Journal of Environmental Management 161 (2015) 163–172

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Research article

Integrated cost-effectiveness analysis of agri-environmental measures for water quality

Bedru B. Balana [a, *, 1], Leah Jackson-Blake [b], Julia Martin-Ortega [b], Sarah Dunn [b]

[a] International Water Management Institute (IWMI), West Africa Office, PMB CT112, Cantonments, Accra, Ghana
[b] The James Hutton Institute, Criagiebuckler, AB15 8QH Aberdeen, UK

ARTICLE INFO

Article history:
Received 27 November 2014
Received in revised form
16 May 2015
Accepted 19 June 2015
Available online xxx

Keywords:
Cost-effectiveness
Integrated approach
Mitigation measures
Water quality
Dee catchment
Nitrate
Phosphorus

ABSTRACT

This paper presents an application of integrated methodological approach for identifying cost-effective combinations of agri-environmental measures to achieve water quality targets. The methodological approach involves linking hydro-chemical modelling with economic costs of mitigation measures. The utility of the approach was explored for the River Dee catchment in North East Scotland, examining the cost-effectiveness of mitigation measures for nitrogen (N) and phosphorus (P) pollutants. In-stream nitrate concentration was modelled using the STREAM-N and phosphorus using INCA-P model. Both models were first run for baseline conditions and then their effectiveness for changes in land management was simulated. Costs were based on farm income foregone, capital and operational expenditures. The costs and effects data were integrated using 'Risk Solver Platform' optimization in excel to produce the most cost-effective combination of measures by which target nutrient reductions could be attained at a minimum economic cost. The analysis identified different combination of measures as most cost-effective for the two pollutants. An important aspect of this paper is integration of model-based effectiveness estimates with economic cost of measures for cost-effectiveness analysis of land and water management options. The methodological approach developed is not limited to the two pollutants and the selected agri-environmental measures considered in the paper; the approach can be adapted to the cost-effectiveness analysis of any catchment-scale environmental management options.

1. Introduction

The need for economic analysis for supporting water management and policy decisions in Europe is explicitly recognised in the EU Water Framework Directive (WFD). EU member States were required to adopt cost-effective water resource management measures to achieve 'good ecological status' for all waters by 2015 (EC, 2003; WATECO, 2003). In relation to the WFD, cost-effectiveness analysis (CEA) involves an integrated appraisal technique that provides a ranking of a set of management measures on the basis of their costs and effectiveness for achieving the objectives set out in the Directive. This entails the assessment of implementation costs of measures and their impacts on the water bodies to meet the pre-specified water quality and/or quantity objective at a minimum economic cost.

Balana et al. (2011) highlighted that costs and effectiveness figures vary not only among EU Member States but also within a country across the landscape and farming systems. Estimates of the costs and effectiveness of measures depend on: (a) how specific measures are implemented, (b) the environmental conditions, (c) scale (both spatial and temporal), (d) baseline situation, and (e) land use types and management practices. Uncertainty and time-scales of effectiveness and obtaining accurate cost estimates of measures over a period are another key challenges in assessing the cost-effectiveness of measures to reduce diffuse pollution from agriculture (Collins et al., 2014). Challenges in assessing the effectiveness of measures are partly due to spatial scale issues. Measures are implemented at farm level, whilst ecological targets are set at the sub-catchment or catchment scale (Bouraoui and Grizzetti, 2014). Temporal issues also need to be taken into account, as achievement of good ecological status over short time-scales appears problematic due to lags in water quality responses (Kronvang et al., 2005; Meals et al., 2010). Different combinations of these

* Corresponding author.
E-mail address: b.balana@cgiar.org (B.B. Balana).
[1] The James Hutton Institute, Social Economic and Geographical Sciences, Criagiebuckler, AB15 8QH Aberdeen, UK (Institutional affiliation where research was conducted).

http://dx.doi.org/10.1016/j.jenvman.2015.06.035
0301-4797/

factors result in different effectiveness and cost estimates. Thus, identification of localized, targeted and context specific mitigation measures and the assessment of their respective costs and effects could help achieve the Directive's objectives in a more cost-effective manner than standardized prescriptions of mitigation measures (Balana et al., 2012).

In assessing the cost-effectiveness of agricultural related measures, Balana et al. (2011) highlighted the need to capture the heterogeneity of real world farms instead of considering ‘representative’ farms, due to the variation in site-specific cost and effectiveness of measures in mitigating pollutant losses. Balana et al. (2011) advocated a need for better integration of biophysical modelling with economic analyses in order to assess multiple effects of mitigation strategies. Such an approach requires the assimilation of detailed data at an appropriate resolution within an interdisciplinary framework in order to establish the environmental and socio-economic criteria used in the cost-effectiveness modelling. One reason why this is important is to ensure internal consistency in terms of the physical definitions of the measures that are being implemented, as a mismatch in this may have significant implications both for the costing of the actions and their effectiveness in practice. A good example of this is a constructed wetland where it is necessary to define not only the location and proposed management of the wetland in order to determine its effectiveness (Berninger et al., 2012), but also its size, method of construction and continued management requirements in order to evaluate its cost.

Few studies have adopted such an integrated approach and the range of mitigation measures explored has been limited. One exception is the study undertaken by Ghebremichael et al. (2013), where an integrated tool was developed to aid in the identification and mitigation of critical source areas of pollution at a catchment scale, while maintaining economic viability at the farm scale. However, Panagopoulos et al. (2011) recognised that there are major limitations of such a combined methodology, linked to the deficiencies of the process-based modelling tools in representing natural processes and mitigation measures and the true costs of their implementation.

A key objective of the EU-FP7 REFRESH project was to develop a system to enable water managers to design cost-effective restoration programmes for freshwater ecosystems at the local and catchment scale, in the context of the Water Framework Directive, accounting for expected future impacts of climate and land use change. To demonstrate this approach, the EU-FP7 REFRESH project (http://www.refresh.ucl.ac.uk/) identified six demonstration catchments across Europe (England, Scotland, Greece, Finland, Norway, and Czech Republic), broadly representing the major climatic regions, land use and water body pressures present across Europe. This paper presents an empirical application of the integrated hydro-chemical and economic modelling approach in the River Dee catchment (one of the six demonstration catchments in the project), in North East Scotland. The methodological approach has been adapted and applied in the other five demonstration catchments of the REFRESH project. The generic step-by-step assessment approach adopted in this paper can be adapted and applied in any catchment or sub-catchment scale cost-effectiveness study.

2. Integrated modelling approach

A common framework for integrating hydro-chemical and economic analysis was developed within the REFRESH project for application across the six demonstration catchments. CEA methodologies are themselves comprised of various sequential steps (Defra, 2005; WATECO, 2003); these were combined with hydro-chemical modelling steps to create an integrated modelling methodology. Briefly, the steps involved were:

Step 1: Assessment of current water quality and ecological status to identify water quality issues and set targets. This includes identification of the major pressures (e.g. excess nutrient inputs) and their sources (e.g. agricultural activities, sewage effluent).

Step 2: Identification of a set of mitigation measures. The types of measures chosen depend on the nature of the key pressures and their sources identified in step 1 above.

Step 3: Baseline application of hydro-chemical models to reproduce recent hydrological and chemical responses.

Step 4: Collaborative refinement of mitigation measures, between hydro-chemical and socio-economic scientists, such that the measures can be realistically represented within the models at the relevant scale.

Step 5: Hydro-chemical simulation of the effectiveness of each individual mitigation measure compared to the baseline.

Step 6: Cost estimates of mitigation measures. This involves the assessment of the economic costs (such as material/resource costs, labour costs, capital costs, and operational costs) of the selected mitigation measures.

Step 7: Assessment of the cost effectiveness of individual mitigation measures and identification of the most cost-effective combination of measures to achieve water quality targets. This involves application of an optimization approach to integrate economic cost and effectiveness data in order to determine the least cost way of achieving environmental objectives.

Additional steps were also included in the REFRESH integrated modelling approach to explore the future robustness of the mitigation measures under scenarios of climate and land use change. However the results of these steps are not reported here.

3. Study area and identification of key pressures

The River Dee catchment (North East Scotland; Fig. 1) is a large (*ca.* 2100 km^2), relatively unspoilt area, famed for its salmon fishing, shooting and hill walking. It has been designated at European level for the species it supports, in particular Atlantic salmon (*Salmo salar*), freshwater pearl mussel (*Margaritifera margaritifera*) and otter (*Lutra lutra*). The catchment is subject to significant pressures, including morphological alterations and nutrient inputs from sewage and agriculture, and the area remains a top conservation priority. Within the Dee catchment there is significant heterogeneity in climate, topography, soils and land use, and consequently the key determinants and targets for water quality are variable across the catchment. Two sub-catchments of the Dee were selected for more in-depth study to explore the cost-effectiveness of mitigation measures under different conditions – the Tarland Burn catchment and the Corskie Burn catchment (see Fig. 1).

Tarland Burn catchment, in the middle reaches of the Dee, is characterized by a mixed land use. The catchment supports a wide range of land uses. On the upper slopes heather moorland used for sport shooting gives way to plantation forestry which in turn meets the upper fields of the farms in which beef cattle and sheep are grazed, interspersed between fields of improved grass. Agricultural activity is typically mixed cereal and livestock, dominated by the fattening of cattle and malting barley production and some sheep on improved pasture on the uplands. There are 4369 cattle and 8566 sheep in total (Agricultural Census, 2008) in the farms located in the catchment. An estimated total of 4472 people are living in and around this sub-catchment. Water quality examinations at the lower end of the Tarland sub-catchment (SEPA, 2009) indicated that faecal indicator organisms (FIO), N and P loadings were significant issues compromising water quality in Tarland. These issues are related to diffuse pollution whose main sources are agricultural