How effective are farmland interventions for reducing Faecal Indicator Organisms (FIOs) in bathing and shellfish waters (especially Escherichia Coli and Intestinal Enterococci) coming from river catchments? A Quick Scoping Review

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Executive summary

Background

Faecal contamination of surface waters is an important water quality concern with human health implications. Many UK bathing waters comply with the mandatory standards defined by the EU Bathing Water Directive (76/160/EEC). Tighter regulations and investments into sewerage treatment works has meant that pollution from sewage and industrial effluents has fallen, meaning that the contribution from agriculture has become proportionately more significant. The revised Bathing Water Directive (2006/7/EC) that will come into force in 2015 brings more stringent water quality standards. Compliance with the new microbiological standards will, in many cases, require the reduction of diffuse sources of faecal indicator organism (FIO) contamination, in particular those deriving from agricultural land.

QSA process

The objective of this quick scoping review was to collate and summarise the type of research evidence available in response to the primary question 'How effective are farmland interventions for reducing Faecal Indicator Organisms (FIOs) (especially Escherichia Coli and Intestinal Enterococci) coming from river catchments, in bathing and shellfish waters'. Further, to produce a summary of the findings pertaining to the question.

Key findings

The most commonly studied interventions identified were those investigating the effectiveness of constructed wetland, slurry/manure and livestock management, and vegetative strips. Although no evaluation of research was carried out, the interventions identified in the QSR were generally reported as being at least partially effective at reducing FIO contamination in rivers.

This QSR did not find studies that linked farmland interventions with direct reduction in FIOs in bathing or shellfish waters. However the interventions identified implied that the reductions in FIO that can demonstrably be achieved at field level would reduce the FIO content of river catchments and ultimately in bathing and shell fish waters.

For FIO reduction to meet future Bathing Water standards, reductions across catchments will be necessary. The QSR indicates need for special consideration of the effects of storm events on the rapid mobilisation and transport of FIOs leading to peaks in occurrence.

Many of the interventions identified by the QSR are 'on farm' practices that are currently being promoted as part of 'agri-environment schemes' and/or represent good agricultural practice. Other interventions can be applied at a larger landscape scale.

Implications for policy and for further research

There may be scope to further promote and improve the targeting of existing interventions with the added objective/additional focus on reducing FIO contamination of receiving waters and especially bathing and shellfish waters – many of the interventions identified in the QSR are currently used to achieve WFD environmental objectives which exclude consideration of micro-biological contaminants or standards.

The QSR found evidence of a major UK study that aims to develop the capability of modelling the transport of FIOs through a catchment to bathing and shellfish waters.

Another useful scientific development is the improvement of techniques in microbial pollution tracking with the capability to trace contamination back to individual sources within a catchment.

Hence whilst no studies were found that explicitly linked diffuse sources of FIOs to bathing and shellfish waters, emerging techniques and new developments in catchment modelling may soon improve our understanding. Further research into interventions and modelling needs to be at catchment scale to include both landscape scale and multiple on-farm interventions. Further research into the effectiveness of existing and possible future amended agri-environment schemes and education to change attitudes and behaviour should also be considered.

Background

Faecal contamination of surface waters is an important water quality concern with human health implications. Adverse health outcomes include gastrointestinal illness, infections of the eye, ear, nose and throat, skin complaints and respiratory disease (Mugglestone *et al*., 2000).

Considerable investment in pollution reduction has meant that many UK bathing waters comply with the mandatory standards defined by the EU Bathing Water Directive (76/160/EEC). As pollution from sewage and industrial effluents has fallen, the contribution from agriculture has become proportionately more significant. The revised Bathing Water Directive (2006/7/EC) that will come into force in 2015 brings more stringent water quality standards. Compliance with the microbiological standards will require the reduction of diffuse sources of faecal indicator organism (FIO) contamination, in particular those deriving from agricultural land.

Currently FIOs are defined by international legislation as escherichia coli and intestinal enterococci. On-farm FIO sources include grazing livestock, spreading organic resources, farmyard runoff and septic tanks. Microbial Source Tracking (MST) is tool which can be used to identify FIO sources by using anaerobic bacteria as FIO surrogates. Genetic markers within these bacteroidetes indicate the type of animal gut that produced them and can distinguish FIOs as emanating from human, ruminant or other sources (Environment Agency, 2010).

Guidance to farmers on how to reduce diffuse pollution takes the form of best management practice guides such as 'Best farming practices' (Environment Agency, 2008). These interventions include soil, water and nutrient management. In addition, separate agri-environment schemes run by England, Scotland and Wales provide financial support for farmers to adopt good environmental practice.

This Quick Scoping Review was designed to identify, collate and summarise relevant literature regarding the effectiveness of different types of on-farm interventions at reducing levels of FIOs in bathing and shellfish waters.

Objective of the Review

The objective of this quick scoping review was to collate and summarise the scale and scope of research evidence available in response to the primary question. This summary of research and knowledge can be used to start to answer the questions posed, and to inform requirements for future evidence synthesis, and primary research.

Primary question

This study aimed to find and collate research that addressed the following question: How effective are farmland interventions for reducing Faecal Indicator Organisms (FIOs) (especially Escherichia Coli and Intestinal Enterococci) coming from river catchments, in bathing and shellfish waters?

PICO elements

In order to better understand the question it was broken down into constituent parts. This QSR was guided by the PICO approach (population, intervention, comparator and outcome). The elements relating to this QSR are shown in Table 1.

Table 1. PICO elements relating to the question 'How effective are farmland interventions for reducing Faecal Indicator Organisms (FIOs) (especially Escherichia Coli and Intestinal Enterococci) coming from river catchments, in bathing and shellfish waters?'

PICO element and definition	How effective are farmland interventions for reducing Faecal Indicator Organisms (FIOs) (especially Escherichia Coli and Intestinal Enterococci) coming from river catchments, in bathing and shellfish waters?
Population - the subject to which the intervention is applied	River catchments, bathing waters and shellfish waters
Intervention - the policy or related intervention/exposure such as management regime	Farmland interventions
Comparator - control example of no intervention or alternative	Non intervention
Outcome	Reduction of FIOs in bathing water and shellfish water

Method

The method used in the development of this QSR was based on the four stages of QSR described by draft Defra guidance for the production of quick scoping reviews and rapid evidence assessments (Miller *et al* 2013). The four stages are: Searching for evidence (Develop and test a search strategy, identify key words and points of reference, identify relevant information sources, apply research strategy); Refining and storing evidence; Knowledge mapping (Develop a conceptual framework to include policy drivers and primary question; and Communicate findings

Search strategy

An initial scoping search was performed to validate the methodology. Search terms (suggested by funders and subject experts) were tested for specificity and sensitivity using the online database Web of Knowledge and used to indicate the volume of relevant literature.

A structured search was undertaken using on-line information sources to capture a sample of electronic literature. The search strategy was developed to identify both published and grey literature.

Keywords

Applicable keywords were faecal indicator organisms (FIOs), escherichia coli, intestinal enterococci, faecal coliform, farm, agriculture, livestock, rural diffuse pollution, river, catchment, bathing water, shellfish water, management, intervention, Wales and England

A wildcard (*) was used where accepted by a database/search engine to pick up multiple word endings. For example pollut* picks up pollutant, pollution. A keyword was made more restrictive by the addition of a qualifier e.g. (agricultur* AND bathing water*), (agricultur* AND pollut*). The combination of qualifiers and keywords were determined by the results of the scoping search. The exact keyword and qualifier combinations used are listed in Appendix 1.

Search sources

The following online sources were searched to identify relevant literature:

Electronic database

- ISI Web of Knowledge

The results of each search term on each database were imported into a separate EndNote Web 3.5 file. Using the automatic function in the EndNote Web 3.5 software any duplicates were removed.

Organisational websites

- DEFRA (http://www.defra.gov.uk/)
- Environment Agency (http://www.environment-agency.gov.uk/)
- NERC Open Research Archive (http://nora.nerc.ac.uk/)

The organisational website searches were restricted to two search terms '*faecal indicator organism'* and '*faecal coliform'* due to time restrictions and expected relevance of results.

Web searches

- Google search engine (http://www.google.co.uk). The first 50 hits from each data source were examined for appropriate data.

Study inclusion criteria

Relevant subjects: Studies that investigated some aspect of water quality improvement by one of the on farm mitigation measures were considered for inclusion, irrespective of scale.

Geographic area: Stakeholders agreed that the study should focus on European temperate countries. Those countries were: UK, Ireland, France, Belgium, Switzerland, Germany, Holland, Luxembourg, Liechtenstein, Denmark, Sweden, Norway, Finland, Austria, Slovakia, Poland, Hungary, Czech Republic, Romania, Lithuania, Latvia, Estonia, Belarus. However some countries (such as USA and New Zealand) were later included as they offered relevant research.

Language: Studies published in English.

Date: No date restrictions were applied.

Types of intervention (mitigation measure): Any on-farm interventions that aim to improve water quality were included.

Article Screening

The inclusion criteria were applied to all potential articles at the title and abstract level. Studies that passed the inclusion criteria were imported into spreadsheets and categorised according to the type of intervention applied. For the purpose of this QSA some modelling studies and non-specific intervention studies were included, where it was considered that they may either a) contain some primary research, or b) offer other background research information that may be useful for informing decisionmaking.

Results

The total search hits and subsequent relevant results are shown in Figure 1.

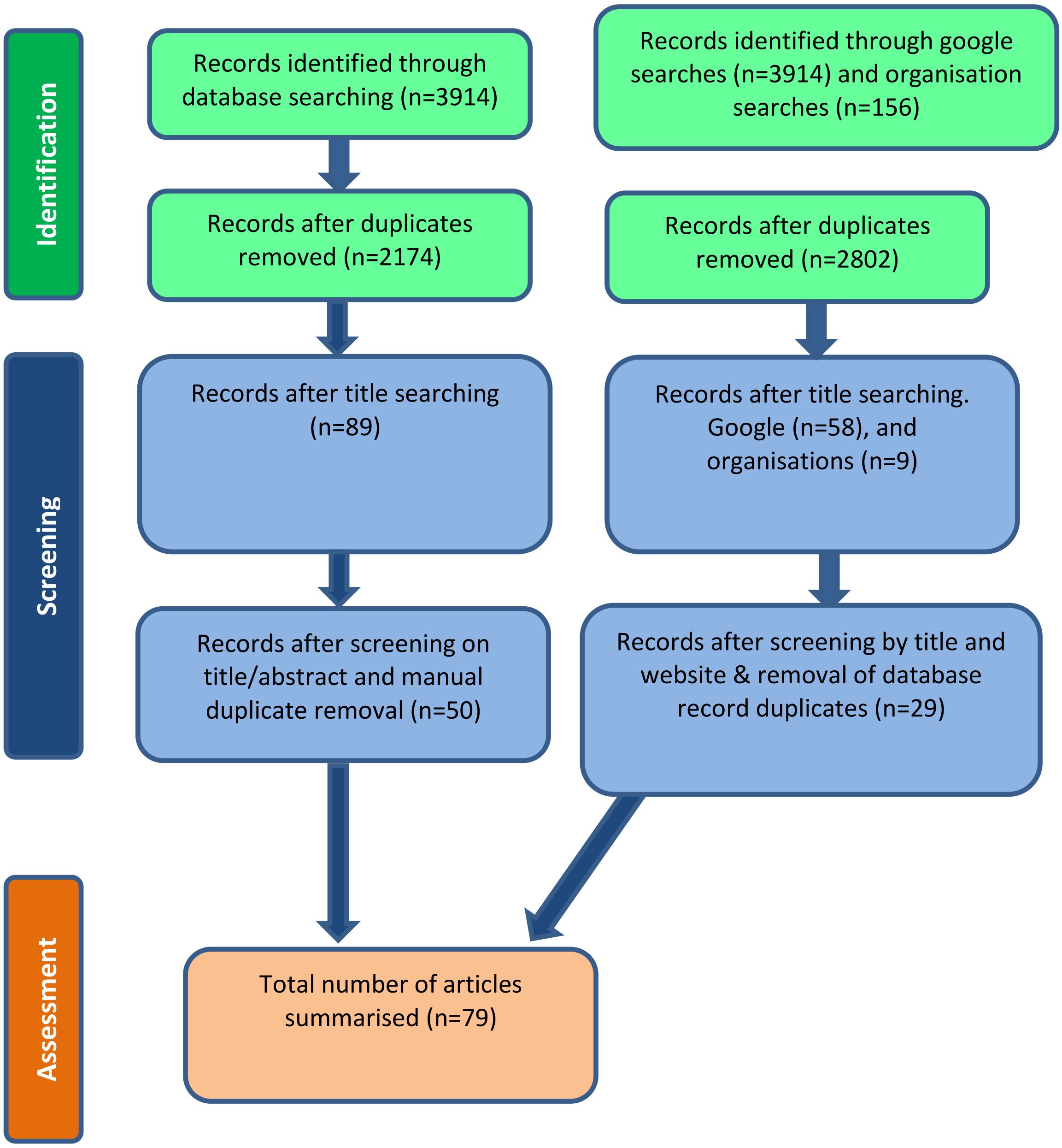

Figure 1. Map of the research collation and screening process.

The searches and screening were carried out in two stages: the Web of Knowledge (WoK) searches, and the google/organisation searches. Only primary research studies were collated from the WoK searches, and initial screening excluded all countries that were not included in the original inclusion criteria. However, at the later screening stages (during abstract reading), it became clear that studies from some other countries (notably the USA and New Zealand) offered potentially useful research information, and so were included from this point. As a result 18 studies were included in the final 50 database studies that would otherwise have been excluded. This represents over a third of the final 50 studies, but is likely to be an under-representation of relevant research outside of the original geographical inclusion limits (Table 2).

Table 2 – Country of study for final 50 included articles from Web of Knowledge. Note studies in countries outside of Europe will be under-represented as many were excluded in the early stages of screening.

Country	No of Reports
Not stated	20
USA	16
UK	6
Germany	2
Australia	1
Canada	1
Finland	1
Ireland	1
New Zealand	1
Sweden & Scotland	1

The geographical exclusion limits were not applied in the google searches, but a UK bias was still found (45 of the 58 most relevant links/findings were from the UK). This may be as a result of the search engine set up, and of English (as opposed to American-English) spelling of some search terms.

Most of the studies included from the WoK searches were identified as field scale research and so indicate an implied, rather than direct link between on-farm mitigations for FIOs, and the reduction of FIOs in bathing waters. (Table 3).

Table 3 – Research scale types based on 50 study abstracts (results from organisation and Google searches are not included)

Scale	No of Reports
Field	15
Farm	6
Catchment	5
NA	24
Total	**50**

The Google searches produced a range of document types. Following screening of title, 58 links of potential relevance to the topic area were saved into a spreadsheet. 38 were research papers or appeared to lead to primary research reports of some sort, and a further 12 were guidance documents covering things such as best practice. There was not sufficient time to read all weblinks produced by the Google search, instead the type was categorised by 'best fit'. 29 articles from the Google and organisational searches were included in the final summary table (Appendix 2).

Reference Type

79 studies were considered either directly relevant to the research question, or to likely include important information to inform decisions related to the research question. These are summarised in Appendix 2. The majority were journal articles (n=56), followed by conference or symposium proceedings (n=14). The other types of outputs are shown in Table 4

Table 4 Type of articles included in the final QSR summary.

Type	**No**
Peer reviewed journal paper	56
Conference or Symposium proceedings (may be published in a book)	14
Report	5
Information sheet	3
Thesis	1
Total	**79**

Interventions investigated

Thirteen types of farmland intervention were identified from the research articles (Figure 2).

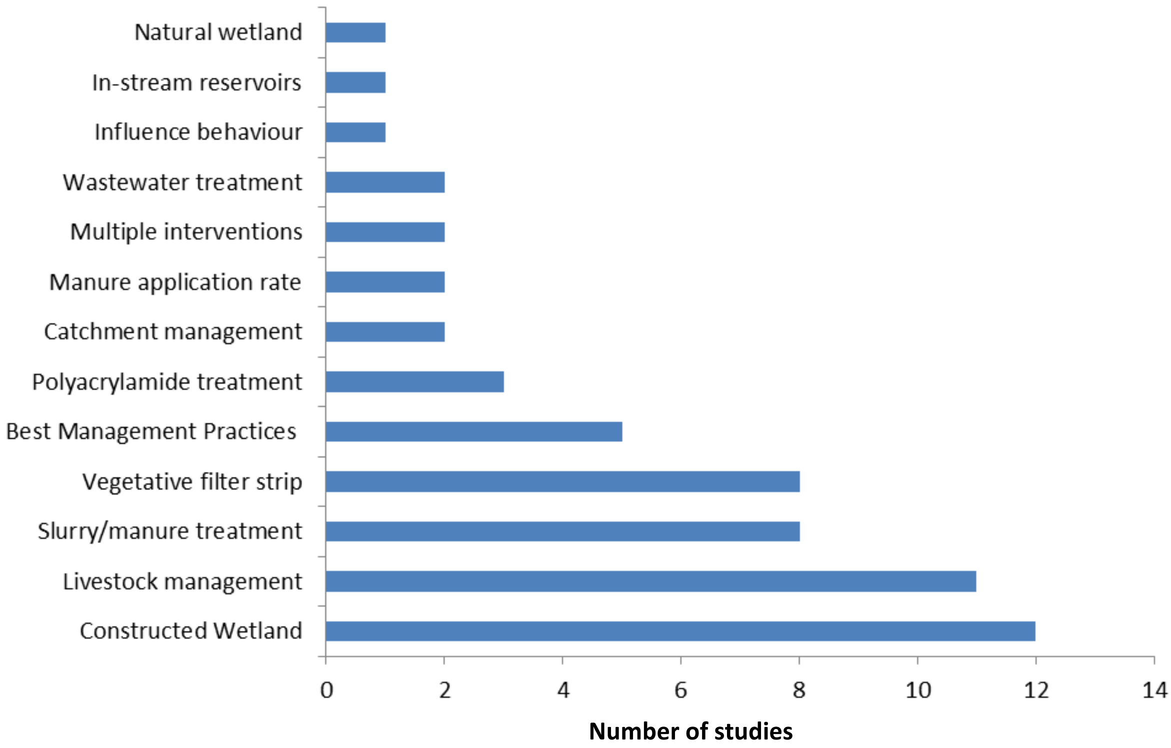

Figure 2. Number of times individual interventions were reported (1 per research article)

Over half of the studies were in the areas of constructed wetland, slurry/manure treatment and vegetative filter strip research or were connected with livestock management. Some studies indicated that relatively small constructed wetland can be effective for treating runoff from large agricultural areas (e.g. Diaz, 2010). Vegetative strip studies showed a mixture of results, being effective at trapping soil particles but not necessary as effective at reducing faecal coliforms (e.g. Coyne, 1995). Good management practice such as removing livestock access to streams can reduce FIO load in watercourses (e.g. McGechan, 2008). The study by Harmel (2010) is interesting as it implies that grazing may produce higher concentrations of *E. Coli* run-off than cultivated sites, and was supported by ADAS (2011) in a report confirming that FIO losses were estimated to be greatest from grazed livestock fields.

In addition to studies that investigated specific interventions, a number of modelling studies (n=7), risk assessment studies (n=2) and other non-intervention studies (n=11) were included in the final table of research (Appendix 2), as was a systematic review study. The additional studies either offered further background/research information relevant to the topic areas (although not directly answering the QSA question), or had the potential to contain further primary research of interest.

Conclusions

Key findings

The most commonly studied interventions identified were those investigating the effectiveness of constructed wetland, slurry/manure and livestock management, and vegetative strips. Although no evaluation of research was carried out, the interventions identified in the QSR were generally reported as being at least partially effective at reducing FIO contamination in rivers.

For FIO reduction to meet future Bathing Water standards, reductions across catchments will be necessary.

Many of the interventions identified by the QSR are 'on farm' practices that are currently being promoted as part of 'agri-environment schemes' and/or represent good agricultural practice. Other interventions can be applied at a larger landscape scale.

This QSR did not find studies that linked farmland interventions with direct reduction in FIOs in bathing or shellfish waters. Instead the interventions identified implied that the reductions in FIOs at field level have the potential to reduce the FIO content of river catchments and ultimately in bathing and shell fish waters. This can be shown to be partly due to the latency of streams and rivers to hold FIOs and release them during increased flow events. Storm events also increases run off from farmland and farm yards (Edward, 2008) increasing FIO loads in river catchments. Nnane *et al*. (2012) identified that following storm events, river FIO increases were mainly of agricultural origin. This indicates a need for special consideration of the effects of storm events on the rapid mobilisation and transport of FIOs leading to peaks in occurrence.

Many of the on-farm interventions identified by this QSR can be considered as good management practices and as such should be seen as complimenting each other as suggested by Mostaghimi *et al.* (1999). Some interventions may provide multiple benefits. For example, riparian vegetative strips both exclude livestock from water systems and trap FIOs and other pollutants, preventing in stream contamination (Kay *et al.*, 2005).

Implications for policy and practice

Catchment-wide interventions are likely to be necessary to reduce FIOs entering water courses and thereby bathing and shellfish waters. Interventions and schemes already exist that have the potential to be re focussed to ensure that pollution from FIOs is better addressed alongside other contaminants. Whilst the WFD excludes explicit consideration of FIOs, many of the measures designed to reduce other contaminants already help to reduce the mobilisation of FIOs. There may, therefore, be scope to further promote and improve the targeting of existing interventions that promise multiple benefits, with the added objective/additional focus on reducing FIO contamination of receiving waters and especially bathing and shellfish waters.

Another useful scientific development that may help inform future decisions is the improvement of techniques in microbial pollution tracking with the capability to trace contamination back to individual sources within a catchment (Stuart Kirk, Environment Agency Pers. Comm.)

Implications for research

As studies were predominately field-scale, further research would be enhanced by more catchment scale investigations, together with modelling studies. This may include the effectiveness of catchment scale projects such as constructed wetlands, but also consideration of the combined effects of on-farm interventions. Further research into the effectiveness of strategies such as funding (e.g. agri-environment schemes) and education to change attitudes and behaviour may be useful. Only one such study was identified in this work, but behavioural studies were not specifically searched for. It is recommended that future reviews include non European studies especially those from the USA.

New developments in catchment modelling and microbial source tracking have the capacity to improve our understanding to help meet the new regulatory challenge associated with FIOs in bathing and shellfish waters. For example, one major UK study currently underway, 'Cloud to Coast', aims to develop the capability to model the transport of FIOs through a catchment to bathing and shellfish waters. (Saul *et al*, 2011)

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References

ADAS, 2011. *Faecal Indicator Organism Losses from Farming Systems: FIO-FARM: Evidence Project Final Report - WQ0111*. Mansfield: ADAS Gleadthorpe.

Blackstock, K.L., Ingram, J., Burton, R., Brown, K.M. and Slee, B. 2010. Understanding and influencing behaviour change by farmers to improve water quality. *Science of the Total Environment.* 408(23) p.5631-5638.

Coyne, M. S. 1995. Soil and fecal-colliform trapping by grass filter strips during simulated rain. *Journal of Soil and Water Conservation*. 50(4) p. 405-408.

Diaz, F. J. 2010. Efficacy of constructed wetlands for removal of bacterial contamination from agricultural return flows. *Agricultural Water Management*. 97(11) p.1813-1821.

Edward, A.C. 2008. Farmyards, an overlooked source for highly contaminated runoff. *Journal of Environmental Management.* 87(4) p.551-559.

Environment Agency. 2008. *Best farming practices*. Bristol: Environment Agency.

Environment Agency. 2010. *Microbial source tracking (MST) – survey design and data interpretation*: Operational instruction 985_10. Bristol: Environment Agency

Harmel, R. D. 2010. Effects of agricultural management, land use and watershed scale on E-Coli concentrations in runoff and streamflow. *Transactions of the Asabe.* 53(6) p.1833-1841.

Kay, D., Wilkinson, J., Crowther, J., Reid, S., Francis, C., Kay, C., Hopkins, M., Watkins, J., Edwards, T. McDonald, A., Wyer, M. and Stapleton, C. 2005. *Monitoring the effectiveness of field and steading measures to reduce diffuse pollution from agriculture to bathing waters in the Ettrick, Cessnock, Nairn and Sandyhills catchments.* Aberystwyth: Centre for Research into Environment and Health.

McGechan, M. B. 2008. A river water pollution model for assessment of best management practices for livestock farming. *Biosystems Engineering.* 99(2) p.292-303.

Miler, J. 2012. *Guidance document for the production of quick scoping reviews and rapid evidence assessments (Beta Version 8).* DEFRA.

Mostaghimi, S., Cook, M.N. and McClellan, P.W. (1999). Long term impact of best management practices on bacteriological quality of runoff water. In: Singh, V.P., Seo, W.I. and Sonu, J.H. *eds. Environmental Modeling*. Highlands Ranch, Colorado: Water Resource Publications.

Mugglestone, MA., Stutt, E.D. and Rushton, L. 2000. *A review of the health effects of sea bathing water*. Leicester: Institute for Environment and Health.

Nnane, D.E., Ebdon, J.E. and Taylor, H.D. 2012. The dynamics of faecal indicator organisms in a temperate river during storm conditions. *Journal of Water and Climate Change*. 3(2) p. 139-150.

Saul, A., Lerner, D., Kay, D., Falconer, R., Shepherd, W., Phillips, A., Stapleton, C., and Guanghai, G. (2011) *Cloud to Coast* [poster]. University of Sheffield. Available from: http://www.shef.ac.uk/polopoly_fs/1.138417!/file/C2C_Poster.pdf