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

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28 Apr.2010

Buffer strip workshop, Ballater, Aberdeenshire, UK

Objective of the study

2Q. Economics of buffer strips?

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

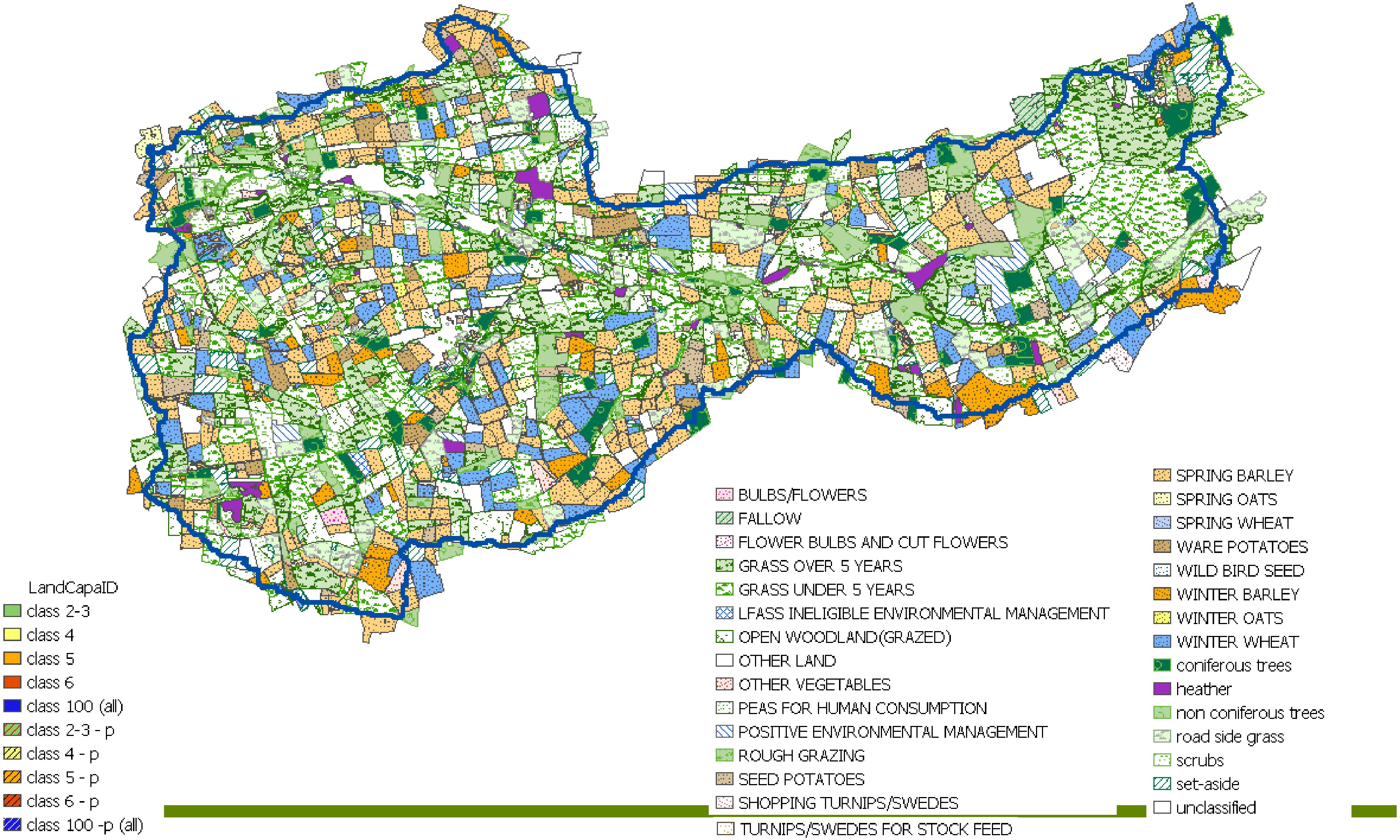
Issue: Minimize econ. cost and achieve env. targets.

(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. (LandSFACTS 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.

$$\left.\begin{aligned} &\min.\sum C_i(e_i) \\ &subjet\ \ to \\ &\sum_i e_i \geq \overline{R} \end{aligned}\right\}$$

(2) CEA based on benefit max.

$$\left.\begin{aligned} &\max.\sum_i \theta_i(a_i) \\ &subjet\ to: \\ &\sum C_i(a_i) \leq \overline{C} \end{aligned}\right\}$$

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:

$$Min.\, C = \sum_{i} \sum_{j} (FGM)_{ij} B_{ij}$$

Empirical … (contd.)

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

Constraints:

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

$$\sum_i \sum_j (PR)_{ij} B_{ij} \geq \left(\frac{k}{100}\right)(EQT); \ for\ 1 \leq k \leq 100$$

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.

Data

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.

beans for human consumption
coniferous trees
field beans
grass over 5 years
grass under 5 years
non coniferous trees
open woodland(grazed)
other land
other vegetables
peas for human consumption
road side grass
rough grazing
Scrubs
seed potatoes
soft fruit
spring barley
spring oats
ware potatoes
winter barley
winter wheat

Data (contd.)

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)

Data (contd.)

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

Expert judgement based on crop/land use

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

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)

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

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

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

Data (contd.)

Cost estimates

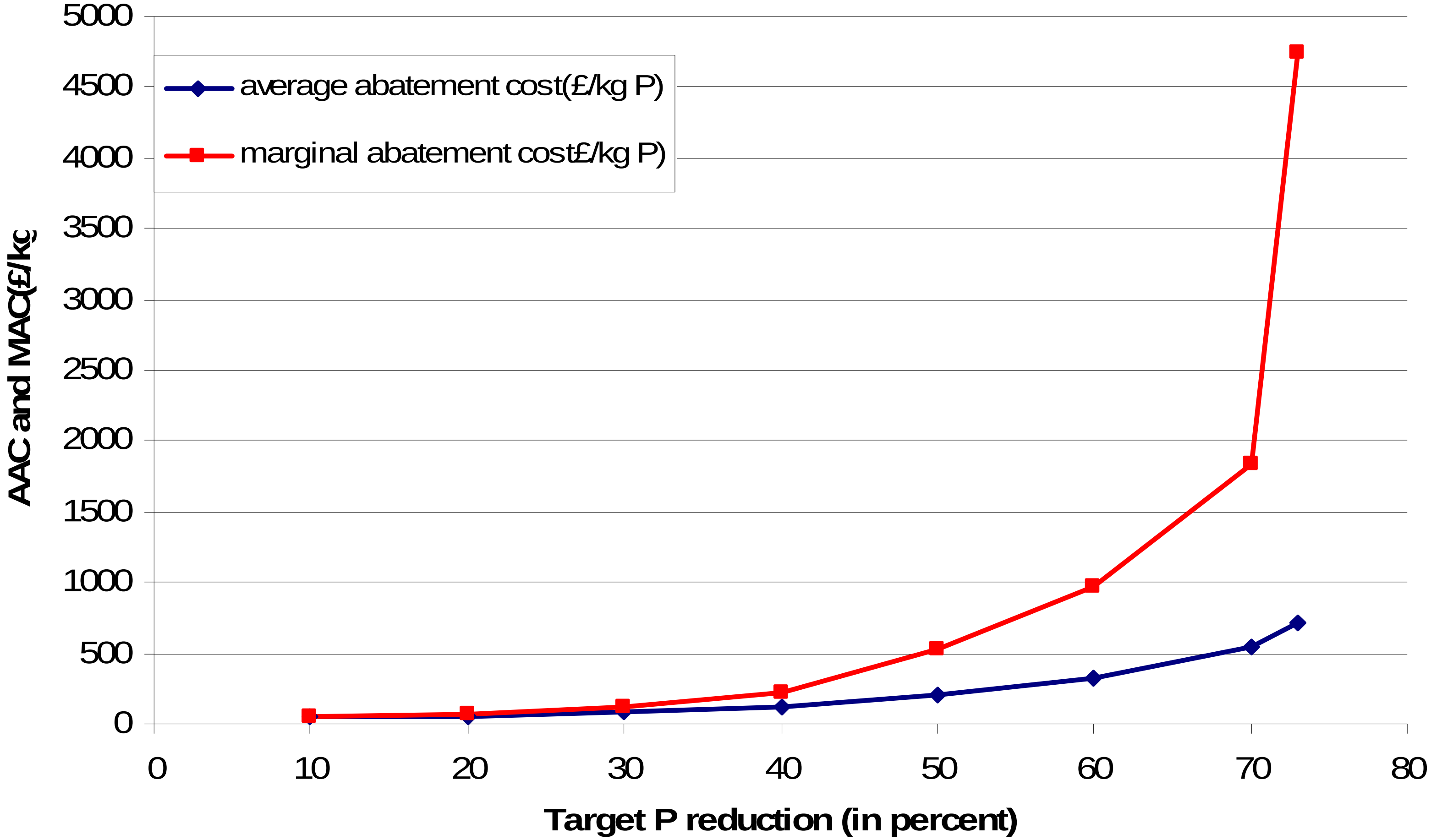
- Average gross margins for various cropping activities based on four rotation cycles were calculated on the basis of RERAD's agricultural census (1995-2007).
- Land capability classes (LCC) have been used as weights to correct the average gross margin/ha for each field (The Macaulay Land Capability of Agriculture index).

Results (contd.)

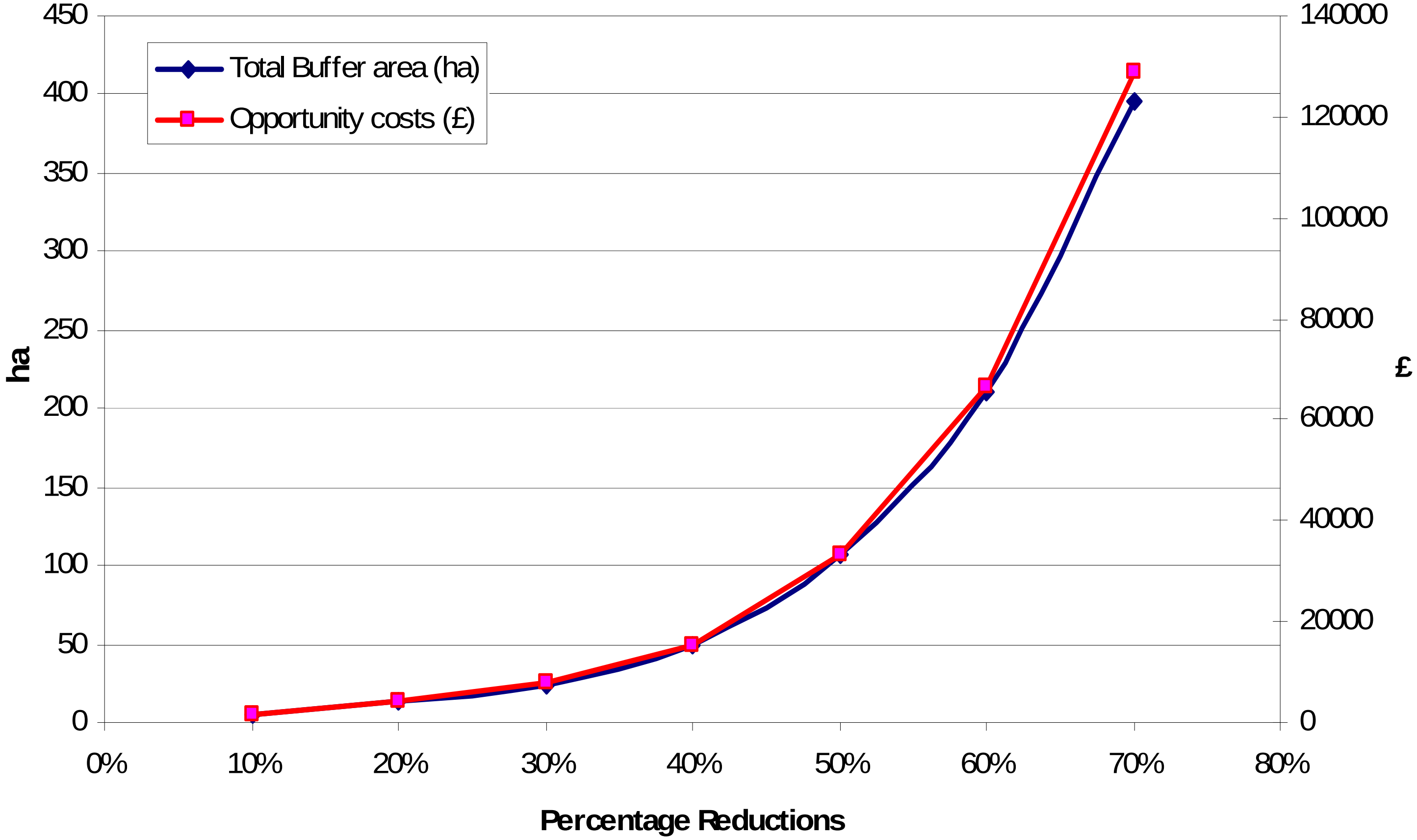
(GM unadjusted by LCM)

P reduction goal (%)	P reduced (kg/yr)	land area in buffers(ha)	Abatement costs (£)		
			total abatement cost(£/yr)	average abatement cost (£/kg P/yr)	marginal abatement cost (£/kg P/yr)
10	34.03	5.28	1507.15	44.33	**44.33**
20	68.00	12.75	3982.98	58.57	**72.82**
30	102.00	24.14	7902.71	77.48	**115.29**
40	136.00	48.87	15433.99	113.49	**221.51**
50	170.00	106.69	33430.68	196.65	**529.31**
60	204.00	209.44	66480.85	325.89	**972.06**
70	238.00	394.96	128955.98	541.83	**1837.50**
73	248.00	518.97	176364.94	711.145	**4740.90**

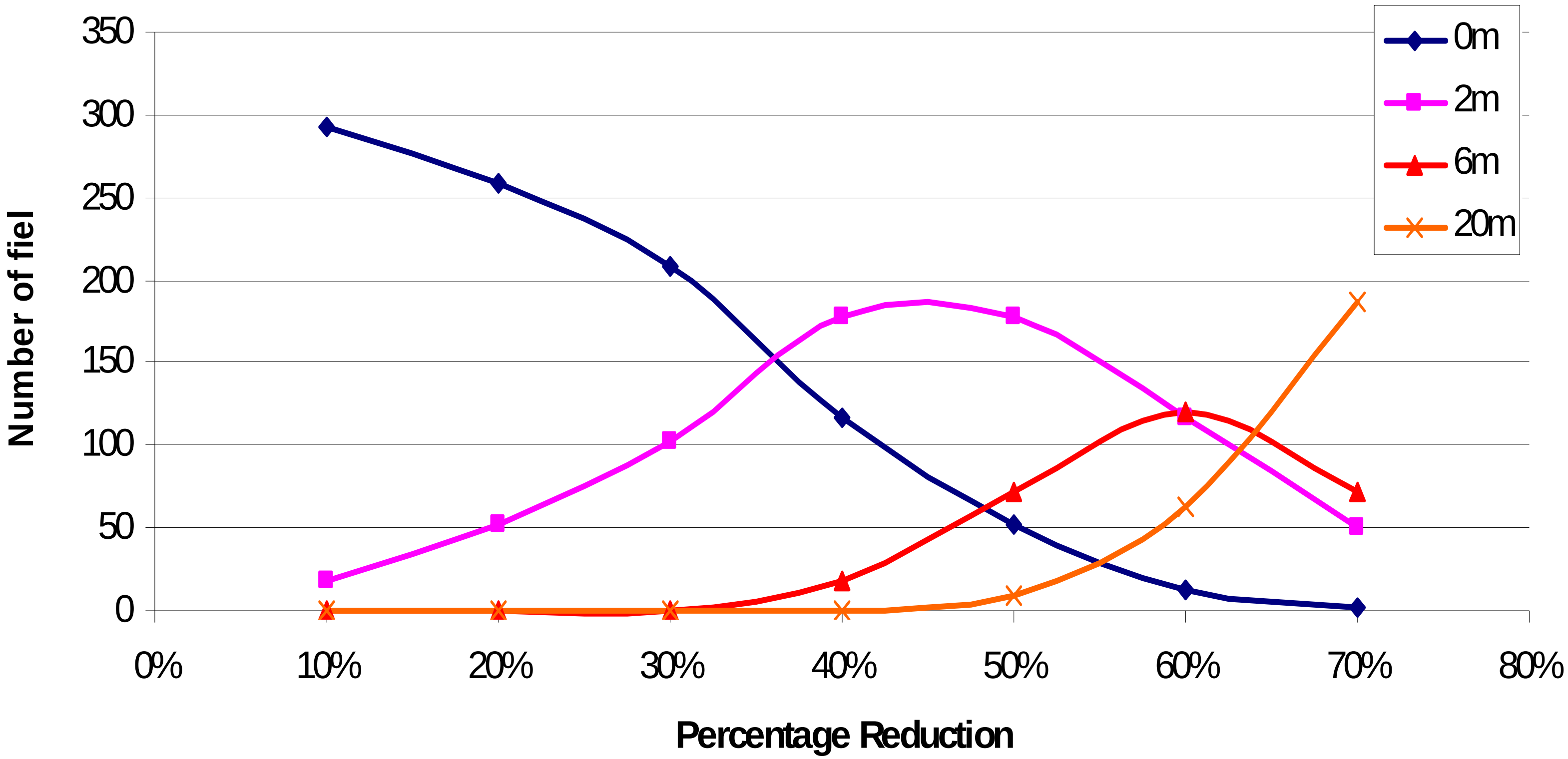
Results (contd.)



Results (contd.)



Results (contd.)



Results (contd.)

(uniform buffer width design)

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

Results (contd.)

(comparison with uniform fixed SNH scheme of £400/ha/yr)

P reduction Target (%)	P reduced (kg P/yr)	Land area in buffer (ha)	Cost (£) based on GM	Cost (£) in fixed reward scheme targeted
10	34	5.28	1507	2112
20	68	12.75	3983	5100
30	102	24.14	7903	9656
40	136	48.87	15434	19548
50	**170**	**106.69**	**33431 (21% lower)**	**42676**
60	204	209.44	66481	83776
70	238	394.96	128956	157984

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!