on the emission of CH_4 (which has approximately 21 times the greenhouse gas effect of CO_2) and nitrous oxides. CH_4 and nitrous oxide generation occurs during anaerobic degradation of organic matter, so to reduce emissions, it is important to control anaerobic decomposition. In the AD process, this is the key process used to generate CH_4, and as the gas is collected and stored, such emissions are avoided. In the composting process, it has been found (Fukumoto et al. 2003) that large compost pile coupled with infrequent turning leads to pockets of compost devoid of oxygen, in which anaerobic fermentation can occur with CH_4 and nitrous oxides released when this material is exposed to air.

The AD process helps reduce greenhouse gas emissions in three ways. Firstly, the CO_2 emissions from any biogas combustion are regarded as carbon neutral, as ultimately the carbon content of the feedstock (digested grass/silage) would have originated from CO_2, sequestered from the atmosphere during plant growth. Secondly the natural emissions of CH_4 during decomposition of manure during storage are avoided as this is controlled within the AD process. Thirdly, if the energy content of CH_4 is used for heat or electricity generation, this displaces conventional generation from fossil fuels and additional CO_2 emissions. A calculation of the CO_2 reductions that could be achieved by a farm scale plant is described in Table 7.4.

Table 7.4 **Energy and CO_2 calculations for a sample farm**

	Unit	Per day during winter months	Year
Slurry production	m^3	25	4,500
Biogas produced	m^3	598	107,640
Biogas used in digester heating	m^3	329	59,220
Available (surplus) biogas	m^3	269	48,420
			0
Total energy value of biogas @ 21.4MJ per m^3	MJ	12,797	2,303,496
Energy value of surplus biogas @ 21.4 MJ per m^3	MJ	5,757	1,036,188
Fuel oil equivalent (litres) of surplus biogas @ 39 MJ per l	l	148	26,569
CO_2 emissions displaced from using biogas instead of fuel oil (based on fuel oil@ 2.68kg CO_2 per l)	kg	396	71,205
Proportion of methane (25%) by volume (m^3) in biogas expected from long term natural digestion/composting of feedstock	m^3	90	16,146
Amount of methane by volume (kg) in biogas expected from long term natural digestion/composting of feedstock	kg	64	11,577
Mass of saved CO_2 from release -greenhouse gas (CO_2 equivalent- CO_2 e) of CH_4 (21 times more potent than CO_2 per unit mass)	kg	1,351	243,110
CO_2 e(kg) saved (natural decomposition and displaced energy)	kg	1,746	314,315

This table has not accounted for the reduced need for artificial fertiliser application that may result from the use of digestate on farm land. Artificial fertiliser production is a very energy intensive process, so any reduced use of such material could further reduce the overall CO_2 footprint of the farm.

([1]Estimates from IPCC and US EPA- see references 62 and 63)

As shown in the table above, for one farm using the biogas produced from the AD treatment of $25m^3$ of slurry per day on a 180 day year (for simplicity the plant has been assumed to run at this capacity only during the period that livestock are indoors), a reduction of over 314 tonnes CO_2 per year is calculated. This shows the significant greenhouse gas savings that can be achieved by small scale plants, if the energy is used on site.

CH_4 is one of the gases proposed for inclusion in the next phase of European emission trading. Potential contributions of CH_4 capture to an Emissions Trading Scheme, and the financial incentives this might bring could be the subject of further study. A life cycle carbon audit could be carried out on both on-farm and co-operative community biological treatment systems for slurries and manure. A more detailed study should be carried out into the contribution which AD and can make to the reduction of greenhouse gas emissions.

7.3.3 Agricultural Benefits

The results given from the MANNER analysis (Chapter 5) show that both composting and AD treatments can lead to a significant reduction in the amount of nitrate leached following land spread. This will help farmers with cross compliance and GAEC requirements.

MANNER has also shown that there is an increase in the amount of plant available N following treatment, especially with composting treatment. Combined with the easier application of the treated materials documented by the farmers, and the possible improved infiltration rates of a more homogenous substrate, this could result in improved nutrient benefit to the land. This should allow farmers to reduce the application of artificial fertilisers, saving money and reducing reliance on the external fertiliser market.

It is hoped that the pilot project will enable farmers to achieve improved production with reduced inputs of artificial fertilisers. The installed plant also brings additional storage capacity to the farms and will allow a greater flexibility of application times.

Odour emissions from the animal material have reduced considerably following treatment by composting and AD. The farmers involved have reported a much improved odour during land spreading. However, adverse comment has been made about the odour generated by the AD process itself. This has arisen if methane vents from the plants.

Other benefits include:

- Treated manure and slurry are easier to handle and store as the resultant compost is more granular and the digestate is more liquid and homogenous
- Both processes are anticipated to kill weed seeds, but this has not be validated during this process; and,
- The digestate and compost are potentially marketable products although there may be constraints relating to achievement of full BSI PAS 100 standards for compost and the lack of relevant standards for digestate.

7.4 Sustainability standards

The framework of the appraisal has been set by the strategic and policy priorities from the Scottish Executive document “Meeting the Needs” (published in 2002) which sets out its basic vision for sustainability in Scotland as:

- Having regard for others who do not have access to the same level of resources, and the wealth generated;
- Minimising the impact of our actions on future generations by radically reducing our use of resources and by minimising environmental impacts; and,
- Living within the capacity of the planet to sustain our activities and to replenish resources which we use.

This vision has been embodied in three main priorities in policy making on which indicators can be built:

- Resource use;
- Energy; and,
- Travel.

7.5 Key and supporting indicators

The Development Commission in its 2004 report and review of Scotland’s ‘Meeting the Needs’ sustainable development strategy, stated that they would like to see a ‘stronger and more comprehensive sustainable development strategy with a better set of indicators and more challenging targets’. They also saw the need for ‘more determined effort to achieve more joined up action and better integration of environment, social and economic policies’. This sentiment has been addressed in the new UK strategic framework, published in March 2005, to reflect the new structure of decision making following the devolution of many powers to the democratic bodies in Scotland, Wales and N. Ireland.

Each area will develop a sustainable development strategy of its own, with the UK wide strategic framework “One future – different paths” acting to help create a shared understanding of common goals and challenges, outline guiding principles and establish indicators to monitor the key issues across the UK. The Scottish Executive published the Scottish Sustainable development strategy- Choosing our future in December 2005. The key areas that this addresses are:

- Sustainable Consumption and Production – reducing the inefficient use of resources and breaking the link between environmental degradation and economic growth;
- Climate Change and Energy – making changes to how we generate and use energy and other activities which release greenhouse gases and drive climate change;
- Natural Resource protection and environmental enhancement – understanding environmental limits better, protecting and enhancing the environment to ensure a decent environment for everyone;

- Sustainable communities – creating sustainable communities that embody sustainable development in all activities at the local level;

and the need to

- Learn to live differently – increasing awareness, understanding and engagement among the public to help incorporate sustainable development principles, actions and decision making across Scotland; and,

- ensure delivery – with appropriate targets and indicators, accountability and governance for Scotland.

However, until this is available in full this evaluation has been based on the 'Meeting the Needs' priorities and approach. It should be noted though that the key priorities in the forthcoming strategy of; sustainable communities, climate change and energy and natural resource protection and environmental enhancement may act as even stronger drivers for AD and composting in rural settings than those identified in this report based on the 'Meeting the Needs'.

The sustainability matrix will therefore address the strategic and policy priorities for Scottish Executive, under the five broad headings:

- Environment, Resources & Energy;

- Economy, Enterprise & Lifelong Learning;

- Public and Animal Health;

- Transport & Travel; and,

- Rural Development and Farming.

It is recognised that these headings are not entirely exclusive of each other and that they include the sub-sustainability themes of waste, land, buildings and construction materials, landscape, health and safety, communities and social values.

Taking this background context into account but still keeping the framework provided by the Scottish Executive, we have incorporated a range of appropriate indicators into the appraisal.

The following key indicators (Table 7.5) have been identified for the appraisal along with a number of supporting indicators. Those in italics are ones which Enviros has used to extend the original Executive policy and guidance. The appraisal contains more detailed subsets of the supporting indicators.

Table 7.5 Summary table of key and supporting indicators

1.	Environment, Resources and Energy
1.1	Climate Change and Air Quality: reduction in emissions and pollution
1.2	Land: reduction in emissions and pollution, protection and enhancement of biodiversity
1.3	Water: reduction in emissions and pollution, *sensitive to local conservation*

	issues, compliance with environmental policy and legislation
1.4	Natural resources; reduction in demand, in particular non-renewable resources
1.5	Energy: reduction in energy consumption
1.6	Waste: reduction in amount produced, increase in the amount of material recycled or reused
1.7	National Waste Strategy: Scotland: compatibility with wider objectives

2.	Economy, Enterprise & Lifelong Learning
2.1	Enterprise
2.2	Economy: maximise value in delivery of requirements, reduction in need and/or cost of remedial measures, maximise funding source opportunities
2.3	Increase economic and social benefits to local business and community

3.	Public and Animal Health
3.1	Public health
3.2	Animal health
3.3	Health and Safety

4.	Transport & Travel
4.1	Transport: Minimises, where practicable, transport of materials and fuel use
4.2	Travel

5.	Rural Development and farming
5.1	Rural development: Contributes to the development of a diverse rural economy, which provides a broad base of employment; contributes to the provision of a new or improved infrastructure in rural and remote areas
5.2	Communities and social values: effects delivery of and access to services in rural and remote areas, address the particular needs of those living in rural or remote communities
5.3	Farming practice

7.6 Methodology - Sustainability Appraisal Matrices

Using the framework of key and supporting indicators, the sustainability appraisal should identify potential issues, rather than generate definitive statements or predictions. The questions in the matrix are not necessarily comprehensive but are designed to promote interpretation and lateral thinking. Each matrix question has a series of options to be ticked. These are:

- not applicable;
- whether the proposal causes a positive change;

- no change; or,
- a negative change.

Each option has a commentary box for explanatory text. Where appropriate, the rationale behind judgements is given. The assessment also draws some comparison between the performance of the technology types, especially in instances where they are essentially performing the same task, but to different levels of risk reduction.

Each checklist sheet has a section for allocating a sustainability score. This records the extent to which the project or proposal supports or contradicts the sustainability objectives for that theme. The five scoring categories are (Table 7.6):

Table 7.6 Sustainability appraisal matrix scoring categories

A	B	C	D	E
Good proactive enhancement in sustainability performance Avoidance of negative impacts Spatially extensive benefits. Permanent enhancement. Direct benefits	Slight proactive enhancement in sustainability performance Minor negative impacts but good mitigation enhances the situation. Local or short-term enhancement. Indirect benefits	Some impacts but they are neutralised by mitigation.	Slight negative impacts, or negatives that are not wholly neutralised by mitigation. Local or short-term negatives. Minor indirect impacts.	Significant negative impacts, especially ones that cannot be mitigated. Spatially extensive detriment. Permanently irreversible. Direct and major indirect impacts.

The sustainability appraisal matrix brings together the indicators and scoring categories. Following analysis, it sets out the main positive or negative issues and impacts in summary form. The ‘Future Action’ box is used to summarise whether any further assessment or mitigation is needed and identifies areas that should be considered in the economic appraisal.

Completion of the appraisal has been iterative, informed throughout the process by the research and the Steering Group, and will change further as more quantitative results of research, such as monitoring and biogas utilisation, are completed. The sustainability appraisal was undertaken primarily by Tricia Henton and John Ferry of Enviros Consulting. These appraisers are familiar with the wide variety of potential issues and impacts and have sourced opinions from a variety of sources in preparing the appraisal. This is summarised in Table 7.7 and full breakdown is given in Annex 4.

Table 7.7 Summary Table for the Sustainability Appraisal

THEME & OBJECTIVE	A	B	C	D	E	Main positive sustainability issues	Main negative sustainability issues
A – Environment, Resources and Energy	9	7	3	2	3	Reduces FIO pollution to bathing water beaches. Improves compliance with Scottish, UK and EC legislation (BWD, Water Framework Directive). Potentially reduces nitrate pollution to groundwater and surface water, reduces NVZ designation needs. AD is a net producer of renewable energy, reduces demand for non renewable energy.	Increases rural use of construction materials. Cost and difficulty incurred when connecting small generating plant to the power grid network. Composting is a net user of energy. AD plants can generate an odour nuisance if methane is vented
B – Economy, Enterprise and Lifetime Learning	2	7	2	1	1	Develops emerging technologies. Reduces the risk of fiscal penalties to Scottish Executive due to non-compliance. Reduces need for remedial actions. Potential positive economic benefit for tourism. Adds economic value to manures.	The capital cost and operating costs can be very high with few economic environmental instruments to support it. Difficult to attract private investment. There are a number of legislative constraints to development.
C – Public Health	2	0	2	0	0	Option protects and enhances human public health by reduction of faecal coliform and *E. coli* and other bacteriological contaminants in designated Bathing Waters	There may be biosecurity issues to overcome
D – Transport and Travel	0	0	2	1	0		Some forms of use of the new technology increase rural transport requirements.
E – Rural Development and Farming .	1	4	3	1	0	Adopting biogas/composting averts otherwise major changes in farming practice. Offers diversity in practice. Supports tourism and mitigates against loss of tourist jobs.	Zero grazing would require major changes in farming practices.
	14	**18**	**12**	**5**	**4**		

7.7 Discussion of Appraisal Key Points

The sustainability appraisal outcomes of this project are focused on local catchment and community gain. The absolute numbers in the sustainability appraisal summary table overleaf are not particularly relevant as it is the overall trend that is important. Nonetheless, it is clear that there are many environmental, public health and rural benefits, but equally some significant negative issues, mainly cost related.

Principal themes that emerge are:

- the scale at which biogas and composting units are most effective;
- potential funding streams and the availability of renewable energy incentives; and,
- potential for improved nitrate management and fertiliser benefits of composting/biogas process.

Both biogas and compost plants could be effective at a number of scales including single farms, local community units or plant serving a large area. In effect, this could be viewed as being of local value and benefit or of national value as part of wider national waste strategy and energy policy objectives. However, it is important in any consideration of sustainability not to lose sight of the basic principles of sustainable development, which include proximity and community.

Large scale

It would be theoretically possible to contribute FYM and slurry as a waste stream in large municipal schemes taking green waste, sewage sludge and other compostable or biodegradable wastes. There could be some benefits for such projects, but these would be countered by the following disbenefits which include:

- Gas would not be available to local farmers;
- End product is different and may have constraints on its use on land through its compatibility. End product will have inherent variability. The marketability of such material is unclear, especially with regard to achieving PAS100 composting standard or other relevant standards. Additional legislation will apply to product resulting from slurry/FYM sourced from multiple farms;
- Substantial transport requirements to take the materials to the plant, which would probably be sited close to large urban areas;
- Lack of local control;
- Little imparting of new skills and technologies into rural areas.

The overall sustainability of such a project would be questionable and it is our opinion that there is a strong case for resisting the option of scaling up to municipal level from the Bathing Water improvement point of view.

Small groups

The case for small local groups of a few farms is more justified. In this case the benefits would include:

- The FIO problem exists on a small catchment scale, making an overall contribution to the larger catchments;
- Solutions will operate best at local scale;
- Much greater control over the end product;
- Benefits go to local farms or businesses e.g. agricultural benefit of composted material can be used locally; a district or dairy heating system could benefit from biogas use; and
- Improved nutrient content and reduced leachate potential of landspread material.

There may be opportunities to link into the GAEC requirements of CAP reform and into other funding sources.

Individual farms

The biggest benefit in operating only at individual farm level is that no waste management licence is needed. If agricultural waste is transported to a central unit, however small, then it is likely to require a waste management licence. Whilst this need not be a barrier, it has cost implications. Benefits include:

- On-farm use of gas;
- Agricultural benefit of composted material on land;
- Local control and individual contribution to solving FIO problem;
- Improved nutrient content and reduced leachate potential of landspread material;
- Management of wastes in this way can also help individual farms within designated Nitrate Vulnerable Zones (NVZs) control their fertiliser use for compliance with Nitrates Directive as required for the new Single Farm Payment; and,
- An on-farm digester can perform more effectively with co digestion of energy crops.

7.7.1 Potential funding streams and the availability of renewable energy incentives

The project has shown that both biogas production and composting perhaps in combination with zero grazing are viable technical solutions to the problem of FIO runoff at farm scale. However, the solution is costly and any means by which finance can be minimised or recouped would be beneficial in gaining wider use.

8. CONCLUSIONS AND RECOMMENDATIONS

This chapter is split into three sections:

- Summary of the main conclusions from the previous chapters;
- A discussion on these, and:
- Recommendations for ongoing and further study.

8.1 Conclusions

8.1.1 Plant construction, permitting and commissioning

i. 10 farm scale pilots have been installed in the Saltcoats (3) and Sandyhills (7) catchments. These comprise 7 AD plants and 3 compost facilities on a total of 9 farms, with one farm having both AD and composting technology. All are now fully commissioned. Each farmer has been trained and issued with a comprehensive operation and maintenance manual. Commissioning was undertaken on slurry without the need for a seed stock being provided from elsewhere.

ii. Six of the AD plants only required GPD permits, whilst one required full planning permission due to proximity to a dwelling house. All of the composting facilities required full planning permission. Building control warrants were required for all of the plants. Building control certificates have been obtained following completion of the works. Relevant approval letters have been obtained from SEPA also.

iii. Formal agreements with farmers, which expire on March 31st 2009, allow access to relevant contractors for plant installation, surveying, monitoring, and maintenance activities during this period. Until then the ownership of the plant is held by SEERAD. The farmer is responsible for routine maintenance of the plant, as set out in the operation and maintenance manual. Pilot plant farmers have given a commitment to use the treatment facilities provided for all slurries and manure, pre spreading.

8.1.2 Pathways and sources

i. Potential and actual mechanisms and pathways by which FIO from steadings could reach surface waters were audited and identified on all farms. These were deemed to be small, at least an order of magnitude less than field run-off. During the summer, livestock are predominantly at pasture and steading FIO pathways are therefore of lower significance. However, they become more significant under zero grazing management scenarios as the cattle are kept indoors year round.

ii. There was a broad similarity in practice across the pilot farms with cattle housed on the steading through the winter from October-November through to March-April (the exact times depending upon the particular weather that year). Some of the farms also housed ewes during the lambing seasons. The vast majority of FYM and slurry was produced during the winter when livestock were housed on the steading. On dairy farms, where cattle are returned to the steading on a daily basis for milking, slurry continues to be produced during the summer, although reduced to around 10% of the winter production rate. On a beef farm, generally no slurry or FYM is produced during the summer. The three Saltcoats area pilot farms produced approximately 8,600 t of slurry and 1,500 t of FYM annually. In the six Sandyhills area pilot farms 3,200 t of slurry and 2,300 t of FYM were produced annually.

8.1.3 AD Process performance

i. The log reduction achieved through mesophilic AD was usually in the range 2.1 to 2.6. Problems with kill efficiency were identified during plant commissioning.

ii. Post-digestion storage of slurry led to a further log reduction of 0.2 and no significant regrowth was measured.

iii. Pasteurisation of digestate reduced the levels of FIO to low levels, in some cases to the limit of detection (<1 to <10 CFU g^{-1}). This represents a log 5 reduction or potential elimination of FIO content, compared with untreated slurry.

iv. In the raw feedstock total nitrogen concentrations ranged from 2,200 to 4,400 mg l^{-1}; the digestate ranged from 2,400 to 4,100 mg l^{-1}; and in the stored digestate ranged from 1,500 to 3,200 mg l^{-1}. Across the sampling regime there was a general reduction in the total nitrogen concentration between raw feedstock and the stored digestate. Nitrate concentrations showed a similar reduction with values ranging from 0.3 to 10 mg l^{-1} in the raw feedstock, 0.4 to 6.6 mg l^{-1} in the digestate and 0.3 to 5.8 in the stored digestate. There was also a general decrease in the ammonium between fresh material and treated and stored material; from 644 to 2,270 mg l^{-1} in the raw feedstock to 536 to 1,900 mg l^{-1} in the digestate and 654 to 1,780 mg l^{-1} in the stored digestate. Part of these changes may relate to difficulties in obtaining representative samples from the digestate storage tanks and to dilution of stored digestate by rainwater.

v. For the other nutrients the changes are less consistent. In some instances the total phosphorus concentration increases with treatment, but in others it does not. Total potassium concentrations tend to increase, but again this is not consistent through the samples. Changes in chloride concentrations are again variable. The percentage solids consistently decrease from raw to treated samples and then further in stored digestate.

vi. A UK accepted standard for digestate quality does not exist. Although there is a German RAL standard no definitive limits are set for the nutrient content. It has not therefore been possible to evaluate the digestate from the farms against nationally or internationally agreed standards.

vii. Farmers have stated that land application of the digestate is much easier than for untreated slurry. It is more homogeneous, with a lower particle size, much reduced odours and is more uniform in consistency which aids spreading efficiency and even application to the land.

viii. All of the farms were found to have lower dry matter content of slurry than that normally expected (typically in the range of 4 to 7.5%, instead of an anticipated 9.5%). This may be due to water ingress from steadings, either from rainwater or dairy wash water and may have contributed to lower operating temperatures, lower biogas yields and lower FIO kill.

ix. Slurry that had been stored for a number of months prior to AD treatment gave a poor biogas yield; this was particularly a problem at one farm during December 2004 and January 2005.

x. Odour problems associated with the biogas have been noted if biogas vents to atmosphere. Full utilisation of the biogas should ensure that any venting is minimised.

xi. One of the plants experienced pump problems due to fibrous material clogging the intake line, but no other operational problems were encountered.

xii. Due to the long residence time of material in the digester (20 days) some of the differences observed may relate to changes in the FIO or nutrient concentration of the feedstock slurry rather than the digestion processes. It has not been possible to fully evaluate this with the data available. Such an evaluation would require a longer data series.

8.1.4 Composting Process performance

i. A wide variability in FIO kill and nutrient concentrations was observed in the samples collected. The timescales of compost treatment operation are dependent upon the farmers rather than automated processes. It was not therefore possible to sample the compost at predefined ages and the results are more difficult to interpret. The lack of full record keeping (windrow age, turning schedule and temperature) also limited the assessment. However, it is clear from the results that the quality of the end material varied widely, both in terms of FIO kill and nutrient content.

ii. The FIO kill results from composting show a maximum $\log_{10}$ reduction of 5.7 for total coliforms; a maximum $\log_{10}$ reduction of 5.7 for *E. coli*; and a maximum $\log_{10}$ reduction of 3.1 for Enterococci. However, the results also show minimum $\log_{10}$ reductions that indicate an increase in FIO under some circumstances.

iii. Both FYM and compost showed wide variations in nutrient concentrations. Increases in the nitrate, potassium, phosphorus (N, P and K) and water soluble chloride content were measured in some samples during the composting process.

iv. As expected, ammonia contents were reduced on average; usually associated with an increase in nitrate (through oxidation of ammonium salts into nitrates by nitrifiying bacteria).

v. Mature and stockpiled compost samples from one farm were also assessed for PAS100 compliance. The results show:

   a. The compost was well within the limits set for metals contaminants and only contained approximately one quarter of the recommended limit.

   b. A particle size distribution test found that 28 mm was the largest particle size, with over 50% within 10 mm. The bulk density was found to be 0.30 t per m^3 for loose bulk density and 0.51 t per m^3 for compacted bulk density.

   c. The mean *E. coli* content of the compost was compliant with the standard (although maximum values did exceed this). The *Salmonella* content was measured on a few occasions at the beginning of the monitoring trial. Although *Salmonella* was detected, values were near to the limit of detection.

d. Other analyses of compost product quality included total nutrients such as N, P and K. The content of these nutrients in the final compost was in line with other composts produced in the UK derived from organic material such as municipal garden waste.

vi. Issues with the composting process were encountered, for example, the use of overly wet compost; insufficient compost turning and the use of material that was aged and already partly decomposed. These issues arose during the commissioning phases and are unlikely to be an ongoing problem if properly managed.

vii. Both the AC and AD plants could be much more effectively utilised if feedstock were available to keep plant running at full capacity for twelve months of the year. With the livestock being housed only in the winter months, some other feedstock materials could help contribute to year round operation. Energy crops and green waste could help 12 month operation at full capacity for on on-farm plant. A community plant would potentially accept feedstock from various sources to ensure full year round operation.

viii. Consultation with the farmers has shown that with the increased FYM storage capacity and the more manageable nature of composted material, they may choose to apply the material to land at different times of the year than previously.

8.1.5 Risk reduction modelling

i. The Enviros compartmental modelling system AMBER formed the basis of a modelling system, the Agricultural Risk Assessment Model (ARAM) which was developed within the project to model FIO fluxes from agricultural systems. ARAM was initially set up with generic parameters to model the overall risk to surface water that arises not just from slurry and FYM spreading during the bathing water season, but from other sources and pathways (e.g. from the steading and livestock access to water). The generic coding in ARAM was then parameterised with site specific data for each farm in the study. All other high risk farms in the two main catchments were also included in the model. However, as farm specific data (apart from livestock numbers) was not available the generic values derived earlier were used. The assessment did not include other FIO sources in the catchments, such as package treatment or septic tanks, or other non-agricultural livestock sources as these were beyond the scope of the project.

ii. The current set-up of ARAM is limited to the assessment of FIO fluxes to watercourses in the catchment. The subsequent dilution or die-off of FIO, in transport and when these freshwater discharges meet the coast, is not assessed by the model. Other Scottish Executive funded research has investigated the FIO flux within bathing water catchments and this research is intended to be complementary. The simple assumption has been made that FIO migration from agricultural land to local watercourses can, in these short catchments, be used as a direct analogue for risk reduction in the associated bathing water.

iii. ARAM was used to test a range of catchment wide treatment and farm management scenarios focusing on event driven flux scenarios. The assessment considered a 'worst-case' scenario where all main farms spread material during the bathing water season immediately prior to a rainfall event and assessed the difference between no treatment and AD and composting treatment of all slurry and FYM produced.

iv. Based on the parameters used in the set up of ARAM, the results give a potential FIO flux reduction of between 54-57% (Saltcoats) and 62-65% (Sandyhills) for combined AD and composting treatment. The remaining flux is unaffected by the biogas and compost treatment and results largely from manure voided to land and into stream water from livestock at pasture during the bathing water season. This represents a primary contributor to microbial contamination of bathing water from agricultural sources.

v. Consequently, zero grazing scenarios combined with full AD and composting treatment have also been assessed. The results indicate a >99% reduction in overall FIO flux under this scenario for both catchments if there are no losses of FIO from the steading or other sources of FIO in the catchment. If more realistic losses from the steading are included within the model, the percentage risk reduction is reduced to 51% (Saltcoats) and 80% (Sandyhills). A clear conclusion that can be drawn is that under zero grazing, particularly careful controls would have to be placed on potential routes of FIO loss from buildings and yard areas. This could include roofing of yards, improved containment and modifications to drainage systems.

vi. The risk reductions described above have been applied to a historical data set of bathing water quality results and the potential values that would have occurred if AD and composting treatment were in place have been assessed. The values before and after treatment were then compared with the current mandatory pass values for total and faecal coliforms. This assessment shows that in the Sandyhills catchment, AD and composting treatment reduce the number of non-compliances and that for total coliforms these could be reduced to zero. However, some instances of non-compliance for faecal coliforms would still occur. Under a scenario of zero grazing, full slurry and FYM treatment and no FIO losses from the steading the number of non-compliances would be expected to be zero. In the Saltcoats catchment the FIO concentration of the bathing water has been significantly greater than the bathing water directive thresholds and zero grazing in addition to full treatment of all manures is required to ensure that full compliance for both total and faecal coliforms is achieved. However, it should be noted that this assessment is based on the assumption that the FIO counts measured in the bathing water arise solely from agricultural sources. If other sources which are not affected by these options exist, the reduction in non-compliances may be less.

8.1.6 Nutrient modelling

i. The MANNER assessment illustrates that there are benefits from the AD and composting treatments in terms of reducing N leaching arising from slurry and FYM spreading to land, and also from spreading in the spring. In the Saltcoats catchment the total N leached could be reduced from 2,180 to 1,270 kg per y (a 40% reduction) and in the Sandyhills catchment 1,530 to 962 kg per y (a 37% reduction). It is also worth noting that compared with FYM application, slurry is the main contributor to N leaching (> 78%). However, it is important to note that the land spreading data and monitoring used in this assessment were provisional.

ii. Despite potential losses in total nitrogen content during manure treatment there is an increase in the plant available nitrogen from composting but little change apparent in the AD treated digestate. It is important to note here the term 'plant available' refers to the form of nutrients in the soil following land application and does not imply that treated manure will necessarily be applied at times when plant uptake is greatest.

iii. Anecdotal evidence provided by the farms suggests that the digestate has enhanced nutrient value.

8.1.7 Climate change, biogas and renewable energy

i. Renewable energy is an output of AD but not composting. The biogas produced in AD can be used in a generator for electricity and heat generation and to maintain the digestion process temperature. There is also potential to export excess electricity to the grid. This would allow all biogas to be used beneficially.

ii. Pasteurisation gives greater FIO reduction than mesophilic digestion but reduces the maximum amount of renewable energy available.

iii. The amount of biogas available for use on the steading depends on the amount of slurry produced from the cattle, the level of dilution of the raw slurry and on the temperature of the raw slurry in the reception tank. The yield of biogas varies significantly from farm to farm and it will require at least one full year of operation before this can be analysed fully. It is anticipated this information should be available in early 2006. The dilution of slurry with washing water, drinking water and rainwater significantly reduces the proportion of organic material in the slurry with a subsequent reduction in the effectiveness of the AD plants. The slurry has a total solids concentration of approximately 6% which is lower than the expected 9%.

iv. The AD plants could, given a different feedstock, produce more than 4 times the amount of useable energy in a year. The addition of high moisture content energy crops (for example ryegrass, maize or lupins) as supplements would improve the biogas yield of the AD plants.

v. Six of the seven farmers with pilot AD biogas plants have opted to use surplus biogas for domestic heating and hot water in one or more houses on the steading. The seventh farmer has purchased a second-hand generator set and will be using biogas to generate electricity for the farm. For the three large AD plants, it is anticipated that there will be surplus biogas available beyond that used for the domestic properties and these farms may in the future consider other methods of energy utilisation.

vi. For optimum utilisation of the gas produced and to provide an income stream, electricity generation with export of surplus to the grid is preferable. However, it is not possible for farms where there is only single-phase electricity, as in Sandyhills, to export electricity to the national grid. Access to the grid in either catchment for small renewable energy sources is expensive and difficult for small sources and may make this route non-feasible at present. In the meantime, using the biogas to provide hot water is the most effective use of the energy.

vii. The main environmental economic instrument for utilisation of renewable energy is the Renewables Obligation (Scotland) Order 2005. This ROC (Renewables Obligation Certificates) system has made provision for smaller (sub 50kW) generators to claim SROCs on a monthly or an annual basis. This has increased the flexibility of SROC accreditation for small generators. However, there is no fiscal incentive for the production of renewable heat nor for the production of renewable fuel.

viii. The current consultation (2005-2006) reviewing the ROS proposes pre-accreditation for ROC eligibility (among other things). This system will allow developers of renewable energy projects to have greater certainty that their developments will be eligible for the support under the ROS prior to the financing and construction of such projects. Since this project has begun a 44MW biomass plant has been announced for the Dumfries and Galloway area signifying the further development of biomass fuelled energy plant in Scotland.

ix. Both processes can help with reduce the climate change impact that occurs with agricultural practices. Greenhouse gas emissions are reduced by

   a. AD reduces greenhouse gases emissions in two ways: firstly, it displaces conventional electricity and heat generation from fossil fuels through the use of biogas for energy generation, and secondly AD also helps to reduce natural methane emissions.

   b. Composting with sufficient turning ensures methane release is kept to a minimum.

x. Approximately 40% of total ammonia emissions from agriculture occur during land spreading of slurries and raw manures. The difference in ammonia release between land spread compost, digestate and raw materials has been quantified using the MANNER evaluation and has shown a very significant decrease in the amount of ammonia volatilised after the composting treatment and a lower reduction in ammonia emissions following AD treatment. However, in composting the value of this ammonia reduction is balanced out by the additional ammonia emitted during composting.

8.1.8 Economics

i. The economic appraisal was developed as an open case study based, largely but not exclusively, on conditions in a Sandyhills catchment wide scenario of six anaerobic digestion plants to cover the farms producing significant slurry quantities and eight composting plants to cover the FYM produced by all high risk farms in the catchment.

ii. The outcome was matched with the FIO flux risk reduction for the catchment as predicted by ARAM and policy conclusions drawn against the overall project objectives. The appraisal was carried out for the following options:

a. Individual high risk farms;

b. On-farm treatment for all high risk farms in the catchment;

c. Community treatment (located next to a farm); and,

d. Community treatment (located next to a dairy).

The net present value of each of these development scenarios under different technological options are shown below (Table 8.1)

Table 8.1 **Summary Results for Normal and Zero Grazing (10% Discount Rate)**

	Normal Grazing				Zero Grazing			
	Treatment (AD & Composting Only)	Treatment with CHP and a market for compost	Treatment with CHP, energy crops and a market for compost	Treatment with CHP, energy crops, separator and a market for compost	Treatment (AD & Composting Only)	Treatment with CHP and a market for compost	Treatment with CHP, energy crops and a market for compost	Treatment with CHP, energy crops, separator and a market for compost
Individual High Risk Farm	-£172,000	-£166,000	-£174,000	-£183,000	-£209,000	-£114,000	-£96,000	-£88,000
On-Farm treatment (catchment total)	-£1,073,000	-£984,000	-£1,017,000	-£1,041,000	-£1,054,000	-£718,000	-£682,000	-£653,000
Community Plant (On-Farm)	-£1,634,000	-£1,344,000	-£1,186,000	-£1,158,000	-£2,048,000	-£1,373,000	-£1,027,000	-£952,000
Community Plant (dairy based)	-£1,411,000	-£1,156,000	-£631,000	-£603,000	-£1,646,000	-£1,022,000	-£16,000	**£59,000**

From this table and the results presented in Chapter 6 it is concluded that:

iii. Zero grazing has emerged as an important method of complying with the bathing water directive during the course of this project and would be required to comply with the bathing water directive in the Saltcoats catchment area but not the Sandyhills catchment area. Zero grazing improves the economics of AD and composting as it allows greater quantities of slurry to be collected during the summer months thereby improving the utilisation of treatment equipment. The wider social costs and benefits of zero grazing have not been assessed in this study. It is acknowledged that zero grazing represents a significant shift from current agricultural practice.

iv. With normal grazing, identifying a single high risk farm and installing AD and composting equipment on the farm, with a CHP Unit, energy crops and a market for compost is the most cost effective development option. However, as this still has a negative NPV, it would not be expected to make a financial gain over the lifetime of the facility. Furthermore, it has only a partial success in reducing FIO kill in terms of achieving bathing water compliance. If all the slurry and FYM arisings in the catchment area require treatment, then a community treatment is the most cost effective option provided that there is sufficient onsite demand for the electricity and the heat generated (we have used the example of the dairy).

v. Unlike the normal grazing scenario there are development options in the zero grazing scenario that have a positive NPV. The project with the highest NPV is treating the material under a community based treatment facility which has a demand for the heat and electricity generated by the AD plant. This generates an NPV of £59,000 for treating both the FYM and slurry arisings if the AD Plant subsidises the composting facility (the composting facility still operates at a loss).

vi. The analysis above was completed with a 10% discount rate, a rate which is representative of commercial investment appraisal. Farmers are unlikely to invest in either an on-farm composting or in an on-farm AD facility without an additional economic incentive under both the normal and zero grazing scenarios as:

   a. An AD facility is only cost effective when a community based site is located close to a site of heat and electricity demand (such as a dairy), zero grazing is implemented and energy crops are also grown and added to the digester feedstock. The payback of 4 years will make this an unattractive investment to agricultural (or other) industries, and

   b. Composting is not cost effective under any development scenarios under expected composting prices. Although under high compost prices of £30 per tonne a composting facility is cost effective for a large farm, this market price is unlikely to be widely achievable.

vii. An alternative consideration is whether a positive investment appraisal is generated by a social discount rate used by government and based on governments lower cost of borrowing (currently the social discount rate is 3.5%).

viii. Projects with a negative annual income will require support payments to maintain their operation and may require a capital grant to give them a positive NPV. Projects with a positive annual income will require a capital grant. The subsidy and grant requirement of each treatment plant under different development options has been summarised in Table 8.2.

Table 8.2 Support Payments and Capital Grant Requirements. These are at 10% Discount Rate

		Normal Grazing				Zero Grazing			
		Treatment (AD & Composting Only)	Treatment with CHP and a market for compost	Treatment with CHP, energy crops and a market for compost	Treatment with CHP, energy crops, separator and a market for compost	Treatment (AD & Composting Only)	Treatment with CHP and a market for compost	Treatment with CHP, energy crops and a market for compost	Treatment with CHP, energy crops, separator and a market for compost
Individual High Risk Farm	AD Facility	75% CG	75% CG	50% CG	50% CG	>75% CG	50% CG	50% CG	25% CG

	Composting Facility	SP&CG	>75% CG	>75% CG	>75% CG	SP&CG	75% CG	75% CG	75% CG
On-Farm treatment (catchment total)	AD Facility	>75% CG	75% CG	75% CG	75% CG	>75% CG	75% CG	50% CG	50% CG
	Composting Facility	SP&CG	>75% CG	>75% CG	>75% CG	SP&CG	75% CG	75% CG	75% CG
Community Plant (On-Farm)	AD Facility	SP&CG	SP&CG	SP&CG	SP&CG	SP&CG	SP&CG	>75% CG	>75% CG
	Composting Facility	SP&CG	SP&CG	SP&CG	SP&CG	SP&CG	SP&CG	SP&CG	SP&CG
Community Plant (dairy based)	AD Facility	SP&CG	SP&CG	25% CG	25% CG	SP&CG	SP&CG	Positive NPV	Positive NPV
	Composting Facility	SP&CG	SP&CG	SP&CG	SP&CG	SP&CG	SP&CG	SP&CG	SP&CG

ix. The increased adoption and implementation of the "polluter pays principle" in Scottish legislation and policies may affect the viability of grant aid or support payment systems.

x. To determine the present day value of the beaches in the area we have discounted the future benefits at the Treasury's real social discount rate of 3.5% over a 15 year lifetime, the same lifetime assumed for an AD and composting facility. It is important to note that these values only include benefits associated with improvements in health. These values are shown in Table 8.3 below

Table 8.3 Valuation Summary over a 15 Year Lifetime – Present Value (2001 prices)

Study	Range	Sandyhills	Saltcoats
Eftec	Low (-30%)	£774,000	£5,208,000
	Mid	£1,106,000	£7,440,000
	High (+30%)	£1,437,000	£9,672,000
Georgiou	Low	£580,000	£4,837,000
	Mid	£829,000	£6,910,000
	High	£1,078,000	£8,984,000

xi. The analysis of the health benefits from an improvement in the bathing water quality in Sandyhills indicated a positive value of the order of £0.8m to £1.4m over a 15 year period. These figures, however, are highly uncertain in the context of Sandyhills as they are based on beaches in England and Wales and only take account of the health benefits, ignoring the other potential societal benefits. They should not be used in a direct cost benefit comparison with the costs of controlling FIO run off.

xii. The expected present value for controlling FIO pollution by implementing a AD and composting facilities for the Sandyhills catchment area with normal grazing and a 3.5% discount rate is -£0.9m and -£1.2m

8.2 Discussion

Successful uptake of composting and AD would significantly improve bathing water compliance and, if combined with zero grazing across all high risk farms in a catchment, is likely to prevent further non-compliance of bathing water quality due to agricultural sources.

This project has considered AD and composting treatment plus zero grazing and the associated risk reduction and associated costs. It should also be noted that risk reductions could be achieved through preventing livestock access to watercourses and limiting cattle access or slurry spreading to areas of the farm that are deemed to have the highest risk of run-off or limiting slurry spreading during the bathing water season. Alternatively, reducing livestock numbers and rural diversification could be considered. It is likely that a range of options could provide the most flexible approach to help improve bathing water quality. AD and composting plus zero grazing are key aspects of this toolbox and these measures should be targeted on farms that generate and spread material either during, or within one month prior to, the bathing water season. This is most likely to apply to slurry production from dairy herds where land spreading is undertaken after first and second silage cuts in May/June and July/August.

It is unlikely though that a blanket approach across a catchment, as modelled, would be required. This study identified that the quantified risk, the main ‘high risk’ farms in the catchment pose to bathing water quality, varies significantly. It is therefore likely that the most cost-effective approach to achieving bathing water compliance, by controlling agricultural FIO, is a selective combination of AD, composting and zero grazing targeted to individual farms and supported by a further detailed review of particular risk indicators. These risks should be assessed on a farm by farm basis according to the relative contribution that farm makes to the overall FIO input to the bathing water, not just from agricultural practices but also domestic and other sources. This could be implemented through further developments of the ARAM assessment tool backed up by farm audit and hydrological study.

There is currently no direct economic benefit to farmers to reduce FIO input to catchment watercourses. Given the significant capital costs for the manure treatment and the uncertainty surrounding product markets for electricity and compost at the present time, it is unlikely that small farmers will be willing or able to implement these treatments without fiscal and other support.

The economic assessment showed that virtually all of the options considered would need some form of capital grant and/or annual subsidy to become financially viable for a farmer to implement. Such aid will influence the farmers in high risk areas to install treatments and adopt entrepreneurial and diversification activity that are likely to be required in the short term at least. However, it is strongly recommended that any grant aid scheme be preceded by prioritising the agriculturally derived FIO risks from farms in the catchments and that this should consider non-agricultural sources of FIO contamination also, so allowing the most effective targeting of support. Full consideration will also need to be given as to whether a grant or support aid system would conform to the “polluter pays principle”.

There is also significant potential for optimising the financial benefits to the farmers hence increasing the viability of the treatments and reducing the investment required. For instance, the NPV's and off farm impacts for both AD and AC, (although not zero grazing) are sensitive to the proportion of products which can be utilised, to the ability to run the treatments at full capacity and to markets for electricity, heat and compost products. Legislative drivers, economic instruments and infrastructure issues also impact on the operating costs and profits very significantly and should be assessed further.

There may also be CAP financial drivers for farmers to reduce FIO releases from land, linked to bathing water quality. These are unlikely to be of the sufficient magnitude required to justify the treatment plants. However, if capital investment or annual subsidiary grants were to be made, these are considerably less than the estimated amenity value of improved bathing water quality.

Improved guidance and a policy to help farmers add value to the outputs of the treatment facilities and take on ownership, would make the treatment more viable and ensure farmers would be more motivated. Farmer interest is likely to increase if renewable energy policy favours these processes, as composting skills and markets improve and as slurry and FYM controls and the imposition of non-grazing/ waste spreading rules in high risk farms tighten. However, farmers may adopt completely different responses which ameliorate some of the expected profit reduction.

The text of a new EU bathing water directive has recently been agreed and this is due to enter into force in 2006. It represents a significant tightening of the health standards relating to faecal pollution. Compared with the current Directive, the proposed standards greatly reduce the allowable FIO concentrations in bathing water. This is anticipated to have significant implications for designated bathing water compliance in areas of diffuse agricultural pollution and highlights the importance of identifying and establishing effective methods of minimising diffuse agricultural pollution.

Recommendations to help facilitate the identification and establishment of methods to minimise diffuse agricultural pollution and hence improve bathing water are given in the final section of this report below.

8.3 Recommendations

The value of the research and knowledge base that this project has provided could be increased greatly by further monitoring and evaluation work. An extended and in-depth monitoring period would build upon the data gathered in the relatively short period of research that followed project construction. There exists much variability in the data collected to date; a longer more detailed programme of monitoring would allow an evaluation of the assumptions made in the initial research to be validated and a more comprehensive data set that could lead to more conclusive findings. Further work would also help with the cross evaluation of other bathing water compliance work conducted by SEPA and the Executive, and an identification of a catchment wide strategy for bathing water compliance management. Emerging themes, such as nutrient availability changes and greenhouse gas emissions could also benefit from a detailed investigation programme and would help draw more substantive conclusions on the extended benefits of AD and compost treatment. The specific recommendations are detailed below:

Table 8.4 highlights recommendations for ongoing monitoring and support to the Pilot Project.

Table 8.5 identifies additional modelling and data interpretation to address data gaps identified during the project. It also puts forward options for further research and suggestions on how to make the best use of tools develop and existing data.

Table 8.6 puts forward recommendations to address themes that have emerged during this project but have been beyond the scope of the work to address fully.

In each table the recommendations have been categorised into the following priorities:

- High – these are aspects that we consider are essential to the full evaluation of the Pilot Project and should be undertaken to substantiate the preliminary conclusions given before other aspects are considered;

- Medium – are aspects that we consider are required for full evaluation of the project, however, these can be completed at a later stage; and,

- Low – these are studies that we consider would be useful and would contribute to a broader and more holistic assessment of the project but are not considered essential.

For each entry in the tables the priority, recommendation, a brief description of what is involved and a summary of the benefits produced is given.

A potential future monitoring schedule for AD and composting process assessment is also appended (Annex 5). This covers the high priority requirements in Table 8.4 and recommends that the following monitoring schedules be implemented:

- AD process monitoring of:
    - o Full operation of an AD plant during the winter (Oct/Nov to Jan/Feb)
    - o Partial operation of an AD plant during the summer (Jun/Jul to Sep/Oct)
- Compost process monitoring Jan/Feb to Apr/May and July/August

During this pilot project the complexity of gathering and interpreting data from the AD and composting processes was identified. The recommended additional monitoring programme is designed to address these difficulties and provide a detailed data set.

Table 8.4 Recommendations for Monitoring and Continuing Support to the Pilot Project

Recommendation	Description	Benefit
High Priority		
Further monitoring of AD process	Assessment of FIO kill, nutrient changes and biogas production	• Development of a larger and more refined data set from which more solid conclusions can be drawn.
Energy utilisation	Assessment of amount and methods of energy utilisation	• Would allow validation of assumptions made in the economic and sustainability aspects of the project.

Further monitoring of composting process	Assessment of FIO kill, nutrient concentrations and composting management	• Evaluate whether problems encountered have been overcome. • Assess uncertainties associated with post-treatment storage and variability in FYM feedstock. • Identification of minimum requirements and problems to avoid based on experience to date.
Composting support	Ongoing support to farms with composting facilities	• Ensure that farmers understand and implement the process and monitoring requirements properly. • Ensure that any issues are identified and resolved. • Evaluate compost production and method of utilisation.
Further assessment against PAS100 guidelines	Assessment of compost quality from all three farms against PAS100 guidelines	• Demonstrate whether material suitable for use as a commercial compost can be routinely produced by each farm.
Medium Priority		
Alternative AD feedstocks	Assessment of digestate quality and biogas production through the introduction of energy groups	• Provide a robust assessment of the problems and benefits associated with alternative feedstocks. • Inform strategies on how best to capitalise on the AD plants.
Alternative compost feedstocks	Assessment of compost quality through the use of green garden waste	• Identify problems and benefits associated with the use of alternative feedstocks should be explored. • Inform strategies on how best to capitalise on the compost facilities.
Gaseous emission monitoring	Assessment of ammonia, methane and carbon emissions	• Data gaps exist on ammonia, methane and carbon dioxide emissions from composting and AD and need to be clarified. • Issues of odour problems associated with the biogas plants need to be fully assessed. • Broader climate change implications could be assessed.
Low Priority		
Weed seed kill and growth trials.	Assessment of weed seed kill and small scale growth trials	• Potential for weed seed kill could be validated. • Validation of compost and digestate as a beneficial soil conditioner.
Pasteurisation and regrowth trials	Assessment of microbial regrowth following prolonged storage of AD and pasteurised digestate	• Evaluate how the FIO load within untreated, AD digestate and pasteurised samples varied with storage. • Validate assumptions of die-off rates in untreated material. • Provide guidance on post-treatment storage practices.

Table 8.5 Recommendations for Developing Project Resources and the need for Further Assessment

Recommendation	Description	Benefit
High Priority		
Validation of ARAM	ARAM predictions based on realistic spreading times and rainfall events will be compared against bathing water quality data and other monitoring results	• Model predictions would be validated and model performance quantified.
Application of ARAM to another catchment	Undertake a quantitative assessment of risks per pathway per farm to inform mitigation measures across a catchment	• Identify and rank by risk the pathways and processes that lead to poor bathing water quality. • Use ARAM to test a range of mitigation measures appropriate to each pathway. • Identify the most cost-effective approach on a farm by farm basis and hence derive a management strategy for a whole catchment.
Assessment of non-agricultural FIO sources	Quantitative assessment of catchment sources of FIO	• Quantify the relative risk from agricultural and non-agricultural sources. • Substantiate assumptions upon which the pilot project was based.
Bathing water data analysis	Assessment of bathing water microbial quality data collected by SEPA	• Provide a scientific analysis of variations in bathing water quality relative to land spreading of manures. • Substantiate anecdotal evidence that slurry spreading leads to poor bathing water quality.
Low Priority		
ARAM-database integration	Modification of ARAM and linking to a database front end.	• Develop user friendly front-end for ARAM. • Couple the model to a database to allow the rapid assessment of risks by pathway and farm for a large number of farms.

Table 8.6 Recommendations for the evaluation of emerging themes

Recommendation	Description	Benefit
High Priority		
Assessment of research potential	Evaluate the potential for the Pilot Farm clusters to be used to support research interests of academia, government, NGOs and industry	• Identify routes by which other organisations can implement or support broader research programmes. • Capitalise on the 5 year asset ownership period • Disseminate findings of the project.
Assessment of nutrients	Further evaluation of nitrate leaching and of	• Provide a more robust assessment based on a larger data set of compost quality.

	plant availability of other nutrients based on further monitoring	• Provide a more robust assessment based on better data on FYM/compost production and spreading. • Assess the implications of a broader range of spreading scenarios. • Expand the study to assess the implications of changes of nutrients other than nitrate. • Conduct a cost benefit analysis of reduced reliance on chemical fertiliser
Medium Priority		
Funding and commercial opportunities	Assessment of the opportunities for funding via direct grant, emissions trading scheme, CAP funding, EU Structural Funds, CCL, and ROCs sales. Combined with the commercial aspects of composting and AD systems	• Identify ways to reduce the capital grant or annual subsidiary required to make the AD and composting technologies financially viable
Low Priority		
No low priority recommendations have been identified		

REFERENCES

ADAS 2001, Making better use of livestock manures on grassland. Booklet 2 Managing Livestock Manures

ADAS 2001, Spreading systems for slurries and solid manures .Booklet 3 Managing Livestock Manures

Bagshaw,C.S. Factors influencing direct deposition of Cattle Faecal Material in Riparian Zones. MAF(Ministry if Agriculture and Fisheries) New Zealand Technical Paper 2002/19

Bateman, I, Day, B, Lake, I, Lovett, A (2001). The Effect of Road Traffic on Residential Property Values: A Literature Review and Hedonic Pricing Study

Biffa-award - Dairy Energy Consumption
http://www.biffa.co.uk/files/pdfs/MassBalance_Agriwastes_04_Energy.pdf

Brenner, F. J. and Mondok,J.J. Non-point source pollution potential in an agricultural watershed in North-western Pennsylvania. Water Resources Bulletin, Vol 31 No.6 1101-1112 1995

Chambers, B.J., Nicholson, F.A., Moore,A., Nicholson, R.J. and Hickman, G. Assessing and managing the risks of pathogen transfer from livestock manures into the food chain. 7th European Biosolids and Organic Residual Conference. Wakefield, UK, November 2002, Session 3, Paper 14.

Composting Association/WRAP. Introduction to BSI PAS 100 standards for composting.
http://www.compost.org.uk/images_client/texttable/WRAP_2302_Web%20Organics_v3.pdf

Crowther J, Kay D, Wyer MD, Faecal-indicator concentrations in waters draining lowland pastoral catchments in the UK: relationships with land use and farming practices Water Research 36 (7): 1725-1734 Apr 2002

DEFRA Risk Assessment (2002): Use of Composting and Biogas Treatment to Dispose of Catering Waste Containing Meat

DEFRA (2004). Greenhouse Gas Inventories, for England, Scotland, Wales and Northern Ireland: 1990 – 2002

Doyle, Mitchell and Topp Effectiveness of farm policies on social and economic development in rural areas. A paper from a conference on New Regional Roles for Agriculture, based on a study for SEERAD, 1998

Drapcho,C.M. and Hubbs, A.K. Fecal Coliform Concentration in runoff from fields with Applied Dairy manure Louisiana Water Resources Research Institute. 2000-02. USGS supported Project.
http://water.usgs.gov/wrri/01grants/ prog-compl-reports/2001LA2621B.pdf

Duchateau, K., Vidal, C. Statistics in focus. Environment and Energy.Theme 8-1/2003 Eurostat- EC 2003.

Eftec (2002). Valuation of Benefits to England and Wales of a Revised Bathing Water Quality Directive and Other Beach Characteristics Using Choice Experiment Methodology. Final Report to Department for Environment, Food and Rural Affairs.

Environment Agency (2003). Guidance for the Assessment of Benefits for Water Quality and Water Resources Schemes in the PR04 Environment Programme (+ Corrigendum).

Environment Agency (2003b) Report of an Expert Workshop on the Benefits Assessment Guidance for PRO4: Review of Non-use Values for Water Quality and Water Resources and Values for Bathing Water Improvements. Peterborough.

Filip Z, Kaddumulindwa D, Milde G, Survival Of Some Pathogenic And Facultative Pathogenic Bacteria In Groundwater Water Science And Technology 20 (3): 227-231 1988

Fukumoto, Y., Osada, T., Hanajima, D. and Haga, K. Patterns and quantities of NH3, N20 and CH4 emissions during swine manure composting without forced aeration- effect of compost pile scale. Bioresource technology 89 (2003) 109-114

Georgiou, S., Bateman, I., Langford, I, Day, R. (2000). Coastal Bathing Water Health Risks: Developing Means of Assessing the Adequacy of Proposals to Amend the 1976 EC Directive. Centre for Social and Economic Research on the Global Environment. School of Environmental Sciences, University of East Anglia.

Harchegani, H. and Cornish, P. A catchment approach to understanding the sources and fate of indicator bacteria in an intensive agricultural area. Diffuse Pollution Conference Proceedings , Dublin 2003.

Hunter C, McDonald A, Beven K. Input Of Fecal-Coliform Bacteria To An Upland Stream Channel In The Yorkshire Dales Water Resources Research 28 (7): 1869-1876 Jul 1992

Kress M, Gifford Gf, Fecal Coliform Release From Cattle Fecal Deposits Water Resources Bulletin 20 (1): 61-66 1984

Kudva It, Blanch K, Hovde CJ Analysis Of Escherichia Coli O157 : H7 Survival In Ovine Or Bovine Manure And Manure Slurry Applied And Environmental Microbiology 64 (9): 3166-3174 Sep 1998

Lets Recycle.com – Compost Prices as quoted on website accessed on 29 July 2005 http://www.letsrecycle.com/prices/compostingPrices.jsp

MAFF Project Report. Enhancing the effective utilisation of animal manures on- farm through compost technology. 2000

Mawdsley JL , Bardgett RD, Merry RJ, Pain BF, Theodorou MK Pathogens In Livestock Waste, Their Potential For Movement Through Soil And Environmental-Pollution, Applied Soil Ecology 2 (1): 1-15 Mar 1995

McDonald A, Kay D. Enteric Bacterial Concentrations In Reservoir Feeder Streams - Baseflow Characteristics And Response To Hydrograph Events Water Research 15 (8): 961-968 1981

McGee P, Bolton DJ, Sheridan J, Earley B, Leonard N, The Survival Of Escherichia Coli O157: H7 In Slurry From Cattle Fed Different Diets Letters In Applied Microbiology 32 (3): 152-155 Mar 2001

Morrison, V. (April 2003) Zero Grazing Greenmount College and Department of Agriculture and Rural Development Technical Note 16 Dairy.

Mubiru, D.N., M.S. Coyne, and J.H. Grove. 2000. Mortality of Escherichia coli O157:H7 in two soils with different physical and chemical properties. J. Environ. Qual. 29:1821–1825

Niemi RM & Niemi JS., Bacterial pollution of waters in pristine and agricultural lands Journal Of Environmental Quality 20 (3): 620-627 Jul-Sep 1991

Nielsen, JBH &and Al Seadi, T (2002): The present and future of Biogas in Europe. The Future of Biogas in Europe II, European Biogas Workshop Proceedings, October 2-4, 2003, Esbjerg / Denmark

Nix. 2005. Farm Management Pocket Book

OFGEM. (Nov 2004). Electricity Distribution Price Control Review 2004

Oliver,D.M., Clegg, C. D., Haygarth,P.M. and Heathwaite, A.L. Determining Hydrological Pathways for the transfer of potential pathogens from grassland soils to surface waters. Diffuse Pollution Conference Proceedings, Dublin 2003.

Risk Policy Analysts, 2003; Section 3 Bathing Waters – Corrigendum – Coasts and Estuaries – Bathing Waters.

Scottish Executive (2005). Research and Design of Pilot Schemes to Minimise Livestock Pollution to the Water Environment in Scotland";
http://www.scotland.gov.uk/Resource/Doc/1057/0012202.pdf

Scottish Executive (2005) "Choosing our Future" Scotland's Sustainable Development Strategy.
http://www.scotland.gov.uk/Publications/2005/12/1493902/39032

Scottish Executive Environment Group Paper 2002/6. Scotland's Bathing Waters - A strategy for improvement March 2002

Sustainable Development Unit (DEFRA) 2005. One future - different paths - The UK's shared framework for sustainable development
http://www.sustainable-development.gov.uk/publications/uk-strategy/framework-for-sd.htm

SEPA (2003) Ayr. Risk assessment Reports for Farms within Saltcoats and Sandyhills Bathing Water Catchments

SEPA 2004. Scottish Bathing Water report 2004. Bathing waters signage project
http://www.sepa.org.uk/publications/bathingwaters/2004/5_3.html

Sjogren, Re. Prolonged Survival Of An Environmental Escherichia-Coli In Laboratory Soil Microcosms Water Air And Soil Pollution 75 (3-4): 389-403 Jun 1994

Tyrell, S and Quinton, J. Overland flow transport of pathogens from agricultural land receiving faecal wastes. Journal of Applied Microbiology 2003, 94, 87S-93S

Vinten, A., McGeehan, M., Duncan, A.., Aitken, M., Hill, C., Crawford, C., and Lewis D.L Achieving Microbiological compliance of bathing waters influenced by Livestock inputs: Reduce stocking levels or improve mitigation measures. Diffuse Pollution Conference Proceedings, Dublin 2003.

Wilkinson J, Jenkins A, Wyer M, Kay,D. Modelling Fecal-Coliform Dynamics In Streams And Rivers Water Research 29 (3): 847-855 Mar 1995

Wulf S., Vandré R. and Clemens J. (2002): Mitigation options for CH_4, N_2O and ammonia NH_3 emissions from slurry management. in: Van Ham J. et al. (eds.): Non-CO_2

greenhouse gases: Scientific understanding, control options and policy aspects. ISBN 90-77017-70-4, pp 487-492.

Wyer MD, Kay D, Dawson HM, Jackson GF, Jones F, Yeo J, Whittle J, Delivery of microbial indicator organisms to coastal waters from catchment sources
Water Science And Technology 33 (2): 37-50 1996

BIBLIOGRAPHY

Ammonia in the UK published in 2002
http://www.defra.gov.uk/environment/airquality/ammonia/pdf/ammonia_uk.pdf

The Animal By-Products (Scotland) Regulations 2003 No. 411, Scottish Executive

Animal Health and Welfare Strategy for Great Britain 2004
http://www.scotland.gov.uk/library5/environment/ahwsgb-00.asp

Anthropogenic Methane Emissions in the United States: Estimates for 1990. EPA 1993
http://www.epa.gov/nonco2/reports/anthrotoc.html

Bundesgütegemeinschaft Kompost. German RAL standards.
http://www.bgkev.de/en/news/index.htm

DEFRA biosecurity guidance to prevent the spread of animal diseases 1 July 2003
http://www.defra.gov.uk/animalh/biosecurity/farmguidance/biosecurity_guidance.pdf

DEFRA Nov. 2004. Guidance note on the control of manure and digestive tract content under the EU animal by-products regulation (EC 1774/2002)

DEFRA September 2004 Scientific and technical aspects of climate change, including impacts and adaptation and associated costs.
http://www.defra.gov.uk/environment/climatechange/pdf/cc-science-0904.pdf

EC Bathing Water Directive (76/160/EEC)

EC Groundwater Directive (80/68/EEC) and proposed future groundwater directive (COM(2003)550).
http://europa.eu.int/comm/environment/water/water-framework/groundwater.html

EC Interinstitutional File 2002/0254 (COD)- Proposed Revision of Bathing Water Directive 26 November 2004- from communication with Scottish Executive

EC Nitrates Directive 91/676/EEC
http://europa.eu.int/comm/environment/water/water-nitrates/directiv.html

EC Waste Framework Directive 75/442/EEC
http://europa.eu.int/scadplus/leg/en/lvb/l21197.htm

Energy White Paper DTI/DEFRA Our energy future – creating a low carbon economy
http://www.dti.gov.uk/energy/whitepaper/ourenergyfuture.pdf

EU Biowaste Directive – current developments, perspectives and arguments for a strategic approach of source separation.
www.biowaste.at

EU consolidated Animal By-Products Regulations 2003. Office for Official Publications of the European Communities

EU National Emissions Directive (2001/81/EC)
http://europa.eu.int/eur-lex/pri/en/oj/dat/2001/l_309/l_30920011127en00220030.pdf

EU proposal for amendment to the Bathing Water Directive
http://europa.eu.int/eur-lex/en/com/pdf/2004/com2004_0245en01.pdfEU bathing water

European Waste catalogue CONSLEG: 2000D0532 — 01/01/2002 Office for Official Publications of the European Communities

IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories
http://www.ipcc-nggip.iges.or.jp/public/gp/bgp/4_3_CH4_Animal_Manure.pdf

Promoting and Accelerating the Market Penetration of Biomass Technology in Scotland. FREDS biomass group. Scottish Executive, 2005.

The Renewables Obligation (Scotland) Order 2005. The Stationary Office

The Renewables Obligation (Scotland) Consultation 2004-2005
http://www.scotland.gov.uk/consultations

The Renewables Obligation (Scotland) Consultation 2005-2006.
http://www.scotland.gov.uk/consultations

Scottish Executive, Dec. 2004. Guidance on the treatment in approved composting or biogas plants of animal by products and catering waste

Scottish Executive 2002 “Meeting the Needs” Sustainable Development Strategy.
http://www.scotland.gov.uk/library5/rural/mtnsd.pdf

Scottish Statutory Instrument 2003 No. 531 The Control of Pollution (Silage, Slurry and Agricultural Fuel Oil) (Scotland) Regulations 2003
http://www.opsi.gov.uk/legislation/scotland/ssi2003/20030531.htm

SEPA annual bathing waters report
http://www.sepa.org.uk/publications/bathingwaters/2004/5_4.html

Strategic review of organic waste spread on land   SEPA 1998
http://www.scotland.gov.uk/library/documents6/owl.pdf

The Waste Management Licensing Regulations 1994.The Stationary Office

The Waste Management Licensing Amendment (Scotland) Regulations 2003.The Stationary Office

The Waste (Scotland) Regulations 2005 No.22 Environmental Protection. The Stationary Office.

ANNEX 1 – PROCUREMENT, CONSTRUCTION AND COMMISIONING OF PLANTS

1.1 Procurement of AD Plants

The procurement of the AD plants commenced when the process design was complete at the end of January 2004. It was a requirement of the contract that all major equipment for six of the seven AD plants was to be delivered either to site or to the Greenfinch factory in Shropshire by the end of March 2004. This short timescale placed considerable pressure on the procurement process, and it is recommended that this should not be normal practice.

The glass-coated steel tanks were the most significant item for procurement and the consortium negotiated a single contract for supply, erection and bases for all seven AD plants. The total of 17 tank kits was delivered to the six farms by 31st March. Procurement of the tanks for the last farm was undertaken when required.

The mechanical equipment comprised the following key items:

- Reception tank chopper pump;
- Raw slurry in-line macerator;
- Digester feed pump;
- Digester discharge pump;
- Gas mixing compressor;
- Gas mixing rotary valve;
- External heat exchanger;
- Heat exchanger slurry circulation pump; and,
- Water circulation pumps.

The mechanical equipment was assembled as pump-sets in the Greenfinch factory. This approach ensured close control of quality. The only difficulty encountered was in the procurement of 3.0kW single-phase electric motors, twelve of which were required for the Sandyhills AD plants. (This was not an issue for the Saltcoats plants since all the farms there have three-phase electricity). The project timetable prevented full evaluation of them and there remain concerns about their reliability although all have performed well to date. All the mechanical equipment for the six AD plants was delivered to the Greenfinch factory by 31st March 2004 and for the seventh farm when required.

The electrical equipment comprises instrumentation, control panels and cabling. The control panels were designed and assembled by Greenfinch using base components; there were no significant issues arising from the procurement of the electrical equipment.

A key feature of the design was the assembly of the mechanical and electrical plant inside a steel container. This assembly work was carried out at the Greenfinch factory and enabled the plant room to be completed and tested before being delivered to site.

The gas mixing system, comprising a gas compressor, rotary valve and interconnecting pipework formed part of the containerised plant room for safety reasons.

In summary, the following key components were delivered to site for each AD plant:

- Three tank kits for the reception tank, digester tank and digestate storage tank;
- Containerised plant room; (Figure A1.1)
- Gas mixing system, skid-mounted;
- Bell-over-water gas holder; and,
- Interconnecting pipework.

In addition to the components which made up each individual AD plant, it was necessary to procure equipment to enable the plant to be integrated with the existing farm operations. For example, new pumping systems were required to enable slurry to be transferred from the underground storage tanks to the AD plant reception tank on one farm and to enable digested slurry to be pumped into open-top tankers on another. The procurement for additional works was time-consuming and needs to be taken into account when designing new systems.

Figure A1.1 Plant Room Container

1.2 Construction of AD plants

The construction of each AD plant was carried out in the following steps:

- The site was set out and stripped of top soil;
- The working area was covered with compacted stone;
- The footings for the three main tanks were excavated and formed in reinforced concrete, with drainage pipework and gas mixing pipework cast in as necessary;

- The three tanks were erected on the footings;
- The tank bases were formed in reinforced concrete;
- The plinths for the gas mixing, for the gas holder and for miscellaneous plant were formed in reinforced concrete;
- The containerised plant room, the gas mixing skid and the gas holder were delivered to site and craned into position;
- The interconnecting pipework and cabling were completed between the tanks, the plant room, the gas mixing skid and the gas holder;
- The digester tank was insulated with mineral wool and covered in steel cladding;
- The electricity incomer cable and water supply were laid and connected to the plant room; and,
- The site was finished with a layer of gravel.

In addition to the construction works required for the AD plant itself, significant additional works were needed to complete its integration with the farm; including project management, farmer liaison, installation of areas of concrete and diversion of an open field drain.

Following completion of construction the mechanical and electrical equipment was comprehensively tested prior to setting the AD plant to work.

1.3 Commissioning of AD plants

The AD plant was commissioned with the following key steps:

- Pre-commissioning checks were carried out to ensure that all valves were in the correct position and that the control circuits were operating correctly;
- The reception tank was filled with raw slurry and the raw slurry transferred to the digester tank, ensuring that all material passed through the macerator. This operation normally took about a week;
- When the digester was full of slurry the digester heating system was switched on. This involved using heating oil to fuel the standby oil boiler until the digester reached its operating temperature of 37°C. This operation normally took about a week to ten days;
- When the gas holder first filled, which was soon after the heating was switched on; the digester mixing was switched on;
- During the steps above the individual items of mechanical equipment were tested and calibrated to verify actual flow rates and instrumentation settings;
- The AD plant was then allowed to stand with the heating and mixing in automatic and with the temporary oil tank topped up as necessary. This

period lasted for two to four weeks in order to establish the microbial culture;

- When burnable biogas was first produced the biogas boiler was commissioned and the oil boiler ceased operation;

- The digester feed rate was set to automatic at about 25% of its design rate, i.e. with a hydraulic retention time of 80 days;

- Over a period of two to four weeks the feed rate was increased to its design figure, ensuring that there was sufficient biogas being produced to maintain digester temperature.

As is normal in the commissioning of a biological process using mechanical and electrical equipment, a number of operational difficulties were encountered. For example:

- The macerator for reducing particle size tended to block; this was remedied by redesigning and modifying the cutter plate.

- The starting torque on the positive displacement pumps was too high for the single-phase motors; the rotors were changed for under-size ones.

- The slurry circulation pump blocked with grass; this was owing to the commissioning of the AD plant on raw slurry, whilst the pump was designed to operate on digesting slurry. The clearance was increased on the pump rotors until the plant was at design feed rate when the clearance was returned to its original position.

- On a number of farms the raw slurry was over-diluted with rainwater and with leaking drinking water; this reduces the specific gas yield without reducing the digester heat requirement. The result was that oil needed to be burned, as well as biogas, for a period whilst farm waste management practices were amended.

The combination of these problems slowed the commissioning process in some cases, but had the positive benefit of enabling the farmer to gain a greater understanding of the AD plant and its integration into the management of the farm.

The 7 AD plants following commissioning are illustrated in Figure A1.2.

Figure A1.2 AD Plants

Sorbie Farm (Saltcoats)

Castle Farm (Sandyhills)

New Farm (Sandyhills)

Ryes Farm (Sandyhills)

Meikle Laught (Saltcoats)

Knockrivoch (Saltcoats)

Corsock (Sandyhills)

1.4 Procurement of Composting Facilities

The procurement of the compost facilities commenced when the process design was complete at the end of January 2004. It was a requirement of the contract that all major equipment for two of the three compost facilities was to be delivered to site by the end of March 2004 with the third procured when required.

The design philosophy identified that the facility and equipment should be readily available in the agricultural industry. Using one of the participating farmers as a sub-contractor to construct the compost slab and building widened this philosophy.

This helped demonstrate that composting facilities could be at least, in part, self-built by farmers to reduce costs.

Similarly, Enviros actively promoted a policy to invest as much of the project procurement and construction costs into the local community. Around 90% of these costs were spent in the Dalbeattie and Dumfries areas. This often reduces project expenses as travel time and costs for operatives are normally low as are mobilisation and site establishment costs. Any additional works would also be correspondingly cheaper.

The mechanical equipment and associated buildings comprised the following key items:

- 3 No. Sandberger 300T windrow turners – this was the only item that was not adopted from the agricultural industry. However, it was procured from an agricultural equipment supplier.

- 3 No. Abbey VF10 mixer/shredders – An initial trial with a unit using twin horizontal augers demonstrated that it was ineffective in mixing and shredding the FYM. A trial with an Abbey unit that uses a single, vertical, conical auger proved acceptable.

- 3 No. Compost thermometers.

- 3 No. Portal framed compost sheds based on a standard agricultural building design from a local supplier.

1.5 Construction of the Composting Facility

Construction of the compost facilities was designed to be simple and the following key activities took place:-

- Topsoil stripping and earthworks construction. This was undertaken within the area of the compost building, the external hard standings and access roads. The soil that was not required for restoration was stockpiled. During this phase bedrock was encountered at the south end of two of the study farms and the designed slab levels were altered to mitigate additional rock excavation.

- Capping and sub-base layers – loose rock was excavated at one site and crushed to provide capping material for two other farms. Type 1 sub-base was imported from a local quarry.

- Portal frame compost shed – this was erected prior to the casting of the compost slab. The lower walls were pre-cast concrete panels to contain leachate and prevent mechanical damage to the structure. Upper walls were timber ‘Yorkshire Boarding’ that excluded rain, etc, but maintained a free airflow and additional lighting into the building.

- Concrete compost slab – comprised a 200 mm thick reinforced concrete slab.

- Concrete hard standings – comprised a 150 mm thick reinforced concrete slab at each end of the building to provide turning and mixing areas for the compost equipment.

- Access roads – were provided at all three farms primarily as a planning requirement to allow fire fighting equipment access to the sites in the event of a fire and secondarily as an environmental risk reduction when transporting FYM to the compost operation from the steading.

- Fences and gates – standard agricultural post and wire fencing with rylock was provided at all three farms to prevent 3rd party and livestock access to the compost area.

One of the participating farmers undertook all the construction works, including the erection of the compost sheds. No significant problems arose and the construction programme was broadly met with no delays.

On completion of the compost facilities and prior to commissioning, the building control officer inspected the works after which the building completion certificate was issued.

1.6 Commissioning of the composting facilities

The compost process and associated mechanical equipment is readily understood and broadly familiar to farmers. Commissioning of each plant took about 4 weeks and comprised:

- Training in the use and maintenance of the windrow turner and mixer/shredder;

- Instruction in the preparation of FYM feedstock, windrow formation and turning;

- Monitoring and sampling during the compost process to optimise the composting process; and,

- Provision of operating & maintenance manuals for the compost process and mechanical equipment.

The farmer involved in the construction of the plant assisted in commissioning the compost facilities. This promoted self-help for the future between the participating farmers within the pilot scheme.

The 3 composting facilities following commissioning are illustrated in Figure A1.3.

Figure A1.3 Composting Facilities

Upper Clifton Farm (Sandyhills)

Fairgirth Farm (Sandyhills)*

Castle Farm (Sandyhills)

*Fairgarth farm – The farmer has added his own sheds to either side of compost shed, this facility is no larger than facilities on other participating farms

ANNEX 2 - CONCEPTUAL BASIS AND MODEL DEVELOPMENT

This appendix describes the conceptual basis, modelling system developed and parameters used in the assessment of diffuse agricultural pollution.

2.1 FIO Sources and Assessment Tools

2.1.1 FIO Sources

Diffuse agricultural sources of FIO in a catchment may arise from:

- livestock access to, and defecation within, catchment watercourses;
- run-off and drainage from agricultural land following landspreading of animal manures or livestock at pasture; and,
- faecal material being washed off or draining from steading yards or seeping or draining from livestock housing.

Run-off or drainage from land and wash-off from yards will typically only occur during rainfall periods. Direct defecation to watercourses and seepage or drainage from livestock buildings is likely to be independent of rainfall and more closely linked to whether livestock are out at pasture or housed on the steading. Run-off and drainage from land will be influenced by the land type, the amount of livestock on that land and the application of livestock manures to that land. Manure application to land can be intermittent and hence the potential sources of FIO within a catchment can fluctuate widely. As previously described in the main report, livestock types and farm management procedures varied from farm to farm and there are clear seasonal differences in the way livestock and livestock manures are managed.

The situation described above is complicated by the fact that within any environmental media, FIO loads tend to decrease through microbial die off and that this die-off can vary from one media to another. One of the central concerns of the process is the degree to which anaerobic digestion and composting can also lead to significantly enhanced rates of microbial die-off.

Further work by the Scottish Executive has shown that there are also large seasonal differences in FIO fluxes from farm land to watercourses and that these fluxes tend to be highest in the summer when livestock are out at pasture.

Assessment Tools

Systems for predicting bathing water quality exist. For instance, the Scottish Executive's Bathing Water Signage project, which is managed by SEPA, provides daily updates on predicted water quality across a range of Scottish bathing waters. The system is based on large data sets of observed rainfall and/or river flow and microbial water quality from which statistical relationships have been derived. These relationships are then used to forecast bathing water quality based on observed rainfall or river flow data on a day by day basis. Approaches like this have been demonstrated to provide an effective method for predicting bathing water quality at some locations. Extensive validation shows that between 85% (2004) and 94% (2003) of the time the model accurately predicts bathing water quality. However, the system can, for a limited percentage of the time, under predict or over predict bathing water quality. This uncertainty probably arises from the fact that the approach only considers the influence of rainfall events and does not account for the fact that the episodic spreading of manures to land may significantly increase the risk to bathing water quality at specific times during the bathing water season. Also the model cannot be easily modified to account for changes in farm management practices through a catchment and if significant changes were to occur, the model would have to be re-parameterised based on additional monitoring data.

Mechanistic modelling approaches include, for instance, systems based on a catchment sediment transport model. Systems like this attempt to explicitly replicate the movement of water borne sediment and particulate bound FIO based on catchment topography and hydrology. Although such systems take a much more detailed approach to the modelling of FIO through a catchment they are not flexible. For instance varying FIO sources cannot be easily added or variable farm management scenarios tested.

An alternative approach is to use a compartmental modelling system to model FIO fluxes from agricultural systems. The compartmental approach forms the basis of the Enviros modelling system AMBER. This is software designed for the development and application of compartmental models. It has therefore been selected to evaluate the range of different farm management strategies using a risk assessment tool developed during this project, the Agricultural Risk Assessment Model, ARAM.

2.2 Nutrient Sources and Assessment Tools

Diffuse agricultural sources of nutrients are believed to be more closely linked to land application of manures and fertilisers, rather than point sources such as drainage and seepage from steadings. Nitrogen based nutrients such as nitrate and ammonia applied to land in livestock manures may be lost to the atmosphere through volatilisation, leached from the ground into surface or groundwaters or retained within the soil where a proportion will be available for uptake by crops.

The proportion of nitrogen available to plants or leached from the ground depends upon the physical and chemical characteristics of the manure, soil type, land application and incorporation methods and rainfall. Software tools (e.g. MANNER) to assess these proportions exist and have been developed under funding from DEFRA. These software tools are therefore set up with default values for conditions typical of lowland areas of England. However, it is possible to modify these values to make them more suitable to the Scottish context.

It has been demonstrated that anaerobic digestion and composting treatments influence the total and available concentrations of nutrients in animal manures, and also that the new infrastructure and potential for storage of material that these technologies bring to each farm can result in altered land spreading regimes. The software packages mentioned above and modified to the Scottish context have been used to evaluate these scenarios. An evaluation of the nutrient availability and uptake from livestock manures has also been undertaken.

2.3 Conceptual Model Development

A conceptual model of how agriculturally derived FIO could lead to reduced bathing water quality has been developed as part of the design phase for the quantitative model. The conceptual model is described below.

2.3.1 Potential Agricultural Sources of FIO

Agricultural sources of FIO arise from livestock faecal material and areas where livestock manures may accumulate (slurry tanks, middens or field piles) or land on which they may be spread. It is important to note that livestock are not the only source of FIO within a catchment, other sources include waste water treatment works and plants, septic tank overflow and non-livestock animals, but in rural catchments agricultural sources are believed to dominate.

There are two primary categories of FIO sources. These are:

- **Point Sources** – seepage or drainage from steadings direct to watercourses; and,

- **Diffuse Sources** – run-off or drainage from land used for spreading of animal manures or pasture and direct cattle access to water.

It is important to note that these sources vary through the year. For instance, during the bathing water season most livestock are at pasture for the vast majority of the time and only dairy cattle will spend part of their day on the steading due to milking (about 10%). Slurry and FYM spreading may also be intermittent and can lead to episodic increases in FIO on the land that can be washed off or drain into surface waters.

A key aspect of the conceptual model is that the amount of FIO produced by any animal depends on the livestock type, the age specific manure production rate and the FIO loading of that manure. The FIO source from livestock in any particular area is then simply a function of the animal numbers and their occupancy in that area.

2.3.2 Pathways of FIO Transport to Surface Watercourses

FIO transfer pathways represent routes and processes by which FIO contamination can be transferred from land or the steading to watercourses in the catchment. Pathways include:

- Seepage or drainage into watercourses from steading yard or buildings;

- Wash-off from yards and other hard standing areas on the steading;

- Direct deposition of faecal material into watercourses;

- Overland flow and wash-off of FIO from the soil surface; and,

- Land drainage flow of FIO to watercourses.

2.3.3 Mechanisms or Processes which Control Transport Pathways

In well managed farms there should be minimal, or no, seepage and drainage from steading yards or buildings, although the potential for this to exist obviously occurs. Seepage and drainage from buildings, if it does occur, is likely to be independent of weather conditions, controlled rather by the presence or absence of animals in the steading buildings.

Wash-off, run-off or drainage of FIO from land or yard areas to watercourses is intrinsically linked to the rainfall events and increases of FIO in watercourses following such events are common [Niemi and Niemi, 1991; Wyer et al., 1999; Crowther et al., 2002; Harhcegani & Cornish, 2003] The degree of run-off or drainage will also depend upon soil types, land topography and extent of local watercourses.

Direct deposition of faecal material into watercourses occurs when livestock are at pasture, where they have access to a watercourse, for example where they are not fenced. The extent of fencing can vary from farm to farm and the introduction of fencing across a farm may help improve microbial water quality by preventing livestock access to watercourses.

2.3.4 Bathing Water Receptor

There are two designated bathing waters in the pilot catchment, one at Saltcoats and one at Sandyhills. The designated bathing water season in Scotland is from the 1st June to mid September.

2.4 The Agricultural Risk Assessment Model (ARAM)

2.4.1 Enviros Modelling System, AMBER

AMBER is a flexible modelling system that has been developed, marketed and is supported by Enviros. AMBER is currently operated by over 60 users in 24 countries that include industrial waste producers, regulators, consultancies and researchers.

Using AMBER the system can be set up to model how biological or chemical contaminants, nutrients or other substances are transported around, changed and the impact that these have on agricultural or natural environmental systems.

The AMBER modelling approach is based on the concept that any environment can be conceptualised as a series of discrete compartments and that the contamination (in this instance by FIO) of any one compartment is determined by the balance between inputs and losses from that compartment. For instance, these could include:

- Inputs and losses due to the transfers via direct or indirect pathways between one source area and another (e.g. the addition and removal of FYM from a midden store); and
- Inputs and losses due to processes that do not involve transfer of FIO via a direct or indirect pathway (e.g. bacterial die-off or re-growth within the midden).

This is illustrated below (Figure A2.1):

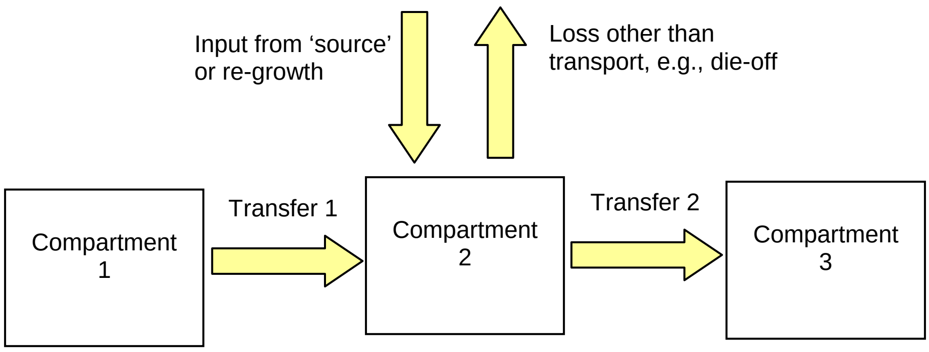


Figure A2.1 Inputs and Pathways through compartments

The FIO loading within any compartment therefore depends upon the balance between inputs from sources, losses, and transfers from one compartment to another. This concept is based on a 'mass-balance' approach and that within this system the contaminants are conserved and only lost or gained through the pathways and processes described above.

- AMBER gives the user flexibility to define:
- any number of compartments and contaminants (e.g. E. coli and Enterococci);
- algebraic expressions to represent biogeochemical and physical processes governing fluxes between model compartments;
- deterministic and probabilistic assessments; and,
- time varying parameter values.

AMBER can be adapted and tailored for specific purposes and for time-steps ranging from seconds to years. Units can also be specified (e.g. mol, mg, g, kg, etc). The model can accommodate at least one million time-steps transferring decaying or non-decaying contaminants between compartments. Time dependent parameters can be set up with repeated cyclic processes. Multiple source terms, continuous or intermittent, or one off events can be modelled. Local decay rates to represent degradation or die off of contaminants can be specified.

The flexible user friendly graphical format of the AMBER modelling suite means that the model format can be used by non-specialists without the need for any coding or software knowledge.

2.4.2 Conceptual Model - Features, Events and Processes

The conceptual model was therefore designed so that the structure can then be coded into a numerical model using the Enviros software system AMBER. Identification of features, events and processes is a key stage in developing an AMBER model. These are described below.

Features, are used to describe the compartmentalisation process by which an environmental system is broken down into a series of discrete areas and to identify how these areas are connected. Features include:

- Livestock housing types, e.g. high level slatted building, straw bedded courts (SBC) cubicle houses (CH), and byres;
- Other steading areas, e.g. yards and dirty water irrigation systems;
- Animal waste storage, e.g. slurry towers, slurry lagoons, and yard or field heaps of FYM;
- Pasture and silage fields (both those that are hydrologically connected and unconnected);
- Watercourses including burns, reservoirs and bathing waters;
- FIO contaminant sources e.g. agricultural livestock;
- Transfer pathways. These represent the linkages between different model compartments and indicate how FIO contaminants are transferred from one model area to another depending upon farm management or natural processes.

Events are discrete periodic or episodic occurrences that can influence the flux and fate of FIO contaminants with the catchment. Events include:

- Seasonal livestock transfer between pasture land and the winter housing on the steading;
- Mucking out or other transfer processes of animal waste within the steading or other storage areas (e.g. field heaps);
- Slurry or FYM spreading to land; and,
- Rainfall and enhanced river flow.

Processes may be dependent or independent upon events. Processes include:

- Run-off and drainage rates from pasture and silage land. These will increase with precipitation;
- Run-off from other exposed areas, such as farm yards will also increase with precipitation;
- The rate of FIO input from livestock to the various model compartments will depend upon animal numbers, types and ages;
- The drainage or seepage rates of FIO contaminated water from housing types. These are likely to be independent of weather conditions;
- Microbial die-off rates.

2.4.3 ARAM structure - Features

Figure 11 illustrates the basic features of a specific farm model. Agricultural land has been classified purely as 'fields'. The different types of land, such as pasture, silage, arable etc have not been explicitly represented. However, the parameterisation of the model has taken these factors into account.

Similarly, the individual buildings within a farm steading have not been explicitly represented, but the transfer rates off the steading can be set to different values on different farms to take account of the different livestock housing types and building structure and integrity. This is illustrated below (Figure A2.2):

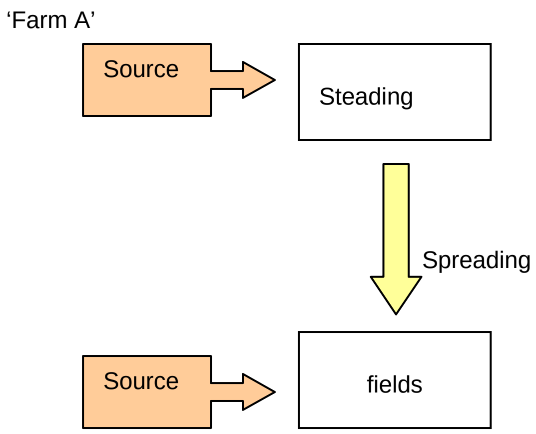


Figure A2.2 Features of an individual farm model

Sources of FIO to the system are based on livestock numbers expressed as 'adult equivalents' and waste production rates. FIO can enter the system via livestock on the steading, in fields, or from animals defecating in or near water-courses (referred to as direct access to water courses). Transfer pathways such as drainage, seepage, wash-off and runoff can also result in the transfer of material direct from the steading to watercourses.

Figure A2.3 illustrates how the individual farms are linked via the local watercourses to the designated bathing waters.

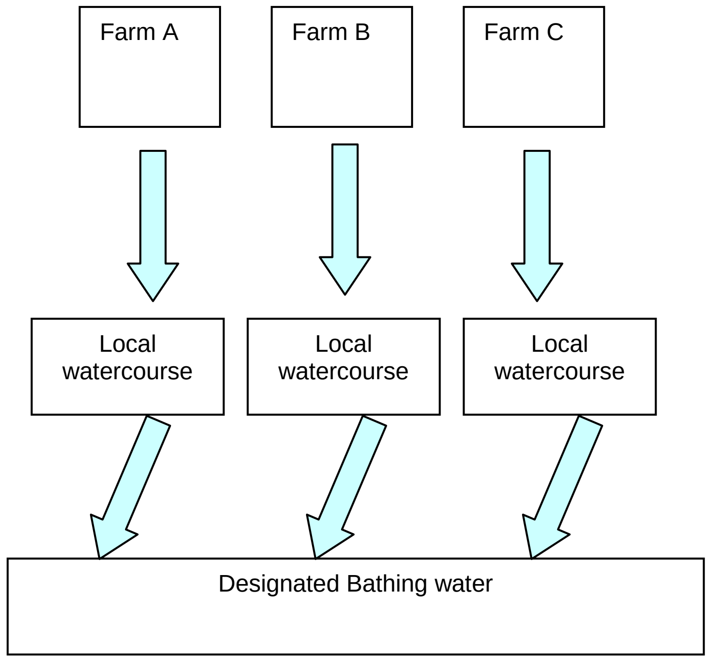


Figure A2.3 Features of the catchment model

2.4.4 ARAM structure - Events and variability with time

ARAM has been encoded to run on a day by day basis for 365 days from January 1st through to December 31st.

Four types of event have been included in ARAM:

- The occupancy of the livestock, either on the steading or at pasture is time-dependent. For most animals they are housed on the steading during the winter (generally October to April) and at pasture during the summer. Adult dairy cattle also spend a proportion of the day during the summer on the steading for milking.

- Mucking out or other transfer processes of animal waste within the steading or other storage areas (e.g. field heaps) is assumed to occur continuously. A continuous transfer has been assumed because, although an individual building may only be mucked out once a week/month, it is assumed that not every building will be mucked out on the same day, but rather a rotational system employed on the farm so that different buildings are mucked out on different days. This would lead to a continuous transfer of animal waste within the steading or from steading to storage.

- Slurry or FYM spreading to land is assumed to occur intermittently throughout the year. The model has the facility to specify specific spreading dates based on data provided by farmers, or to test hypothetical spreading times

- Rainfall events are assumed to occur intermittently for one day every 2 weeks. This is based on the rainfall trigger levels and event frequency determined by the SEPA Signage team. Specific rainfall history based on monitored data or other hypothetical rainfall scenarios can be included.

The time lag between spreading and a rainfall event can be modified.

2.4.5 ARAM structure - Processes

The following processes are included in the model:

- Microbial die off rates are compartment specific. Different die-off rates have been set for soils, slurry, FYM, biogas digesters and composting plants;
- Run-off and drainage rates from fields have been set for each farm. The processes are only assumed to occur with a rainfall event;
- Wash-off rates from the steading have also been set for each farm, but are only assumed to occur with a rainfall event;
- The rate of FIO input from livestock to the various model compartments (steading, field and where appropriate, local watercourse) is determined by the number of adult equivalents of each livestock type, the FIO loading and the occupancy of the livestock in the model compartments; and,
- The drainage or seepage rates of FIO contaminated water from the steading are controlled by the occupancy of the animals on the steading.

2.5 Research background and Parameterisation

Conceptual models such as that described in the previous sections can be used to provide quantitative risk assessments and to prioritise the risk associated with each source or pathway. In a quantitative assessment, features, events and processes are described using numerical values and the end point of the assessment is a value (or range of values) rather than a category of risk. To develop a quantitative risk assessment model, values have to be derived for the source and transfer features, events and processes described in the previous section. These are described below.

2.5.1 Agricultural Sources of FIO

Two specific types of FIO are used to assess bathing water quality. These are:

- Faecal coliform (FC) of which the most commonly used indicator is *Escherichia coli* (E. coli); and,
- Faecal streptococci (FS) now more commonly termed Enterococci.

Total coliforms (TC) refer to the total microbial loading consisting of FIO and microbes from non-enteric origin.

Faecal indictor organism inputs to a catchment can be derived from agricultural livestock (e.g. cattle, sheep, pigs, and chicken), anthropogenic sources such as waste water treatment works, septic tanks and application of domestic sewage to agricultural land and other animal sources such as birds. This study addresses the FIO loading to agricultural catchments from cattle and sheep only.

The waste production rate also varies depending upon the type and age of the animal and is, for instance, higher in adult dairy cattle compared with beef cattle or younger animals. The waste production rate of sheep is less than 3% of that of an adult dairy animal. Waste production rates derived from literature are summarised in Table A2.1.

Table A2.1 Livestock waste production rates

Adult Dairy Cattle	Wet weight (kg/day)	[a]Dry weight (kg/day)
Dairy (650 kg)	[a]64	6.4
Dairy (550 kg)	[a]53	5.3
Dairy (450 kg)	[a]42	4.2
Average	53	5.3
Dairy Replacements, Beef Stores, Sucklers & Followers		
Grower/fattener > 2 yr (500 kg)	[a]32	3.2
Grower/fattener 1-2 yr (400 kg)	[a]26	2.6
Grower/fattener 0.5-1 yr (180 kg)	[a]13	1.3
Average	24	2.4
Calves		
Calf 0-0.5 yr (100 kg)	[a]7	0.7
Sheep		
Sheep	[c]2	1*
Lamb	0.72	0.4*
Average	1.4	0.7

[a]ADAS [2001], [c]Brenner and Mondok [1995], [1998] *Assumes a 50% dry matter content.

Typical FIO loads in cattle and sheep manure were assessed during both the baseline and process monitoring aspects of the project (Chapter 4). FIO loading of between 2.6E+05 and 7.6E+08 in fresh faeces during the summer were identified. A value of 1.1E+08 cfu/g has been taken as an average and used in the modelling

The model considers three types of livestock; adult beef cattle, adult dairy cattle and sheep. The source of FIO to each of the farms is defined in terms of these 3 types of livestock. However, to include the FIO produced by younger stock, the livestock numbers can be defined using 'adult equivalents.'

The number of adult equivalents for a particular animal type can be calculated by multiplying the number of each age category of that animal on a farm by the ratio of that age group's waste production to the adult waste production data. This is illustrated by an example below:

A farm has 163 dairy adults, 9 replacements and 73 calves.

1. A dairy adult is assumed to produce 5.3 kg of excrement a day; a dairy replacement 2.4 kg and a calf 0.7 kg per day (dry mass).

2. Thus, one replacement is the equivalent of 0.452 (2.4/5.3) adults and one calf is the equivalent of 0.132 (0.7/5.3) adults.

3. The number of adult equivalents of dairy cattle on the farm is thus 163+ (9 x 0.452) + (73 x 0.132) = 176.7 dairy cattle.

4. The adult equivalents for beef cattle and sheep can be similarly calculated.

The FIO production rate is then simply a function of the number of adult equivalents of each livestock type, their waste production rate and the FIO load.

2.5.2 FIO Pathways to Watercourses

Several pathways by which agriculturally derived FIO can be transferred to watercourses were defined previously. These are discussed below.

Seepage and Drainage from Steading Buildings

Although there should be minimal seepage and drainage from steading buildings, it is apparent the pathways could potentially exist and were identified to some degree or other on the farms visited. Direct loss of slurry to watercourses may occur within each housing type, midden and slurry store. High level slatted buildings that continually weep are an obvious example of persistent FIO losses from a building; however intermittent loss may occur during washing and cleaning procedures.

The extent of any slurry seepage from the steading will depend on the extent of a slurry containment system, its state of repair and general farm management practices. However, it should be noted that all these pathways are ultimately controllable.

Wash-off from Yards

Cattle may spend varying amounts of time in yard areas where faecal material can accumulate. Wash-off from yard areas to watercourses or surface drains may occur, again the extent of any loss will depend upon the slurry containment system, its state of repair and general farm management practices.

Run-off and Drainage from Land

Diffuse catchment sources make a substantial contribution to the faecal indicator loads [Wyer et al., 1996] and this contribution is particularly important at high river discharges [McDonald and Kay, 1981]. Under these conditions, the combination of a large contribution of overland flow to streamflow [Hunter et al., 1992], shorter travel times of bacteria in streams, entrainment of stream sediment [Wilkinson et al., 1995] and mixing of a larger fresh water input with seawater all contribute to orders of magnitude increase in FIO concentrations in bathing water samples, for beaches influenced by river estuaries [SEPA, 2002].

The source of FIO organisms to land or water can be calculated from the faecal indicator loadings per animal per day. A proportion of this may be defecated directly into a watercourse and other faecal material deposited on the ground surface may subsequently wash off via overland flow or may percolate into drainage systems. Tyrrel & Quinton [2003] suggest that slurry spreading leads to a 10 fold higher availability of FIO for event run-off compared to slurry injection, other methods of manure incorporation into the soil profile or direct deposition by animals at pasture [Drapcho and Hubbs [2003].

Catchment studies on Cessnock Water [Vinten et al., 2003] found that up to 20% of the estimated daily input from grazing dairy livestock was transported to river. The authors do not, however, identify how this transfer was proportioned between overland and field drainage routes. Higher concentrations of E. coli in drainage waters coincided with periods of high rainfall and with times of increased outflow through the draining hydrological pathways [Oliver et al., 2003]. For a period up to eight weeks after the removal of cattle from the land the authors measured E. coli concentrations in both overland and drainage waters that exceeded 3,000 cfu/100 ml. In drained pasture the percentage of bacteria transported via overland flow was 39% and that via drainage systems was about 61%. The coliform loss from an undrained pasture was similar to that via the drains in a drained pasture.

Livestock Access to Watercourses

The extent of faecal transfer from the animal to the watercourse will depend upon livestock access to watercourse or grazing areas in proximity to watercourses, soil type and slope and drainage system.

The amount of time that livestock spend in watercourses is variable and can depend upon access conditions; season (typically higher in the summer) and whether other sources of drinking water are available to the animals. In a study by Bagshaw [2001] beef cattle spent about 4% of the day in or close to watercourses (i.e. approximately 30 minutes). Bagshaw [2001] also identified that there was no difference in defecation rate whether the cattle were near water or not. The faeces produced could be directly linked to the amount of time cattle were present.

Assuming a mean value of 20 min/cow/d (i.e. about 3% of a 12 hour day) the daily microbial input per adult dairy cow with access to water would therefore be of the order of 9E+06 cfu/day. In the absence of other data it has been assumed that sheep will spend a similar proportion of a day near to water where access is available.

2.5.3 FIO Survival Times

FIO indicator organisms and associated pathogens are adapted to live within the guts of warm blooded animals. Their survival within the environment is therefore limited. However, there is an increasing body of evidence demonstrating that under certain conditions survival times can be quite extensive and under certain conditions the microbes are able to grow and multiply (regrow) within certain natural environments or those generated by farm management practices [e.g. Kress & Gifford, 1984; Filip et al., 1988; Sjogren, 1994; Kudva et al., 1998; Mawdsley et al., 1995 and McGee et al. 2001].

Most studies of microbial survival associated with livestock waste have focused on E. coli because of the direct pathogenic risks associated with human exposure. It must be noted though that few studies have attempted to verify the assumption that mortality rates of indicator organisms accurately reflect those of pathogenic bacteria species [1981; Filip et al., 1988]. However, limited studies that have been conducted have found that indicator organisms appear to survive longer than pathogens [Mubiru et al., 2000]. Thus, FIO calculations for die-off can be taken to be valid conservative indicators.

Based on data set out by various authors [e.g. Kress & Gifford, 1984; Filip et al., 1988; Sjogren, 1994; Kudva et al., 1998;; Mawdsley et al., 1995 and McGee et al.2001] the following mean microbial survival times have been derived (Table A2.2).

Table A2.2 Mean Survival Times and Die-off Rates of Microbes in Environmental Media

Medium	Mean Survival Time	*Die-off Rate (d^{-1})	Half-life (days)
Faeces	1.5 months	0.05	14
Slurry	2.5 months	0.03	23
FYM	8 months	0.01	61
Soil	5 months	0.02	34

*The die-off rate is the proportion of the bacterial population that is lost through microbial die-off in one day.

Based on the log_{10} kill data derived from the process monitoring of anaerobic digestion and composting the following maximum die-off rates have been derived (Table A2.3).

Table A2.3 Maximum Die-off rates associated with a anaerobic digestion and composting

Medium	Log_{10} Reduction	Die-off Rate (d^{-1})	Half-life (days)
Biogas	Log 2.8	0.25	3.5
Composting	Log 3.8	0.30	2.3

2.5.4 ARAM Parameterisation

Two model set-ups have been developed for each bathing water area. In each set-up (the 'case-file') the following have been included in the model for each main farm.

The following farm specific features have been included:

- Livestock numbers.
- Animal waste storage facilities have been parameterised according to the individual farms, for example if a farm spread slurry direct to land, no slurry stores were included in the model. However, if the farm had a store this was included.
- Fields were included with every farm, but the proportion of the land which was hydrologically connected to the coastal area varied from 60 % to 100%.
- The watercourses including burns, reservoirs and bathing waters were included with each farm as appropriate.
- FIO sources are input to the system depending on where the livestock are at the different times of the year.
- Transfer pathways are included or excluded as appropriate to the individual farm. The following pathways were considered on at least one farm, and the transfer rate given is expressed as a percentage of the inventory of the donor compartment which is moved during that transfer process :
- Seepage from steading ranging from 0.5% to 1% per day;
- Drainage from steading ranging from 0% to 0.5% per day;
- Wash-off from steading ranging from 10% to 20% during event conditions;
- Run-off during event conditions from land is set at 10% for all farms in the absence of more specific data; and,
- Drainage from land during event conditions is set at 1% for all farms in the absence of more specific data.
- Wash-off of FIO deposited to land during manure spreading is assumed to be 10 times higher than that from faeces voided direct to the field.
- The model is currently set up to assess the flux of FIO, that is the total number of FIO transferred from a steading or field system to water over a

specified period of time. Model results can be manipulated to assess the flux via either:

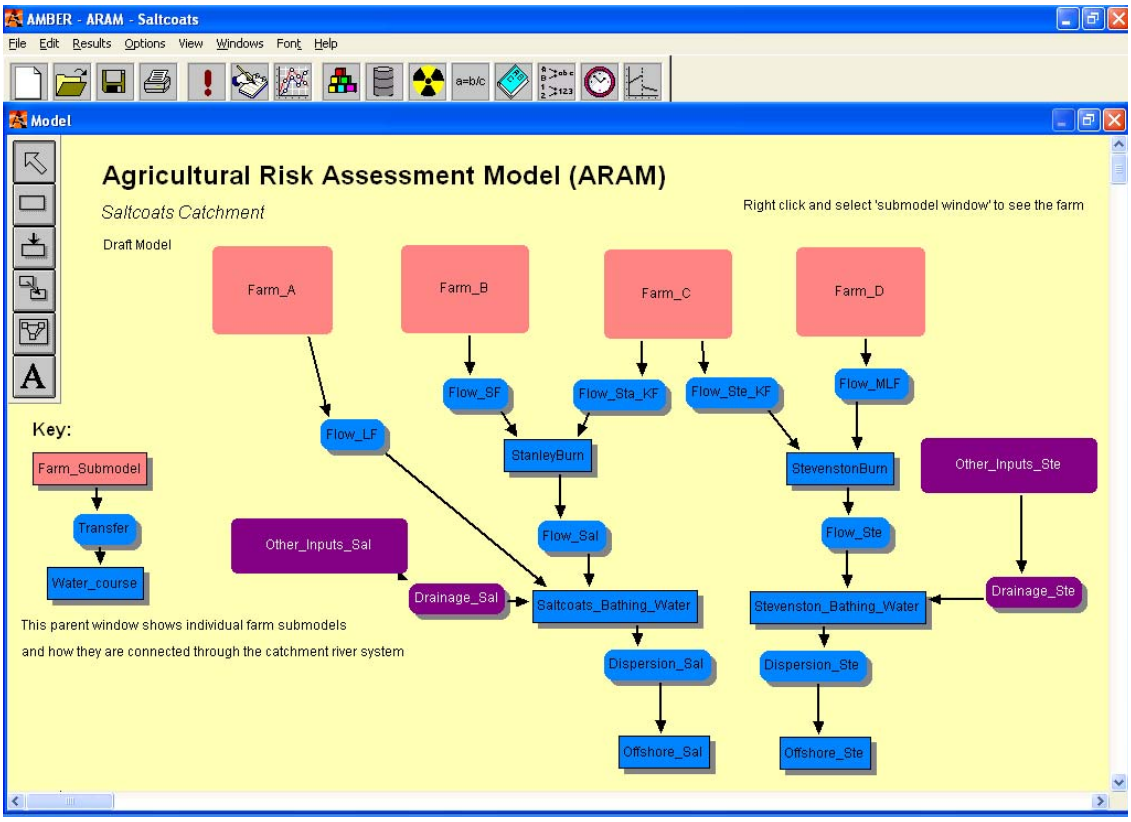
- Specific pathway (i.e. cattle defecation direct to water or seepage from a building);
- Summed across pathways (i.e. from wash-off, drainage and direct assess of cattle to water while livestock are at pasture);
- Summed across all pathways per farm; and,
- Summed across all farms in a catchment.

How these fluxes vary through the year as a function of livestock and manure management and rainfall events can be extracted direct to MS Excel.

2.6 Model Structure and Use

As ARAM has been developed using the AMBER software system, this provides a visual 'front-end' from which the user can access data input table, model parameter values and output data. The model set-up is also expressed in a visual manner with main screens and farm specific screens as shown in Figures A2.4 and A2.5.

Figure A2.4 ARAM Main Screen for Saltcoats Catchment



2.6.1 Output Options and Collation of Results

ARAM allows the user to specify output data. ARAM is a dynamic, i.e. time variable, model where results can be extracted for different pathways for different times of the year representing different environmental, livestock or manure management scenarios.

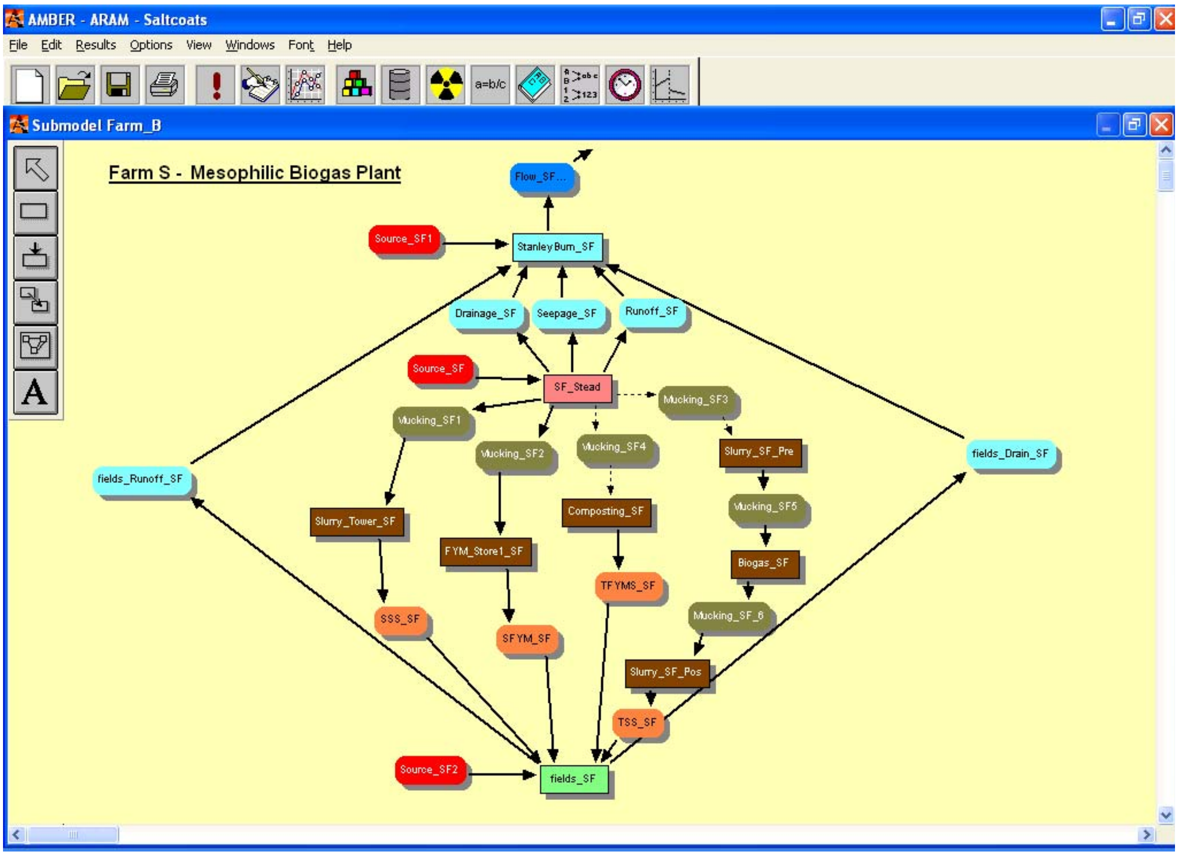
2.6.2 Results Form

The model has been set up provide two types of results. These are:

- The FIO inventory - This is the total number of FIO with any model compartment (i.e. the steading or a field). It should be noted that this is not a concentration.

- The FIO flux - This is the total number of FIO that are transferred from one model compartment to another within a set amount of time, this is again not a concentration.

Figure A2.5 ARAM Sub-Screen Showing Set-up for a Mesophilic Biogas Plant



In this assessment the 'concentration' i.e. number of FIO per unit mass or volume of a particular substrate or environmental media is not routinely used. This simplifies the assessment and reduces the number of environmental processes that need to be included in the model.

The total FIO flux is taken to imply all pathways considered in the model. The non-event driven flux relates to those pathways that are independent of rainfall i.e. seepage and drainage from livestock buildings and livestock access to watercourses. Event driven pathways are those that are triggered by rainfall i.e. wash-off and run-off from land and yards and drainage from land.

2.6.3 Assessment Period

ARAM is set up to represent agricultural processes through a year (the model can be run over several years to represent longer term changes such as livestock numbers in a catchment, but this has not formed part of our assessment). The model calculates the FIO inventory and flux on a day by day basis depending upon the source terms (i.e. livestock numbers and occupancy) and event drivers.

2.6.4 Event and Non-Event Conditions

The model has been set up to represent discrete rain events. Simulation periods can therefore be chosen that represent event or non-event conditions. However, the model still has the ability to be able to separate out those pathways that are uninfluenced by rainfall when assessing an event (i.e. the contribution of seepage from a steading).

2.6.5 Output Options

The functionality to assess individual pathways has been included in ARAM. However, to manage output data individual pathways can be amalgamated to provide farm or catchment wide results.

Pathway

Individual pathways include seepage and drainage from the steading, run-off from yards and land surface and drainage from land. The contribution from animals with direct access to water can also be extracted. This allows pathways to be prioritised and to assess which has the greatest impact on the overall FIO flux under different management scenarios.

Farm

Individual pathways on any farm can be amalgamated when outputting results so that the total flux from any particular farm and how this varies can be assessed. This allows easy comparison between farms.

Catchment

The output from multiple farms within any catchment can be amalgamated to compare the FIO flux between each catchment in the assessment (Stanley and Stevenston Burns and Fairgarth Lane and Southwick Water).

2.6.6 Time Integration

The model provides flux and inventory data on a day by day basis through a year. This assessment has focused on fluxes during the bathing water season (1 June to mid September), these are between days 152 to 258 in the year.

Various time integration periods have been assessed and the effect of biogas or composting over these periods evaluated. This has considered the FIO reduction over:

- One year;
- The bathing water season;
- Events during the bathing water season; and,

- A single event during the bathing water season

2.6.7 Post Processing of Results

This model allows results to be plotted and viewed within the model software. Data can also be exported as data tables direct to MS Excel.

To facilitate more rapid processing of model results, a series of MS Excel post-processes spreadsheets has been developed. Using these, model output can be exported to Excel copied into one of these sheets and graphs and summary statistics (e.g. percentage reductions) calculated automatically.

2.7 Model Testing and Protocols for Application

At each stage of model development a programme of testing and evaluation was undertaken and assessed through consultation with the Steering Group.

2.7.1 Model Evaluation

Qualitative evaluation of the model involved peer review of model structure and model results by the project team, Steering Group, SEPA and outline discussion with CREH. This process has been used to ensure that:

- Model features such as compartments and pathways adequately describe agricultural systems.

- Event conditions and processes that are triggered by rainfall events are realistic and that the conceptual basis behind these is sound.

- Model results are presented in an accessible and understandable fashion suitable for regulatory use.

During the project this process has led to several significant developments in the model.

The initial model set up was ‘steady state’ and did not include changing management or environmental processes. However, it was identified at an early stage that event driven fluxes were key to the assessment and that the model needed to be able to represent dynamic situations and variance in how the loss of FIO through die off and transfer.

The initial assessment focused on slurry and FYM spreading pathways only. However, it was identified that the risk reduction through treatment of animal manures needed to be put into the context of overall FIO flux from an agricultural system. Additional pathways such as losses from the steading and animal access to water were then included, together with the ability to extract results via specific pathways added.

Following initial discussions and review, the model set up was designed to represent FIO flux (via drainage and seepage) from different livestock building types within a steading (high level slatted courts, byres, straw bedded courts etc), yards and middens. However, through later discussions with the Steering Group it was identified that catchments with potentially several hundred farms may need to be assessed. In these instances a simpler representation of individual farms was required. To accommodate this, the model was developed further.

During the initial risk evaluation, FIO fluxes were integrated across the bathing water season. Following discussions with the Steering Group it was identified that it would be more valuable to assess the risk associated with a single event and to evaluate how that risk varied depending upon the time lag between spreading and rainfall. To accommodate this new protocols for model use and data output were derived.

The initial risk evaluation identified the FIO fluxes from each farm. Following discussion with the Steering Group it was identified that farm specific results should not be presented and that a catchment wide approach should be taken.

In addition, discussions with the Steering Group identified that the assessment should include all main farms in the catchments and not just the Pilot Farms. These additional farms were added. It was also identified that the model should be used to assess biogas and composting on all main farms and these functions were added to the model.

2.7.2 Sensitivity Testing and Identification of Critical Model Parameters

A sensitivity analysis (Table A2.4) was conducted on eight of the model parameters which were thought to be key to the modelling. The analysis was conducted on one farm, considered to be representative of all farms and so the results could simply be extrapolated up to all main farms within the model.

The impact of changing a parameter value from the default value can be transposed into an impact of the flux of FIO from a farm by multiplying the assessed FIO flux by the 'percentage of median value' given in the table below. For example, by changing the dung availability from 10% to 1%, the flux would be around 73% less (27% of the original flux would still exist). Similarly, by changing the yard run-off from 10% to 100%.

Table A2.4 Results of ARAM Sensitivity Testing

No.	Process	Parameter Description	Parameter Values			% of median value	
			Lower	Default	Upper	Lower	Upper
1	Steading drainage	Proportion of material within steading house that drains to a watercourse per day	0.05%	0.5%	5%	100%	100%
2	Steading seepage	Proportion of material within steading house that seeps to a watercourse per day	0.05%	0.5%	5%	100%	100%
3	Yard Run-off	Proportion of material on yard that is washed off per day during an event	1%	10 %	100%	93.4%	163%
4	Field Drainage	Proportion of material that is transferred from the soil to field drains per day during an event	0.1%	1%	10%	87.5%	205%
5	Hydrological connection of land	Proportion of land that is hydrologically connected	25%	50%	100%	64.1%	163%

6	Wash-off Efficiency	Proportion of material that is transferred from the soil surface to a watercourse per day during an event	1%	10%	100%	32.7%	454%
7	Dung Availability	Proportion of FIO in cow pat available	1%	10%	100%	26.9%	830%
8	Event frequency	The frequency of trigger events	Weekly	Fortnightly	Three weekly	74.8%	187%

As a result of the sensitivity testing, the values assigned to the last 3 listed parameters: event frequency, dung availability and wash-off efficiency were shown to have a larger effect on the FIO flux. The values assigned to these parameters are therefore important when populating ARAM with farm specific data.

2.7.3 Model Validation

Validation typically involves comparison of model results against an independent data set, i.e. data separate to that used in set-up of the project. During the development of ARAM such data sets were limited, particularly during the bathing water season.

FIO Flux

FIO flux measurements were collected by CREH in December 2002. The data were made available to Enviros and provide FIO flux values at various points in the watercourses in the Sandyhills area.

During the CREH monitoring, fluxes varied widely depending upon the status of events. The ARAM assessment is currently set up with generic conditions rather than time specific data, a direct comparison between the two studies is not therefore possible. However, fluxes are comparable and were within 1 to 2 orders of magnitude of those measured.

A subsequent phase of CREH monitoring has now been reported to the Executive which includes FIO fluxes monitored during the 2004 bathing water season. However, there has been insufficient time to include this data within the project.

FIO Concentrations

To model concentrations in water the FIO inventory must be divided by the volume of water in that stream compartment. This would require characterisation of stream frontage, cross-sectional area and flow rate. These data were not collected during the initial assessment. However, for selected waterways provisional information was established from site maps and photographs collected during the initial catchment surveys. This was used to develop predictions of concentrations. These were then compared to generic values reported in the literature. Concentrations were comparable and within 1 to 2 orders of magnitude of those measured.

2.7.4 Protocols for Application of ARAM

Population with Farm Specific Data

Following farm visits and site observations, the generic ARAM models have been populated with data specific to each pilot farm within the Sandyhills and Saltcoats catchments. For the other main farms that had not been visited, information provided by SEPA was used.

Representation of Catchment

All main farms in the catchment have been included in the catchment models. Although the flow through the watercourses to the catchment has not been parameterised, the river structure has been included to demonstrate how the individual farms fit within the catchment structure. The model predicts the FIO flux, not concentration. This value is directly comparable with the measurements collected by CREH.

Assessment of Risk to Bathing Water

This initial phase of ARAM development has focused on assessing the effect of biogas or composting treatment on reducing the hazard posed by landspreading of manures. Under guidance from the Steering Group, ARAM has been developed as a decision support tool that can be used to test a wide range of farm management scenarios. To meet these requirements within the resources available, the modelling has only assessed the transfer of FIO from land to surface waters. It has not included variable retention or transfer processes within the surface waters, but simply assumed that once FIO are introduced into surface waters they are rapidly transported to the bathing water with no loss or retardation. It has also not been possible to evaluate the contribution that releases via the Southwick Water and Stevenston Burns make to bathing water quality at the designated beaches. A set of assumptions has therefore had to have been made. These are:

- The model assumes that an equal risk rating can be applied to FIO fluxes via the Stanley and Stevenston Burn and the Fairgirth Lane and Southwick Water;
- That there is no microbial die-off in the streams and that all material that enters the streams is rapidly washed through the catchment to the sea;
- That dispersion and dilution in the sea remain constant and are unaffected by freshwater inputs and tidal processes;
- That a reduction in FIO inputs into waters in the catchment leads to a direct and linear decrease in those in the sea;
- There is no further increase in microbial release from river sediment and/or riverbed surface during event conditions;
- That the FIO in bathing water arise only from agricultural livestock sources on the main farms in the area. (It should be noted that in catchments such as this the predominant source of FIO during event conditions is commonly accepted to arise from agricultural sources. A quantitative assessment that compares agricultural and urban inputs has not however been undertaken. If there is a significant non-agricultural event driven source the modelling assessment will over-estimate the effect of manure treatment in improving bathing water quality).

Based on the assumptions given above, the catchment wide FIO reduction factor (as a function of the total agricultural source) achieved through treatment has then been applied to monitored bathing water results. These results have then been compared against the current bathing water standards.

ANNEX 3 - ECONOMIC ASSESSMENT

Catchment Area Development Options

Table A3.1 Anaerobic digester – capital costs

ANAEROBIC DIGESTER ECONOMICS		Individual High Risk Farm	Farm 1	Farm 2	Farm 3	Farm 6	Farm 7	Farm 8	Catchment Total	Community Facility
Annual Slurry (Design Capacity)	tonnes / year	4,900	2,900	3,500	1,000	4,900	440	530	13,270	13,270
Digester Capacity	m^3	480	250	320	80	480	60	60	1,250	1,250
Capital Cost of Digester System	£	£140,000	£110,000	£120,000	£90,000	£140,000	£80,000	£80,000	£620,000	£470,000
Capital Cost of CHP	£	£40,000	n/a	£35,000	n/a	£40,000	n/a	n/a	£75,000	£70,000
Capital Cost of Separator	£	£20,000	£20,000	£20,000	n/a	£20,000	n/a	n/a	£60,000	£20,000
Increased Capital Cost for Energy Crops	£	£30,000	n/a	£30,000	n/a	£30,000	n/a	n/a	£60,000	£30,000
Start-Up Cost	£	£500	£300	£400	£100	£500	£100	£100	£1,500	£2,000
Grid Connection	£	£20,000	£0	£20,000	£0	£20,000	£0	£0	£40,000	£20,000

Table A3.2 Composter – (Capital costs)

FYM per month (t)	Slab	Poly-tunnel	Turner	Product store	Weigh-bridge	Leachate tank	Security Fencing	Tractor	Environ-mental License	Planning Permit	Total
60	£13,500	£5,000	£20,000	-	-	-	-	-	£1,000	-	£39,500
120	£20,250	£10,000	£20,000	-	-	-	-	-	£1,000	-	£51,250
180	£33,750	£15,000	£20,000	-	-	-	-	-	£1,000	-	£69,750
240	£40,500	£20,000	£20,000	-	-	-	-	-	£1,000	-	£81,500
300	£54,000	£25,000	£20,000	-	-	-	-	-	£1,000	-	£100,000
360	£60,750	£30,000	£20,000	-	-	-	-	-	£1,000	-	£111,750
800 (Communal)	£182,000	£40,000	£40,000	£80,000	£10,000	£6,000	£10,000	£30,000	£5,000	£20,000	£423,000

Table A3.3 Zero grazing – operating costs

Annual Cost	Unit	£/year
Additional cost of grass cutting	£ / head	£102.66
Additional veterinary costs	£ / head	£20.00
Additional building repair cost due to zero grazing	£/ha (farm size)	£10.50
Slurry Spreading Costs During summer period	£/tSlurry	£0.15
Additional Manure Spreading Costs for summer period	£/tFYM	£0.72
Cost of Land for composting (on-farm)	£ / facility	£30.00
Cost of Land for composting (community)	£ / facility	£105.00

Table A3.4 Anaerobic Digestion – operating costs

Annual Cost	Unit	Individual High Risk Farm	Farm 1	Farm 2	Farm 3	Farm 6	Farm 7	Farm 8	Catchment Total	Community Facility
Labour Cost of Digester Operation	£ / year	£1,000	£900	£900	£800	£1,000	£800	£800	£5,200	£5,000
Labour Cost of CHP Operation	£ / year	£1,000	n/a	£1,000	n/a	£1,000	n/a	n/a	£2,000	£2,000
Labour Cost of Separator Operation	£ / year	£500	£500	£500	n/a	£500	n/a	n/a	£1,500	£500
Labour Cost of Energy Crop Handling	£ / year	£1,500	n/a	£1,500	n/a	£1,500	n/a	n/a	£3,000	£2,500
O&M Cost of Digester Operation	£ / year	£1,500	£1,500	£1,500	£1,500	£1,500	£1,500	£1,500	£9,000	£6,000
O&M Cost of CHP Operation	£ / year	£3,000	n/a	£2,500	n/a	£3,000	n/a	n/a	£5,500	£6,000
O&M Cost of Separator Operation	£ / year	£500	£500	£500	n/a	£500	n/a	n/a	£1,500	£500
O&M Cost of Energy Crop Handling	£ / year	£1,500	n/a	£1,500	n/a	£1,500	n/a	n/a	£3,000	£2,500
Generator Use of System Charges	£ / year	£268		£192	n/a	£268	n/a	n/a	£460	£857
Business Rates	£ / year	£5,774	0	£5,194	0	£5,774	0	0	£10,969	£14,107
Cost of Land Required for AD Facility	£ / year	£7.50	£7.50	£7.50	£7.50	£7.50	£7.50	£7.50	£45.00	£22.50
Cost of Land for Energy Crops	£ / year	£5,880	n/a	£4,200	n/a	£5,880	n/a	n/a	£10,080	£15,920
Cost of Energy Crop production	£ / year	£17,640	n/a	£12,600	n/a	£17,640	n/a	n/a	£30,240	£47,770

Table A3.5 Aerobic Composting – operating costs

Annual Costs	Unit	Cost
Maintenance Costs	% of Capital Cost	2%
Labour cost of compost	£ per tonne	£1.39
Business Rates (Community Only)	£/yr	£9,289.00
Land for composting (On Farm)	£/yr	£30.00
Land for composting (Community)	£/yr	£105.00

The Benefits of Mitigation Options

Table A3.6 Anaerobic Digestion – unit prices for revenue streams

Income stream	Unit	On-Site Use	Exported
Value of Electricity	p/KWh	£49.32 (retail price exc standing charge)	£40.09 (Wholesale price)
Value of Levy Exempt Certificates	£/MWh	£4.30	£4.30
Value of ROCs	£/MWh	£46.00	£46.00
Consolidator Cut on the value of ROCs and LECs	£/MWh	20%	20%
Power Purchase Agreement (for the export of electricity)	Percentage	n/a	50%
Value of electricity	£/MWh	£89.54	£60.29

Results for the Catchment Area

Table A3.7 Normal Grazing – Treatment (AD and composting only)

	AD Plant (NPV)			Compost (NPV)			Catchment (NPV)		
	Low	Mid	High	Low	Mid	High	Low	Mid	High
Individual High Risk Farm	-£109,000	**-£85,000**	-£73,000	-£88,000	**-£87,000**	-£86,000	-£197,000	**-£172,000**	-£159,000
On-Farm treatment (catchment total)	-£555,000	**-£489,000**	-£457,000	-£590,000	**-£584,000**	-£578,000	-£1,145,000	**-£1,073,000**	-£1,035,000
Community Plant (on-farm)	-£1,004,000	**-£938,000**	-£906,000	-£703,000	**-£696,000**	-£688,000	-£1,707,000	**-£1,634,000**	-£1,594,000
Community Plant (dairy based)	-£781,000	**-£715,000**	-£683,000	-£703,000	**-£696,000**	-£688,000	-£1,484,000	**-£1,411,000**	-£1,371,000

Table A3.8 Normal Grazing - Treatment with CHP and market for compost

	AD Plant (NPV)			Compost (NPV)			Catchment (NPV)		
	Low	Mid	High	Low	Mid	High	Low	Mid	High
Individual High Risk Farm	-£146,000	**-£104,000**	-£77,000	-£71,000	**-£62,000**	-£53,000	-£217,000	**-£166,000**	-£130,000
On-Farm treatment (catchment total)	-£633,000	**-£538,000**	-£480,000	-£493,000	**-£446,000**	-£400,000	-£1,126,000	**-£984,000**	-£880,000
Community Plant (on-farm)	-£947,000	**-£813,000**	-£719,000	-£589,000	**-£531,000**	-£474,000	-£1,536,000	**-£1,344,000**	-£1,193,000
Community Plant (dairy based)	-£745,000	**-£625,000**	-£545,000	-£589,000	**-£531,000**	-£474,000	-£1,334,000	**-£1,156,000**	-£1,019,000

Table A3.9 Normal Grazing - Treatment with CHP, energy crops and market for compost

	AD Plant (NPV)			Compost (NPV)			Catchment (NPV)		
	Low	Mid	High	Low	Mid	High	Low	Mid	High
Individual High Risk Farm	-£185,000	**-£112,000**	-£55,000	-£71,000	**-£62,000**	-£53,000	-£256,000	**-£174,000**	-£108,000
On-Farm treatment (catchment total)	-£737,000	**-£571,000**	-£454,000	-£493,000	**-£446,000**	-£400,000	-£1,230,000	**-£1,017,000**	-£854,000
Community Plant (on-farm)	-£908,000	**-£659,000**	-£460,000	-£584,000	**-£527,000**	-£469,000	-£1,492,000	**-£1,186,000**	-£929,000
Community Plant (dairy based)	-£312,000	**-£104,000**	£55,000	-£584,000	**-£527,000**	-£469,000	-£896,000	**-£631,000**	-£414,000

Table A3.10 Normal Grazing - Treatment with CHP, energy crops, separator and market for compost

	AD Plant (NPV)			Compost (NPV)			Catchment (NPV)		
	Low	Mid	High	Low	Mid	High	Low	Mid	High
Individual High Risk Farm	-£200,000	**-£121,000**	-£57,000	-£71,000	**-£62,000**	-£53,000	-£271,000	**-£183,000**	-£110,000
On-Farm treatment (catchment total)	-£781,000	**-£595,000**	-£455,000	-£493,000	**-£446,000**	-£400,000	-£1,274,000	**-£1,041,000**	-£855,000
Community Plant (on-farm)	-£897,000	**-£631,000**	-£411,000	-£584,000	**-£527,000**	-£469,000	-£1,481,000	**-£1,158,000**	-£880,000
Community Plant (dairy based)	-£301,000	**-£76,000**	£103,000	-£584,000	**-£527,000**	-£469,000	-£885,000	**-£603,000**	-£366,000

Table A3.11 Zero Grazing – Treatment (AD and composting only)

	AD Plant (NPV)			Compost (NPV)			Catchment (NPV)		
	Low	Mid	High	Low	Mid	High	Low	Mid	High
Individual High Risk Farm	-£190,000	**-£123,000**	-£78,000	-£88,000	**-£86,000**	-£83,000	-£278,000	**-£209,000**	-£161,000
On-Farm treatment (catchment total)	-£656,000	**-£472,000**	-£349,000	-£594,000	**-£582,000**	-£570,000	-£1,250,000	**-£1,054,000**	-£919,000
Community Plant (on-farm)	-£1,447,000	**-£1,282,000**	-£1,176,000	-£781,000	**-£766,000**	-£750,000	-£2,228,000	**-£2,048,000**	-£1,926,000
Community Plant (dairy based)	-£1,046,000	**-£880,000**	-£774,000	-£781,000	**-£766,000**	-£750,000	-£1,827,000	**-£1,646,000**	-£1,524,000

Table A3.12 Zero Grazing – Treatment with CHP and market for compost

	AD Plant (NPV)			Compost (NPV)			Catchment (NPV)		
	Low	Mid	High	Low	Mid	High	Low	Mid	High
Individual High Risk Farm	-£178,000	**-£78,000**	-£4,000	-£53,000	**-£36,000**	-£19,000	-£231,000	**-£114,000**	-£23,000
On-Farm treatment (catchment total)	-£652,000	**-£412,000**	-£237,000	-£400,000	**-£306,000**	-£213,000	-£1,052,000	**-£718,000**	-£450,000
Community Plant (on-farm)	-£1,226,000	**-£936,000**	-£718,000	-£551,000	**-£437,000**	-£322,000	-£1,777,000	**-£1,373,000**	-£1,040,000
Community Plant (dairy based)	-£849,000	**-£585,000**	-£393,000	-£551,000	**-£437,000**	-£322,000	-£1,400,000	**-£1,022,000**	-£715,000

Table A3.13 Zero Grazing – Treatment, CHP, energy crops & market for compost

	AD Plant (NPV)			Compost (NPV)			Catchment (NPV)		
	Low	Mid	High	Low	Mid	High	Low	Mid	High
Individual High Risk Farm	-£217,000	**-£60,000**	£66,000	-£53,000	**-£36,000**	-£19,000	-£270,000	**-£96,000**	£47,000
On-Farm treatment (catchment total)	-£745,000	**-£376,000**	-£97,000	-£400,000	**-£306,000**	-£213,000	-£1,145,000	**-£682,000**	-£310,000
Community Plant (on-farm)	-£1,093,000	**-£595,000**	-£188,000	-£546,000	**-£432,000**	-£317,000	-£1,639,000	**-£1,027,000**	-£505,000
Community Plant (dairy based)	-£7,000	**£416,000**	£749,000	-£546,000	**-£432,000**	-£317,000	-£553,000	**-£16,000**	£432,000

Table A3.14 Zero Grazing – - Treatment with CHP, energy crops, separator and market for compost

	AD Plant (NPV)			Compost (NPV)			Catchment (NPV)		
	Low	Mid	High	Low	Mid	High	Low	Mid	High
Individual High Risk Farm	-£220,000	**-£52,000**	£88,000	-£53,000	**-£36,000**	-£19,000	-£273,000	**-£88,000**	£69,000
On-Farm treatment (catchment total)	-£751,000	**-£347,000**	-£26,000	-£400,000	**-£306,000**	-£213,000	-£1,151,000	**-£653,000**	-£239,000
Community Plant (on-farm)	-£1,048,000	**-£520,000**	-£76,000	-£546,000	**-£432,000**	-£317,000	-£1,594,000	**-£952,000**	-£393,000
Community Plant (dairy based)	£38,000	**£491,000**	£861,000	-£546,000	**-£432,000**	-£317,000	-£508,000	**£59,000**	£544,000

Social Costs and Benefits

Table A3.15 Net Present Value with 50% Capital Grant with a 10% discount rate

		Normal Grazing				Zero Grazing			
		Treatment (AD & Composting Only)	Treatment with CHP and a market for compost	Treatment with CHP, energy crops and a market for compost	Treatment with CHP, energy crops, separator and a market for compost	Treatment (AD & Composting Only)	Treatment with CHP and a market for compost	Treatment with CHP, energy crops and a market for compost	Treatment with CHP, energy crops, separator and a market for compost
Individual High Risk Farm	AD Facility	-£14,000	-£4,000	£3,000	£4,000	-£53,000	£22,000	£55,000	£73,000
	Composting Facility		-£27,000	-£27,000	-£27,000		-£1,000	-£1,000	-£1,000
On-Farm treatment (catchment total)	AD Facility	-£178,000	-£170,000	-£173,000	-£167,000	-£162,000	-£43,000	£22,000	£81,000
	Composting Facility		-£213,000	-£213,000	-£213,000		-£74,000	-£74,000	-£74,000
Community Plant (On-Farm)	AD Facility							-£299,000	-£214,000
	Composting Facility								
Community Plant (dairy based)	AD Facility			£192,000	£230,000			£712,000	£797,000
	Composting Facility								

Table A3.16 Net Present Value with 75% Capital Grant with a 10% discount rate

		Normal Grazing				Zero Grazing			
		Treatment (AD & Composting Only)	Treatment with CHP and a market for compost	Treatment with CHP, energy crops and a market for compost	Treatment with CHP, energy crops, separator and a market for compost	Treatment (AD & Composting Only)	Treatment with CHP and a market for compost	Treatment with CHP, energy crops and a market for compost	Treatment with CHP, energy crops, separator and a market for compost
Individual High Risk Farm	AD Facility	£21,000	£46,000	£61,000	£67,000	-£18,000	£72,000	£113,000	£136,000
	Composting Facility		-£10,000	-£10,000	-£10,000		£16,000	£16,000	£16,000
On-Farm treatment (catchment total)	AD Facility	-£23,000	£14,000	£27,000	£47,000	-£6,000	£141,000	£221,000	£295,000
	Composting Facility		-£97,000	-£97,000	-£97,000		£43,000	£43,000	£43,000
Community Plant (On-Farm)	AD Facility							-£151,000	-£61,000
	Composting Facility								
Community Plant (dairy based)	AD Facility			£340,000	£383,000			£860,000	£950,000
	Composting Facility								

Table A3.17 Capital Grant Provision under a 25% Capital Grant

		Normal Grazing				Zero Grazing			
		Treatment (AD & Composting Only)	Treatment with CHP and a market for compost	Treatment with CHP, energy crops and a market for compost	Treatment with CHP, energy crops, separator and a market for compost	Treatment (AD & Composting Only)	Treatment with CHP and a market for compost	Treatment with CHP, energy crops and a market for compost	Treatment with CHP, energy crops, separator and a market for compost
Individual High Risk Farm	AD Facility		£50,000	£58,000	£63,000		£50,000	£58,000	£63,000
	Composting Facility		£17,000	£17,000	£17,000		£17,000	£17,000	£17,000
On-Farm treatment (catchment total)	AD Facility	£155,000	£184,000	£199,000	£214,000	£155,000	£184,000	£199,000	£214,000
	Composting Facility		£116,000	£116,000	£116,000		£116,000	£116,000	£116,000
Community Plant (On-Farm)	AD Facility								£153,000
	Composting Facility								
Community Plant (dairy based)	AD Facility			£148,000	£153,000			£148,000	£153,000
	Composting Facility								

ANNEX 4 – SUSTAINABILITY TABLE

A. ENVIRONMENT, RESOURCES & ENERGY

Overall objective: To minimise the risk of polluting air, land and water. To ensure that natural resources, including energy, are used efficiently, minimising the amount of raw material used and the amount of waste produced. To ensure that renewable energy sources are utilised in preference to fossil fuels.

INDICATORS	+ve IMPACT-ve						COMMENTARY	FUTURE ACTIONS	ECONOMIC CONSIDERATIONS
	n/a	A	B	C	D	E			
1.1 Climate Change and Air Quality									
1.1a Option reduces the risk of polluting emissions to air?			✓				AD reduces methane emissions. As a greenhouse gas, methane is 21 times more damaging than CO_2. The energy benefits of AD (if utilised) can displace fossil fuels that would themselves emit CO_2. Ammonia release is reduced compared with raw manure and compost treatment. Composting releases Nitrous oxide, ammonia and CO_2. Taking a wider perspective, CO_2 emissions will be reduced if mineral fertilisers are displaced and if the application of the treated materials requires low energy.	A complete carbon and carbon equivalent balance would be useful further work. Composting with sufficient turning ensures methane release is kept to a minimum. AD treatment on the sites in question should be investigated once energy and heat production for domestic use is established. This would help to further quantify the greenhouse gas reduction benefits of small scale AD treatment.	Future possibility of methane becoming part of the Emissions Trading Scheme, thereby creating an economic advantage to methane capture and use. Carbon trading and small scale renewable schemes may be able to trade carbon credits again enhancing financial viability.
1.1b Option reduces odour during land spreading?			✓				Odour is better contained and managed. Final products have much less noxious odour		
1.1c Option reduces odour during treatment?					✓		Venting of methane from the AD has led to complaints about odour.	Encourage 100% utilisation of methane or install system for flaring off excess gas	

1.2 Land									
1.2a Option reduces the risk of polluting emissions to land?		✓					FIO through land spreading of compost/digestate material is reduced from previous state of spreading of raw slurry/manure. Weed seeds may be killed during the AD process. This may result in a lower requirement for herbicides.	This research could be linked into ongoing CREH and SEPA research.	Reduced emissions to land may avoid future pollution fines.
1.2b Option requires the minimum land take?			✓				The biogas plant and composting units have minimal land take requirements and may be housed in or near existing farm buildings.		Set aside land (from EU agricultural policy and Single Farm Payment Scheme payment) still qualifies for payment if used for production of energy crops.
1.2c Option makes best use of wastes for agricultural benefit?			✓				Potential and anecdotal improvements in fertiliser value of digestate and compost, which may reduce the use of commercial fertiliser.	This is an emerging theme that merits further investigation and field trials.	Avoided artificial fertiliser production can help reduce national greenhouse gas emissions.
1.2d Option protects and enhances biodiversity?				✓			Especially helpful for aquatic biodiversity, by reducing watercourse pollution. May also contribute to protection of plant communities vulnerable to ammonia deposition.		
1.2e Option devised so as to be sensitive to local conservation issues?			✓				Neutral in terms of terrestrial habitats but assists local aquatic conservation through reducing nutrient load and less stimulation of weed growth; better quality habitats for fish.		
1.3 Water									
1.3a Option reduces the risk of polluting emissions to the aquatic environment?		✓					Risk of nitrate pollution from land spreading of treated material is reduced .		Compliance with GAEC and cross compliance will be improved

1.3b Option devised so as to be sensitive to local conservation issues?			✓				Assists local aquatic conservation through reducing nutrient load and less stimulation of weed growth; better quality habitats for fish.		
1.3c Option reduces the risk of pollution event due to abnormal circumstances such as severe weather?		✓					Main pollution risk arises from runoff to surface watercourse. Control and management of the wastes removes most of this risk.		
1.3d Option complies with EU environmental legislation requirements?		✓					Option assists compliance with EC Bathing Water Directive and assists Nitrates and Groundwater Directives. Water catchment modelling adheres to upcoming Water Framework Directive methodology.	Applicability to NVZ areas (increased slurry storage, better farm management, nitrate availability) should be considered for further investigation.	Potential for benefit to help comply with future and more stringent regulations and avoid infraction fines.
1.3e Option complies with Scottish/UK environmental legislation requirements?		✓					Recycling of slurry and FYM to a farmer's own land in appropriate quantities is excluded from waste legislation.	Community use i.e. bringing the wastes to a central reception area for treatment, would require waste management licence with associated costs and an exemption for application back onto land.	
1.4 Natural resources									
1.4a Option reduces demand for non-renewable materials in (i) construction (ii) operation?		✓ (ii)				✓ **(i)**	Option requires plastic, concrete, steel for construction. Low maintenance for operation.		
1.5 Energy									
1.5a Option uses embedded energy within construction materials?						✓	Embedded energy is present within steel, concrete and plastic.		

1.5b Options are net producers of energy?		✓ (i)			✓(ii)		Biogas (i) is a net producer of energy from methane and makes a sustainable contribution to energy recovery from agriculture. Composting (ii) is a net consumer of energy through transport of waste and operation of turner shredder.		
1.5c Option reduces demand for non-renewable energy in (i) construction (ii) operation?		✓ (ii)				✓ (i)	(i) No specific reduction in demand during construction. (ii) Using biogas energy for borehole pumping/space heating/hot water (e.g. for use in dairies) decreases the need to import non-renewable energy.		
1.5d Option has potential for further exploitation as a renewable energy source		✓					Energy (biogas): important renewable energy source. All farms have the potential to use the energy generated from AD. There are technical issues in connection to Grid (a) some farms have single phase electricity supplies and (b) connecting a number of small renewable energy sources to the Grid can be difficult.	Full utilisation of the gas may require lowering of grid entry financial costs for wider uptake through the Renewable Obligations (ROS) scheme. This should be investigated further, including a review of some more successful continental systems.	AD falls under biomass arm of renewable energy, but so far has not gained recognition within the main wood /energy crop based lobby groups and is missing out on potential funding opportunities to help establish generation.
1.6 Waste									
1.6a Option reduces the amount of waste produced?			✓				The original volume and type of waste produced is dependent on farming practice. The installation of processing plants may result in the adoption of improved waste management practices on the farms. The production of bio fertiliser could for example reduce water wastage on the farms.	Options have the opportunity to recycle wastes into resources.	
1.6b The option increases the amounts of materials recycled and reused?				✓			The options process it into useful and/or less harmful form.		

1.7 National Waste Strategy Scotland									
1.7a Options' compatibility with wider waste management objectives?				✓			Possibility of incorporating FYM and slurry in bigger municipal composting projects could be considered. Scale of such an undertaking would have to be evaluated carefully as may lose the sustainability value of the current project.	Integration of project outcomes into wider strategic policy goals eg National Waste Strategy is beyond scope of this project. Good research opportunity.	
SUSTAINABILITY SCORE FOR THIS THEME									

A	B	C	D	E
9	7	3	2	3

B. ECONOMY, ENTERPRISE & LIFETIME LEARNING

Overall Objective: To maintain and encourage a diverse and thriving economy, especially at local level. To encourage enterprise, innovation and business development. To encourage and contribute to a varied skillbase in the community

		+ve IMPACT-ve							
INDICATORS	**n/a**	**A**	**B**	**C**	**D**	**E**	**COMMENTARY**	**FUTURE ACTIONS**	**ECONOMIC CONSIDERATIONS**
2.1 Enterprise									
2.1a Option is new or emerging and can be delivered?			✓ ✓				*Biogas* is an emerging technology in Britain. *Composting* is new at farm and community scale.	Continue development of these technologies.	More investigation is required into making the technologies more affordable at small scale.
2.1b Option can lead to other potential avenues of research			✓				The biogas and compost plants are not operating at full capacity all year round due to livestock summer grazing, Has been much interest in using plants for research, e.g. on fuel cells.	There is the potential to utilise energy crops grown on the farm to supplement the digester during low capacity periods.	
2.2 Economy									
2.2a Option can attract finance?					✓		*Biogas* *Composting*	The ability to attract funding will depend on commercial attractiveness. Possibility for ROC sales to provide major financial attraction. This area could be further explored.	
2.2b Option maximises the opportunities for funding sources?				✓			Possibly R & D funding through SEERAD/EU funds.	Check opportunities for funding of a rollout within, for example, direct grant, CAP funding, EU Structural Funds, CCL, etc.	Many aspects to the work, from bathing waters, nutrients, renewable energy and income, offer farming and the local economy multiple avenues for economic interest.

2.2c Option maximises its economic value?			✓				Compost is a resource; biogas produces energy; digestate from slurry has a soil structure and fertiliser value. Economic assessment has evaluated this. Plant design is robust. As technology develops it will lead to lower CAPEX for both biogas and composting, especially for on farm solution.	Potential commercial aspects involved in community or centralised composting /AD systems should be investigated. These are already emerging with the compost side of the project.	
2.2d Option has 'reasonable' cost?			✓			✓	Scheme start up costs are high at all scales Flexibility to take other biomass inputs. Flexibility allows potential compliance with future environmental legislation and controls.	Needs sustainable modular design/flexibility to adjust capacity and process.	As technology develops, unit costs may be reduced.
2.2e Option reduces the need for and cost of remedial measures? e.g. beach signage				✓			Achieves this with respect to Nitrates, Groundwater and Bathing Water Directives. Some beach signage already in place but recognised as being a management option rather than remediation.	Prioritise catchments where these technologies would provide further real benefit.	
2.2f Option reduces the risk of legal action? (i) composting (ii) AD		**(i)** ✓	(ii) ✓				Helps compliance with Bathing Water Directive . Helps reduce possibility of infraction proceedings and fines.	Option needs to be applied across catchments. Need to prioritise the catchments to ensure the biggest contributors are targeted first.	Sustainable energy production for agriculture, reduced artificial fertiliser demand and better application rates of material will help enhance sustainable agriculture in line with EU policy.
2.2g Option increases the economic benefits to local business and the community?		✓					Amenity value is significant; also for tourism as clean beaches are a key part of tourism marketing		
2.3 Lifetime Learning									
2.3a Option leaves potential benefit for future learning			✓						
SUSTAINABILITY SCORE FOR THIS THEME		A 2	B 7	C 2	D 1	E 1			

C. PUBLIC HEALTH

Overall objective: To maximise the opportunities to promote a healthy and safe living and working environment

INDICATORS	+ve IMPACT-ve						COMMENTARY	FUTURE ACTIONS	ECONOMIC ACTIONS
	n/a	A	B	C	D	E			
3.1 Public Health									
3.1a Option protects and enhances human public health		✓					The research indic ates significant reduction of faecal coliform, *E. coli* and other bacteriological contaminants in designated Bathing Waters. Also reduces FIO in surface waters, with concurrent benefits.	Further detailed assessment of economic benefits of health impacts.	Infraction proceedings by EC are a risk but not quantifiable as yet. The Bathing Water Directive is most likely to become more stringent in future thus increasing infraction risk.
3.2 Animal Health									
3.2a Option protects and enhances animal health at present?				✓			The project enhances animal health in that land spreading of digestate may result in lower FIO loading during grazing season.	Review bio security implications for community/centralised based compost/AD plant.	
3.2b Option will protect animal health in the future?				✓			Need to ensure that bio security procedures and codes of practice at facilities are strictly adhered to.		
3.3 Health and Safety									
3.3a Option promotes good Health and Safety practice and reduces the risk to operators & adjacent workplace?		✓					Positive reduction in risk of infection but production of biogas has inherent natural (manageable) risk attached. Project delivered operational manuals to farmers which include H&S advice		
SUSTAINABILITY SCORE FOR THIS THEME		A: 2	B: 0	C: 2	D: 0	E: 0			

D. TRANSPORT & TRAVEL

INDICATORS	+ve IMPACT-ve						COMMENTARY	FUTURE ACTIONS
	n/a	A	B	C	D	E		
4.1 Transport								
4.1a Option minimizes, where practicable, the use of transport at (i) farm scale and (ii) at the community option?				✓ (i)	✓ (ii)		This covers transport of materials to plant including joint farm systems, and transport of products. If the community option is invested in using a small local pipeline network, the impact would be 'C'.	
4.2 Travel								
4.2a Option causes change in volume of employee commuting traffic?				✓			No change in employment levels anticipated. Number of vehicles involved would be minimal.	
SUSTAINABILITY SCORE FOR THIS THEME		**A**	**B**	**C**	**D**	**E**		
		0	**0**	**2**	**1**	**0**		

E. RURAL DEVELOPMENT AND FARMING

Overall objective: To promote community development in rural areas, improve employment prospects and contribute to improved infrastructure. To promote and support viable farming practice

INDICATORS	+ve IMPACT-ve						COMMENTARY	FUTURE ACTIONS	ECONOMIC CONSIDERATIONS
	n/a	A	B	C	D	E			
5.1 Rural Development									
5.1a Option contributes to the development of a diverse rural economy?			✓				The option does give diversity and opens up the option of larger scale community plants. There may be local work in installing and maintaining plant, but farmers are looking to cut costs and external labour.	Carry out economic analysis at community/ centralised scale rather than farm scale. Potential for wider product and business options.	The energy industry has recognised that future energy markets will see a diversion from large centralised generation to more remote localised sustainable generation sources. There is at present much research ongoing in relation to small scale distributed generation.
5.1b Option provides a broad base of employment?					✓		Scale too small to make major difference		
5.1c Option provides employment opportunities for different skill base?				✓			Composting and AD on small farm scale require some new skills but opportunities may be limited to own farm plant operation	Community or larger scale AD or compost facilities may lead to new jobs in local area.	
5.1d Option contributes to the provision of a new or improved infrastructure in rural or remote areas?			✓				Considered to be 'yes' because it can be installed to serve a group of farms. By installing such systems, it helps remove the possibility of more drastic measures such as going out of dairying altogether	The potential to produce distributed in- house energy generation from AD among the farming community should be further investigated.	The energy industry has recognised that future energy markets will see a diversion from large centralised generation to more remote localised sustainable generation sources. There is at present much research ongoing in relation to small scale distributed generation.
5.2 Communities and Social Values									
5.2aOption promotes relationships / opportunities with agricultural and other tenants, licensees and local communities?				✓			This may vary depending on area		

5.2b Option affects delivery of and access to services in rural and remote areas?				✓			If installation leads to farming activity being able to continue as before, then critical mass of population can be maintained	Further economic analysis necessary	
5.2c Option addresses the particular needs of those living in rural or remote communities?			✓				Assists in managing a serious agricultural nutrient issue and reduces demand for non-renewable energy.		
5.3 Farming Practice									
5.3a Option promotes a positive change in farm practices?			✓				Yes, in that it is a way of averting a major change in farming practice. Increased awareness of FYM and slurries may improve farm nutrient management.	Need for improved nutrient management practices in line with EC Water Framework Directive and other regulations should be investigated as may act as strong drivers for such systems.	
5.3b Product is of sufficient quality to provide for agricultural needs and aspirations?		✓					Innovative application of existing technology		
SUSTAINABILITY SCORE FOR THIS THEME		**A**	**B**	**C**	**D**	**E**			
		1	**4**	**3**	**1**	**0**			

ANNEX 5 – FUTURE MONITORING SCHEDULE

Table A5.1 Future Monitoring Schedule – Anaerobic Digestion

Anaerobic Digester	Time of Study and Duration	Determinants			Frequency of data recording
		Slurry, digestate and stored slurry	**Biogas Plant**	**Farm**	
• 1 Beef cattle farm • 1 Dairy farm	Beef farm – this assumes that the plant is non-operational during the summer. One study only would be conducted. This would start during the initial plant fire-up in the autumn when cattle are returned to the steading and continue until the plant has reached fully running status: • Duration of study – 3 months • Estimated time of study Oct/Nov to Jan/Feb Dairy farm – assumes that the plant is maintained operational through the year. Two studies would be conducted: Summer Performance • Duration of study – 3 months • Estimated time of study Jun/Jul to Sep/Oct Winter Performance • Duration of study – 3 months • Estimated time of study Oct/Nov to Jan/Feb	• Age of material • Temperature • FIO levels • Nutrient Concentration and availability • Percentage Solids	• Digester Temperature • Ambient temperature • Gross Biogas Production • Biogas Use by Digester • Net Biogas Production • Energy utilisation by farm • Digester pump rates and digestate residence time	• Slurry production rate • Rainwater ingress to slurry system • Diary washing water addition to slurry system • Cattle diet • Numbers and ages of cattle • Time and volume of slurry application to land • Time per day that cattle are on steading	• Weekly
Benefits: The study would provide a detailed comparison between performance based on dairy and beef slurry and plant performance under digester start up conditions, partial utilisation and full utilisation. Results would be closely linked to environmental and farm site variables. The high resolution of sampling would allow the results to be presented as a 'time-line' where the progress of a particular mass of slurry from the animal house through the digester and ultimately to the field can be tracked. Variations due to changes in the feedstock or other factors can then be identified.					

Table A5.2 Future Monitoring Schedule – Composting

Anaerobic Digester	Time of Study and Duration	Determinants			Frequency of data recording
		FYM, composting material and stockpiled compost	Composting Process	Farm	
• 1 Beef cattle farm • 1 beef cattle and sheep farm	Concurrent studies would be conducted on 2 farms. It is assumed that FYM production will be limited to autumn/spring periods and that no composting will be conducted during the summer. As sheep tend to be housed on the steading during the spring the study will be timed to coincide with this period. • Duration of study – 3 months • Estimated time of study Jan/Feb to April/May	• Age of material • Temperature • FIO levels • Nutrient Concentration and availability • Moisture content • Texture • Odour • Visual appearance • Position in windrow • PAS100 compliance (final product only)	• FYM/compost temperature • Ambient temperature • Frequency of compost turning • Distance of compost travel along the windrow each time the compost is turned • Additional materials added to FYM feedstock	• Rainwater contact with FYM/compost • Volumes of straw used in bedding per animal • Cattle/sheep diet • Numbers and ages of cattle/sheep housed • Time and volume of compost application to land • Time per day that cattle/sheep are on steading	• Weekly • Separate samples from windrow surface and centre will be collected from both ends and the middle of the windrow. All samples will be assessed separately

Benefits: The study would provide a detailed assessment of composting performance and how this varies depending upon the type and characteristics of the FYM feedstock and how the composting processes is managed. As with the recommended future monitoring programme for AD treatment the high resolution of sampling would allow the results to be presented as a 'time-line' where the progress of a particular mass of FYM from the animal house to and along the windrow to the stockpile and ultimately to the field can be tracked. Variations due to changes in the feedstock or other factors can then be identified. The study would allow greater interaction with the farmers operating the compost plants, best practice for compost management can be identified and the results can be used to clearly indicate to the farmers that good management of the process provides a better end product.