Cost-effective analysis of buffer strips for P mitigation (the case of Rescobie Loch in Lunan)

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Buffer strip workshop, Ballater, Aberdeenshire, UK
2Q. Economics of buffer strips?

- Where to place buffer strips across the landscape? &
- How much (optimal size of the buffer across land units)?

Issue: Minimize econ. cost and achieve env. targets.

(1) Develop a framework to investigate the optimal placement of buffer strips for P mitigation and how placement of buffers influence costs and effectiveness

(2) Apply the framework to a case study (in Lunan catchment)
A scenario of land use (modelled)

Source: Castellazzi, M. (LandSFACCTS project)
Approaches in CEA models

• CEA models can be based on various methods (econometric/regression based methods; mathematical programming based methods, etc).

• Most applied CEA models are based on variants of mathematical programming (economic optimization) models.

• The mathematical programming formulations as applied in CEA can be summarized under two broad headings:

  (1) **Cost minimization**: Achieving exogenously determined level of environmental target/standard at a least possible economic cost;

  (2) **Benefit maximization**: Maximizing aggregate level of environmental benefits from a given cost (budget outlay).
Basic approaches in CEA: mathematical formulations

(1) CEA based on cost Min.

\[
\begin{align*}
\min \sum_i C_i(e_i) \\
\text{subject to} \\
\sum_i e_i \geq \bar{R}
\end{align*}
\]

(2) CEA based on benefit max.

\[
\begin{align*}
\max \sum_i \theta_i(a_i) \\
\text{subject to:} \\
\sum_i C_i(a_i) \leq \bar{C}
\end{align*}
\]
Empirical CEA model

• The empirical CEA model: cost minimization approach.

• Mitigation options: LUC: change portion of crop field to buffer strips

• Problem: Which fields should be selected? What buffer size at each field?

• Accordingly, the objective function would be:

\[
\text{Min. } C = \sum \sum (FGM)_{ij} B_{ij}
\]
Empirical ... (contd.)

\[ i = 1, \ldots, 311 \text{ (crop fields)} \]
\[ j \quad \text{= buffers with various widths (0 m, 2 m, 6 m, 20 m)} \]
\[ B_{ij} = \text{buffer of width } j \text{ in field } i. \]
\[ \text{FGM} = \text{forgone cropping returns (farm gross margin)} \]

Constraints:

(1) **Environmental constraint**: $P$ reduction shouldn’t be less than a certain proportion (%) of environmental target

\[
\sum_{i} \sum_{j} (PR)_{ij} B_{ij} \geq \left( \frac{k}{100} \right) (EQT); \text{ for } 1 \leq k \leq 100
\]

where \((PR)_{ij}\) = the amount of $P$ reduction from field ‘i’ if buffer of size ‘j’ is installed in the field; \(EQT\) = environmental quality target. The model was solved for $k$ = 10, 20, 30, 40, 50, 50, 60, and 70.
Constraints... (contd.)

(2) **Buffer width constraint**: a field is attached to one specific chosen buffer widths (0m, 2m, 6m, or 10m).

(3) **Bounds to choice variables**: the choice variable (field) should be constrained to take **binary values** (i.e., one or zero value).

(4) **Feasibility conditions**: Buffer area should be less than or equal to total field area for each field.

The Obj. fcn. & the constraints (1-4):

Non-linear mathematical programming (integer programming) model of cost minimization were built with various scenarios and solved using Excel ‘Risk Solver platform’ software.
Two sets of data were employed

(1) **Field-by-field based estimates of effectiveness**

(1) Estimates of the **economic opportunity cost** of putting buffers on crop fields.

**General info on Data**

(1) Initially **695 fields** with various cropping and tree activities (about 20 activities) were considered.

(1) But data for FGM was not obtained for fields with **coniferous, non-coniferous, scrubs, and other land activities**.

(2) The **311 fields** included in the model accounts 55% of the sub-catchment area under study.
Effectiveness estimates

Estimates of P export coefficients and P delivery ratios were obtained at field-by-field level. These estimates were based on crop-rotation (LandSFACTS project) and field distance from the loch. Using the Lunan-SIACS (Scottish Integrated Administration and Control System) data; field boundary, size and perimeter were determined with GIS tools.

Illustration: (next page)
Crop: Winter wheat export 0.7kg/ha/yr  (LAND USE)
Area: 5ha
P produced: 0.7kg/ha/yr*5 ha = 3.5 kg/yr
Distance from loch: 0.5 km

BUFFER STRIP: 2 m
Lets through 60% of P produced in field
P leaving buffer: 3.5 kg/yr*0.6=2.1kg.yr
(also reduced by reduction in cropped area by putting in buffer)

Over 0.5 km P is reduced by 20%
(delivery ratio =0.8)

P in loch with no buffer:
0.7kg/ha/yr*0.5ha*0.8=2.8 kg/yr
P in loch with buffer: 0.7 kg/ha/yr*5 ha*0.6*0.8=1.7 kg/yr
Reduction: 2.8-1.7 = 1.1 kg/yr

Can be changed to different width (6 m and 20 m in this study)

Expert judgement based on crop/land use

Assigned to field in geo-database based on distance of field from loch (FIELD DISTANCE)

Buffer will let through a certain % of P at the moment these numbers are a “guess”
(Set in “Buffer Width” sheet)
They can be changed and the rest of the calculations will be updated automatically
Data (contd.)

Cost estimates

- **Average gross margins** for various cropping activities based on four rotation cycles were calculated on the basis of RERAD’s agricultural census (1995-2007).

- **Land capability classes** (LCC) have been used as weights to correct the average gross margin/ha for each field (The Macaulay Land Capability of Agriculture index).
## Results (contd.)
*(GM unadjusted by LCM)*

<table>
<thead>
<tr>
<th>P reduction goal (%)</th>
<th>P reduced (kg/yr)</th>
<th>land area in buffers (ha)</th>
<th>Abatement costs (£)</th>
<th>Marginal abatement cost (£/kg P/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>total abatement cost (£/yr)</td>
<td>average abatement cost (£/kg P/yr)</td>
</tr>
<tr>
<td>10</td>
<td>34.03</td>
<td>5.28</td>
<td>1507.15</td>
<td>44.33</td>
</tr>
<tr>
<td>20</td>
<td>68.00</td>
<td>12.75</td>
<td>3982.98</td>
<td>58.57</td>
</tr>
<tr>
<td>30</td>
<td>102.00</td>
<td>24.14</td>
<td>7902.71</td>
<td>77.48</td>
</tr>
<tr>
<td>40</td>
<td>136.00</td>
<td>48.87</td>
<td>15433.99</td>
<td>113.49</td>
</tr>
<tr>
<td>50</td>
<td>170.00</td>
<td>106.69</td>
<td>33430.68</td>
<td>196.65</td>
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<tr>
<td>60</td>
<td>204.00</td>
<td>209.44</td>
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<tr>
<td>70</td>
<td>238.00</td>
<td>394.96</td>
<td>128955.98</td>
<td>541.83</td>
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<tr>
<td>73</td>
<td>248.00</td>
<td>518.97</td>
<td>176364.94</td>
<td>711.145</td>
</tr>
</tbody>
</table>
Results (contd.)

Target P reduction (in percent)

Average abatement cost (£/kg P)
Marginal abatement cost (£/kg P)

AAC and MAC (£/kg P)
Results (contd.)

![Graph showing percentage reduction in number of fields over different distance intervals (0m, 2m, 6m, 20m).]
### Results (contd.)
(uniform buffer width design)

<table>
<thead>
<tr>
<th>Buffer Width (m)</th>
<th>Area under buffer (ha)</th>
<th>Max. potential P Reduction</th>
<th>P reduced from the target</th>
<th>Total cost (£/yr) (GM unadj.)</th>
<th>Total cost (£/yr) (GM adj. by LCM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 m</td>
<td>51.90</td>
<td>134.71</td>
<td>0.40</td>
<td>17636.49 (T ~15434) (13%↓)</td>
<td>22931.21 (T~18 836) (21%↓)</td>
</tr>
<tr>
<td>6 m</td>
<td>155.69</td>
<td>179.61</td>
<td>0.51</td>
<td>52909.38 (T~ 33 430) (36%↓)</td>
<td>68793.68 (T ~38937) (68%↓)</td>
</tr>
<tr>
<td>20 m</td>
<td>518.98</td>
<td>248.39</td>
<td>0.73</td>
<td>176364.94</td>
<td>229312.25</td>
</tr>
</tbody>
</table>

(Markdown Format)
## Results (contd.)
*(comparison with uniform fixed SNH scheme of £400/ha/yr)*

<table>
<thead>
<tr>
<th>P reduction Target (%)</th>
<th>P reduced (kg P/yr)</th>
<th>Land area in buffer (ha)</th>
<th>Cost (£) based on GM</th>
<th>Cost (£) in fixed reward scheme targeted</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>34</td>
<td>5.28</td>
<td>1507</td>
<td>2112</td>
</tr>
<tr>
<td>20</td>
<td>68</td>
<td>12.75</td>
<td>3983</td>
<td>5100</td>
</tr>
<tr>
<td>30</td>
<td>102</td>
<td>24.14</td>
<td>7903</td>
<td>9656</td>
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<tr>
<td>40</td>
<td>136</td>
<td>48.87</td>
<td>15434</td>
<td>19548</td>
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<tr>
<td><strong>50</strong></td>
<td><strong>170</strong></td>
<td><strong>106.69</strong></td>
<td><strong>33431 (21% lower)</strong></td>
<td><strong>42676</strong></td>
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<tr>
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<td>209.44</td>
<td>66481</td>
<td>83776</td>
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<tr>
<td>70</td>
<td>238</td>
<td>394.96</td>
<td>128956</td>
<td>157984</td>
</tr>
</tbody>
</table>
Work on progress…

- Better estimate of effectiveness of buffer strips (scale issues; width; reliability of estimates;...)
- Cost of implementation (scale issues; private vs. social costs; externality issues;...)
- Better way of integrating physical and economic models?
- Think of Multi-criteria analysis/evaluation of measures
- Analysis of combined implementation of BMPs
- Riparian buffers vs. buffer strips in all fields across landscape
- Do we really need putting buffers along the entire boundary of a field?
Thank you!