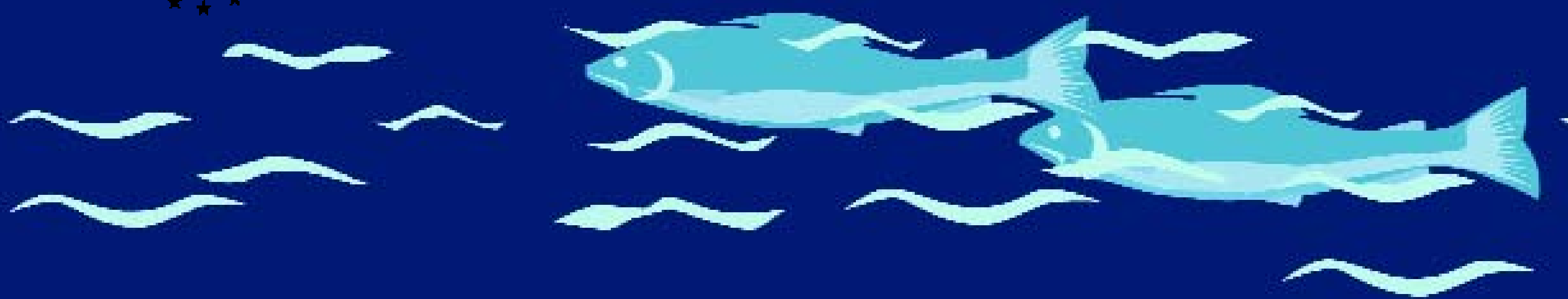
Reducing Diffuse Pollution to Rivers

A Protocol for Identifying Best Management Practices

Conserving Natura 2000 Rivers
Conservation Techniques Series No. 11



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A protocol to identify the most appropriate, site-specific Best Management Practice to reduce the input of suspended solids from diffuse sources into SAC Rivers.

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1 Summary

A simple protocol is presented to assist river managers to identify potential Best Management Practices (BMPs) to reduce the erosion of soil and subsequent run off into rivers. The method, which is for use on a site-by-site basis, uses information in an accompanying document: "Reducing Diffuse Pollution to Rivers: A Dictionary of Best Management Practices" which can be downloaded from www.riverlife.org.uk.

The basic methodology, in its most practical form, has five sections: a) identification of the area(s) in the catchment where suspended solids in the river exceed target levels; b) identification of likely local sources using local knowledge; c) an initial sort of BMPs to identify practices applicable to the generic problem (e.g. arable farming, livestock farming, urban run-off, etc.); d) a more detailed assessment of the practicality of each BMP in the light of local conditions to produce a short list of useful BMPs for the specific situation(s); e) an assessment of costs to clarify one of two routes: i) persuade of farmers to adopt low or no-cost BMPs to reduce erosion and soil run-off or ii) development of a scientifically justified plan for the introduction of measures costing significant sums of money. The methodology was demonstrated on two areas of high suspended solids in the Hampshire Avon catchment. These areas were identified, in part, from an analysis of suspended solids data from which average concentrations and annual loads of suspended solids at each sampling site were derived (Appendix 1).

A potential methodology to quantify the costs, on a catchment wide scale, of moving field gates to the up-slope side of fields was developed (Appendix 3). The method used GIS technology to identify field gates with significant run-off catchments, near to, and up-slope of roads, i.e. those where soil loss through the gate onto the road was a potential hazard. The total cost for gate relocation in the Hampshire Avon catchment to practical locations in the same field was estimated to be between £1M and £100K.

2 Protocol for Using the Dictionary of Best Management Practices

A dictionary – "Reducing Diffuse Pollution to Rivers: A Dictionary of Best Management Practices" - has been compiled, which lists a large range of BMPs for different applications, e.g. arable agriculture, livestock farming, urban run-off, forestry. It can be downloaded in PDF format from the web at www.riverlife.org.uk.

The following protocol has been developed to show local river managers how the dictionary can be searched systematically to assist them to identify the most practical solutions to problems of high, suspended-solids loads in a specific river catchment, without incurring major costs. It also suggests what additional data should be obtained in order to make a formal case for expenditure. Ideally the general approach should be as follows (Figure 1):

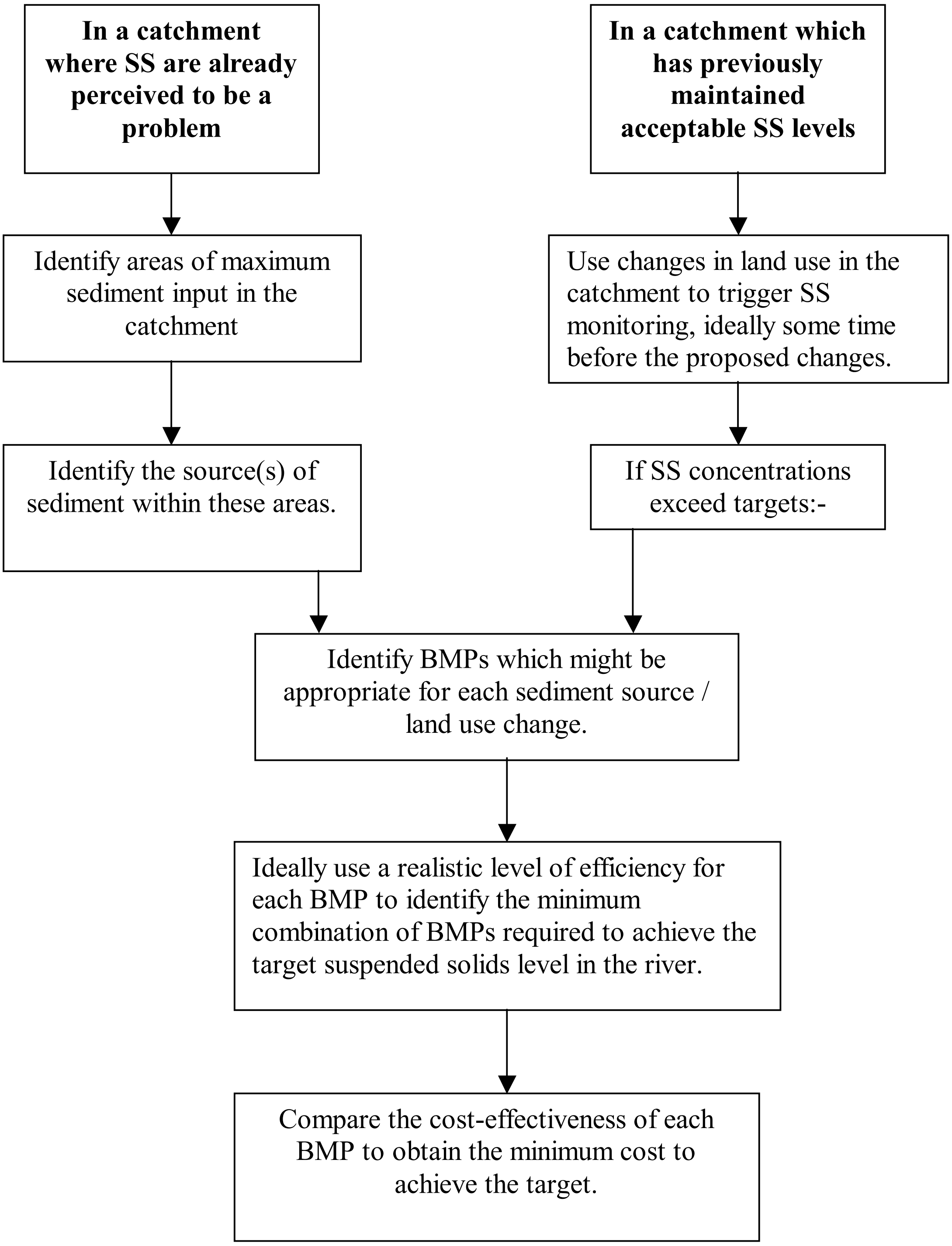

Figure 1. Flow chart of the process to identify appropriate BMPs to reduce suspended solids levels in a specific catchment

In a catchment where either suspended solids concentrations are perceived to be too high or where monitoring has shown levels to exceed target levels:

1) Identify the areas of maximum sediment input in the catchment from:
   a) Local knowledge

   And / or

   b) A one-off survey of suspended solids concentration or load in the river at high flows.

   And / or

   c) A survey of suspended solids concentration in the river over a time period (minimum 1 year) which includes some high flow events. These data can be transformed to loads and the erosion from different sub-catchments can be compared.

2) Identify the source of sediment input within the high input area using:
   a) Local knowledge

   And / or

   b) A localised survey of suspended solids concentration or load in the sub-catchment.

   And / or

   c) A visual survey of land use in the area.

For rivers which have previously maintained suspended solids concentrations below the target level, use the observed or proposed change in land use in the catchment to trigger a suspended solids monitoring programme. Ideally the programme should obtain some data before the land use changes occur. If monitoring shows that the change in land use increases average SS levels above the target or if water quality is below SS targets, as outlined above, then:

1) Identify BMPs which might be appropriate for each sediment source.

2) Apply a realistic level of erosion reduction efficiency of each BMP to the river system and identify the minimum combination required to achieve the target.

3) Compare the cost-effectiveness of each BMP to obtain the minimum cost to achieve the target.

In practice the effect on the river of applying a BMP may be different from the actual efficiency of the BMP in reducing the run-off at one site. In part this results from the fact that, by its nature, diffuse pollution has many sources spread through the catchment and, if only a small proportion of the sources (e.g. maize fields) in the catchment have BMPs applied then, although the efficiency in each field may be high the resulting reduction in SS in the river may be low. Similarly if, say, run-of from maize fields only constitutes 10% of the input of solids to the river then application of BMPs to all maize fields will have a small effect on the problem in the river. A full analysis to identify the contribution of different sources is quite costly. As a result it may not be possible to carry out sections 4 and 5 with sufficient rigour to make it worthwhile. In this case a stepwise introduction of low cost BMPs to as many of the perceived problem locations as possible, followed by monitoring the effects may be more practical.

3 A case study/protocol of the use of the BMP Dictionary for catchment management

3.1 Identification of problem areas

Figure A1.2a clearly shows that average silt concentrations much higher than general background values are found in both the Eastern and, to a much lesser extent, Western Avon in the north of the catchment, and on the River Sem in the West of the catchment. This is consistent with local knowledge (P.Bryson, N. Smith, C.Westcott – Environment Agency), which suggested that there were two main areas of high particulate run-off in the Hampshire Avon catchment:

a) Potatoes grown in the north of the catchment (a reducing problem)
b) Run-off from livestock (particularly dairy cattle) units on clay soils in the west of the catchment.

A comparison of the areas where average suspended-sediment concentrations exceed the target values of 25 mg/l for bullhead and lamprey and 10 mg/l (annual average) for salmon are shown in figure 2a and 2b, respectively. The two regions already identified are clearly visible, particularly the Sem. However a number of other locations were identified where average suspended solids concentrations were also greater than the 10 mg/l target for salmon, although they do not exceed the 25 mg/l target for bullheads. These included the Western Avon and some of the tributaries, which join the Avon down stream of Ringwood.

There was general agreement that the main problems in the potato-growing region in the north of the catchment on the East Avon are:

i) Long periods of exposed ground.
ii) Soil susceptible to erosion since it rapidly forms a cap, which prevents water percolating through but can be easily eroded by sheet run-off.
iii) Strongly sloping land
iv) Channelling of land by agricultural processes.
v) Planting very close to watercourses.

In the livestock area on clay soils in the Sem catchment to the west of the catchment the main problems are:

i) Strongly sloping ground
ii) Long periods of exposed ground (mainly from maize growing)
iii) Over-dosing of fields with slurry at inappropriate times.
iv) Run-off from farm tracks.

Since the areas in the Western Avon and the tributaries downstream of Ringwood were unrecognised by local knowledge, there are no identified sources of erosion in these areas and they have not been considered further in this example.

3.2 Matching BMPs with problem - General

There are six points in the diffuse pollution run-off process where it may be possible to intervene to reduce the suspended solids concentration in rivers:

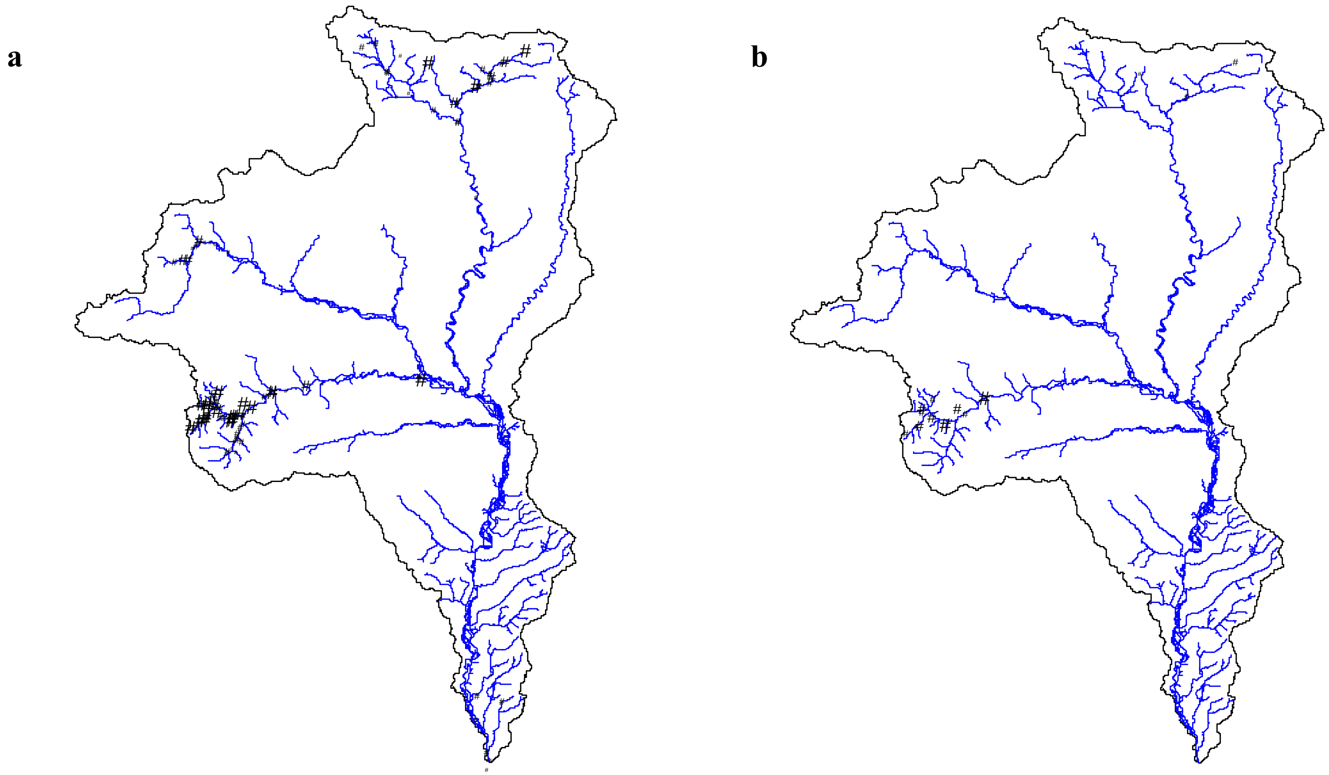

Figure 2. Suspended solids sampling sites where concentrations exceed a) the 10 mg/l target for Salmon by greater than 10%.scale ranges = 11% • 30% • 50% • 60% • 90%; b) the 25 mg/l target for Bullheads by greater than 1%.scale ranges = 1% • 10% • 30% • 50% • 70%;.

a) Reducing the input of pollutants (generally, but not exclusively more important for nutrients)
b) Reducing the total area and/or length of time that bare soil is exposed, which reduces the opportunity for particles to be dislodged from the soil surface.
c) Reducing either the slope angle or uninterrupted distance down-slope, which reduces the erosive force of surface run-off.
d) Detaining run-off water on the catchment for longer periods near to the source(s), reducing peak flows in the river and allowing some time for settlement of solids.
e) Intercepting run-off and trapping particles low down in the catchment, before they reach the river and
f) In-river remediation processes.

As a general rule it is best to reduce the losses from specific sources first, before trying interventions further along the transport pathway. The pollutant interception BMPs should only be used as a last resort because: a) there is a potential for the trap system to break down at high flows causing scouring and, hence, worse pollution in the short term; b) erosion of soil is still taking place at the source location and this is not compatible with soil conservation requirements.

It is highly unlikely that a single BMP will solve a problem in a catchment. Typically a combination of BMPs will be required to reduce the soil loss from a catchment and bring the suspended solids in a river down to the target level. Sometimes the target will be achievable by introducing different BMPs at different locations in the catchment to address different sources. Under these circumstances the efficiencies multiplied by the area will simply add. However, on some occasions it will be necessary to apply more than one BMP at the same location. Under these circumstances it should be noted that the efficiencies are not necessarily additive. For example, the inclusion of a cover crop not only reduces soil detachment but also increases water infiltration and reduces the uninterrupted distance for surface run-off to gain momentum. Hence if a slope distance reduction BMP were applied after a soil cover BMP it would result in a much lower (additional) reduction in the mass of soil retained efficiency for the slope distance reduction BMP than if it were applied by itself.

The simple approach outlined in this protocol can help to reduce suspended solids in a river. However, it should be noted that it is designed to identify no-cost or low-cost solutions that farmers could be persuaded to introduce themselves with little or no financial incentives. If the most appropriate BMPs appear to those which are expensive to implement then it is highly likely that a more rigorous approach than the one given here would be required to justify the expenditure.

The table at the front of the BMP Dictionary groups the BMPs according to the intervention points listed above. It can be used to identify all BMPs, which have potential to reduce the diffuse run-off for the desired combination of the relevant pollutant (e.g. suspended solids) and for the relevant type of agriculture (arable/ livestock) or other polluting operation (e.g. forestry, urban, etc. A simple initial sort at this level will reduce the number of applicable BMPs significantly. However, the BMPs needed to combat the effects of, say, long periods of exposed ground and planting close to watercourse could well be different and need to be applied at different times of the year; hence it is often easier to then carry out an assessment of the suitability of remaining BMPs for each source/ problem type separately.

A modified version of the table at the front of the Dictionary is given in Appendix B of this report and can be photocopied and used to record your assessment of each BMP for each particular problem. The BMPs should be worked through systematically identifying those with potential to reduce the run-off from the process/ system in question. Having identified the possible BMPs each one should be considered in turn, using information in the dictionary and feedback from local farmers to identify those that are practical in the particular circumstances.

3.3 Matching BMPs with problem - Potatoes.

<u>Background information</u> (from a local potato merchant)
Potatoes in this region are normally sown in March / April and ridged at the same time. Main crop or general-purpose potatoes are grown so that harvesting takes place in September/ October. The expectation is that they would be part of a rotation with minimum 5 years return period, ideally 7 years. Typical rotations might be:

Arable rotation:
Winter Wheat, Winter Barley, Oil Seed Rape, Winter Barley, Spring Barley, Potatoes

Arable/Grass rotation:
Winter Wheat, Spring Barley, Winter Barley, Grass, Grass, Potatoes

An assessment of the relevance of BMPs to the problems in the North of the catchment is shown in Table 1 (the information on all problems has been displayed on a single table to save space). The resulting analysis suggest that the following BMPs are likely to be practical:

i) Long periods of exposed ground.

In both the typical rotations winter wheat follows potatoes establishing some ground cover fairly quickly after the potato harvest, so that no additional BMPs should be required at this time of the year. Problems may arise in the arable rotation when potatoes are sown in the late spring following harvest of the spring barley the previous autumn. Appropriate BMPs are:

a) Green manure cropping – immediate rough cultivation after harvest with green manure crop sown directly into rough cultivation. Depends on the ability of the crop to establish a cover late in the season, which is better in the South than the north of the country. It has an added advantage that it also improves the soil structure over the long term reducing the likelihood of soil capping. It is efficient at reducing soil loss and is relatively low cost (seed cost + additional seed bed preparation /rough cultivation cost) but has no direct economic benefits. Most appropriate for purely arable farms.

b) Cover crops – as for green manure cropping but generally uses rye grass. If it can be used for an early hay or silage cut it has some economic benefits, which reduce the costs significantly. More appropriate for mixed farming systems.

c) Conservation tillage – since, in the arable rotation, barley precedes the potato crop the straw could be left on the field until cultivation prior to planting the potatoes. Low cost BMP with medium efficiency.

Table 1. An example of the use of the table in Appendix 2. The suitability of different BMPs to combat the suspended solids inputs to rivers caused by potatoes in the north of the Hampshire Avon catchment.

Description of Soil loss Cause …Losses from potato fields due to (i) long periods of exposed ground; (ii) soil capping; (iii) strongly sloping land; (iv) channelling of land by agricultural processes; (v) planting close to water courses.

Target Solids Concentration 25mg/l or 10 mg/l annual mean **Target Efficiency** about 75%

		Potential BMP	Not Practical	Efficiency	Cost
A	**BMPs to reduce pollutant inputs**				
A-1	Use of soil P analyses to indicate over fertilisation	N			
A-3	Location of the fertiliser closer to the plant root	N			
A-4	Timing of fertiliser applications – "incidental losses"	N			
A-5	Timing of fertiliser applications - Split application of fertiliser/ slow release fertiliser	N			
A-6	Nutrient management plan	N			
A-8	Reduction in the dietary intake of P by livestock	N			
A-9	Liming of acid soils to utilise existing P reserves	N			
A-10	Reassess the need for continued maintenance dressings of P	N			
A-11	Waste (manure) management	N			
A-12	Farmyard run-off interception	N			
A-13	Roof run-off interception	N			
A-14	Prevention of misplaced fertiliser (spills)	N			
A-15	Pre harvest and harvest planning of timber felling	N			
A-16	Composting manures	N			
A-17	Infiltration systems – 1 – Porous pavement	N			

		Potential BMP	Not Practical	Efficiency	Cost
A-18	Infiltration systems – 2 – Infiltration (or percolation) trench	N			
A-20	Infiltration systems - 3 - Infiltration basin	N			
A-21	Infiltration systems - 4 – Sand filter basin	N			
A-22	Street sweeping/cleaning	N			
A-23	Catch-pot emptying	N			
A-24	BMPs for construction sites	N			
A-25	Soil erosion and sediment control plans	Y	Basically incorporates all steps shown here		
A-26	Non- structural BMPs	N			
A-27	Incorporation of manures	(ii)	Totally dependent on having manure.		
A-28	Manure injection	N			
A-29	Manure sharing scheme	N			
A-30	Manure incineration	N			
A-31	Urban –source reduction BMPs	N			
B	**BMPs to reduce the amount of bare ground and, hence, particle dislodgement**				
B-1	Critical area planting (changing land use)	Y	Not for small farmers	100	0
B-3	Triple cropping	(i)	Not practical in UK.		
B-4	Green manure cropping	(i / ii)	OK	high	Seed and cultivation costs
B-5	Grassland rotation	N			
B-6	Cover crops	(i)	OK		

		Potential BMP	Not Practical	Efficiency	Cost
B-7	Consideration of the time of planting	(i)	Planting times set by variety and frost damage risk - little leeway.		
B-8	Conservation tillage 1 - Crop residue management	(i)	OK	80%+	v. low
B-9	Conservation tillage 2 – till planting	N			
B-10	Conservation tillage 3 – strip rotary tillage	N			
B-11	Conservation tillage 4 – no-till planting	N			
B-12	Conservation tillage 5 – annual ridges	N			
B-13	Conservation tillage 6 – Chisel plough	N			
B-14	Conservation tillage 7 - Discing	N			
B-15	Ecotillage	N			
B-17	Compaction management	N			
B-18	Use bulky organic manures and/or incorporate straw residues	(ii)	OK	Med / high	v. low
B-19	Under sow cover crop	(i)	Not really practical because of ridge system of cultivation.		
B-20	Irrigation management	N			
B-21	Livestock exclusion	N			
B-22	Feed/water trough location	N			
B-23	Livestock trails	N			
B-24	Grazing management	N			
B-25	Reduce strip grazing of fodder crops	N			
B-26	Location of outdoor pig units to minimise the risk of erosion	N			
B-27	Access tracks/roads	N			
B-28	Field boundary/access points	N			
B-29	Vehicle movements	N			

		Potential BMP	Not Practical	Efficiency	Cost
B-30	Timber harvesting (traditional felling techniques)	N			
B-31	Tree felling - cut-to-length harvesting	N			
B-32	Reforestation/forest stand management	N			
B-33	Soil spreading	N			
B-34	Reduce run-off onto fields from farm roadways	N			
B-35	Rough ploughing/cultivation in late autumn	(ii)	Would be beneficial in breaking the soil cap and encouraging infiltration if conservation tillage is not used.		
C	**BMPs to reduce run-off water speeds by reducing the angle or length of slope.**				
C-1	Strip cropping	(iii / iv)	Possible but not safe on land >11°. Farmers generally consider the management to be too complex.		
C-3	Contour cropping	(iv)	Often not cost effective because of field length up-down slope. Not safe on slopes greater than about 11°.		
C-4	Hedgerow planting	N			
C-5	Terracing (or contour bunds)	(iii)	Not possible on steep slopes but may be workable elsewhere.		
C-6	Contour cultivations	(iii)	Often not cost effective because of field length up-down slope. Not safe on slopes greater than about 11°		
C-7	Soil berms (low ridges to divert water flow	(iii)	Since ridges are at an angle to the slope cannot be used in some steep slopes but may be workable elsewhere.		
C-8	Intersperse grass banks or ditches	(iii)	Breaking up the slope into small units would make cultivation very difficult and expensive. Given the ridges in potato cultivation probably gives little extra benefit compared to contour cultivation.		

		Potential BMP	Not Practical	Efficiency	Cost
C-9	Ditch management	N			
C-10	Hedgerow management	N			
D	**BMPs to delay the flow time and reduce the peak flow of run-off through the system**				
D-1	Water retention systems – 1 – Filter drains (French drains)	N			
D-2	Water retention systems – 2 - Grass waterways (generally called swales in urban systems)	N			
D-4	Water retention systems – 3 - Detention basins	N			
D-6	Water retention systems – 4 – Retention ponds	N			
D-8	Artificial reed beds	N			
D-10	Wetland restoration	N			
D-12	Oxidation pond sedimentation basin	N			
E	**BMPs to trap pollutants carried in run-off before it reaches the river.**				
	Riparian buffer zones (also called buffer strips, riparian filters, filter strips)				
E-1	Riparian buffer zones – 1 – protection from machinery operation	N			
E-3	Riparian buffer zones – 2 – solids reduction	(v)	OK	Med-High	Low-med
E-5	Riparian buffer zones – 3 –dissolved pollutant reduction	N			
E-7	Intercept flow at the bottom of a slope by a grass buffer zone	(iii)	OK	Med-High	Low-med
E-8	Focus run-off into buffer zones at critical places on a slope	(iii)	OK	Med-High	Low-med
E-9	Water/sediment basin/retention	(iii)	OK	Med-High	High
E-10	“Stormtreat®” system	N			
E-11	Hydro-Kleen ® - system	N			

		Potential BMP	Not Practical	Efficiency	Cost
F	**In-stream amelioration techniques**				
F-1	Bank erosion	N			
F-2	Stream bank stabilisation	N			
F-3	Stream crossing	N			
F-4	Water jetting of sediments	Y	Cost borne by EA		
F-5	Bank width manipulation to increase flow rates	N			
G	**Miscellaneous**				
G-1	Minimising water table fluctuation	N			

ii) **Soil susceptible to erosion since it rapidly forms a cap,** which prevents water percolating through but can be easily be eroded by sheet run-off. Appropriate BMPs are:

a) Incorporation of manure (or sewage sludge). Totally dependent on having access to manure, either from the same farm or via a manure sharing scheme. Use of sewage sludge is only possible in the arable rotation since it can only be applied before growing an "industrial" crop, such as rape. The arable / grass rotation contains no "industrial" crops. It has additional cultivation costs and, on arable farms, organisational costs to obtain manure/ sludge. It improves the soil structure and allows easier infiltration so that run-off, and hence erosive losses are reduced. It has medium efficiency but is relatively low cost.

b) Green manure cropping – see above.

c) Incorporation of straw residues. – Both rotations contain wheat, hence it is not a major task to chop the residue in the field and incorporate it into the soil. As with other BMPs in this section it has medium efficiency but is relatively low cost, although there may be a small opportunity cost on livestock units where the straw would be used and there may also be a need for additional fertilizer to combat co-uptake of nutrients in breaking down the carbon in the straw.

iii) Strongly sloping land

a) Terracing / contour bunds – Small banks are constructed along the contour. They can be as simple as a plough furrow but are often more substantial. They are not practical on steeply sloping land (>11^{o}) but can be effective on more gentle slopes. Would have potential benefits for potatoes if cultivation were only cost effective up – down slope. In these cases a tractor-wide, ploughed section along the contour every 50 to 100m down slope would stop run-off gaining momentum down the long slope. As well as additional manpower to plough there would also be opportunity costs and, probably, additional costs due to the ploughed out seed potatoes.

b) Contour cultivations – An unsafe practice on slopes greater than about 11^{o}. In many fields in the UK, which are long up-down slope and narrow along the contour this practice is deemed too labour intensive, but is an option on wide fields.

c) Soil berms – shallow ditches or banks on the diagonal across the slope to channel water at a lower angle down the slope. Effectively the same limitations as terracing but can be used on steeper slopes.

d) Intercept flow at the bottom of the slope by a grass buffer. Only effective if the slope ends some distance away from the riverbank, otherwise it is the same as a normal buffer strip.

e) Focus run-off into buffer zones at critical places on slope. As for iii-d above but may be a number of buffers below particularly steep sections.

iv) **Channelling of land by agricultural processes.**

a) Sediment basin retention – Generally quite an expensive option since it requires the construction of a ditch between the field and the river which channels run-off into a sedimentation basin. It also does nothing to reduce erosion at source.

b) Contour cropping – Has some potential on wide fields, i.e. maximum length parallel to the contours, but not safe on slopes >11^{o}.

v) Planting very close to watercourses.

a) Riparian buffer zone for solids reduction – low cost medium efficiency system which also reduces the effects of run-off from other causes e.g. capping and potato ridges.

vi) Reducing the effects of all five factors:

a) Soil erosion and sediment control plans – the process we are following through is a simplified form of plan.

b) Critical area planting – basically not growing crops which produce sediment problems on the most sensitive areas. It is very effective and very cheap on large farms where there is a choice of sites for planting potatoes but space limitations make it impractical for small farmers

c) Water jetting of sediments – Although it is practically possible it has many disadvantages. Firstly, it does not address the causes so that, secondly, it needs to be repeated at regular intervals. Thirdly the full cost is transferred to the Environment Agency. Fourthly, it is relatively expensive, not least because it needs a lot of close management to ensure that sediments are cleaned at depth and not just on the surface.

A practical strategy to reduce suspended solids pollution in rivers in the North of the Avon Catchment.

Following the assessment of BMPs practicality, effectiveness and cost, a few BMPs are clearly useful in reducing soil erosion and the subsequent run-off of suspended solids into the river and have little or low financial impact on the farmer. In order of precedence they are:

1) Persuading farmers not to plant potatoes in sensitive areas. However, this is only an option for large farmers who have a wider choice where to plant. There is no financial cost associated with this BMP.

2) Retaining the barley straw on the field between harvesting the barley and cultivating / planting the potatoes (which should be carried out near the planting time rather than in autumn). This reduces the amount of soil particles dislodged by rain, the first stage in eroding soil. The only cost associated with this BMP is the lost value of the straw.

3) During cultivation incorporate the barley straw to improve the soil structure and reduce the capping. There is no direct additional cost with this BMP, although some additional fertiliser may be required.

4) Introducing riparian buffer zones along the edge of rivers (minimum 5m width) to keep the cultivation away from the river and reduce any run-off that does occur. There is a cost associated with this but it can be limited by using grants or set-aside.

Although they have little or no cost implications they will require changes in current practice and, as such, will generally require patient persuasion to achieve any benefits. Without a great deal of study it would be difficult to identify the proportion of the different processes, i.e. (i) long periods of exposed ground; (ii) soil capping; (iii) strongly sloping land; (iv) channelling of land by agricultural processes; (v) planting close to water, but clearly critical area planting would remove the problem completely. Conservation tillage is generally highly efficient if the straw covers a reasonable proportion of the ground and, although the incorporation of organic material only has a low to medium benefit it will reduce the amount of capping, especially of repeated a number of times. Riparian buffer zones have a variable efficiency but the combination with the other BMPs is likely to improve the efficiency significantly. If a significant proportion of the farmers can be persuaded to accept these BMPs then there is a high likelihood that the suspended solids run-off to rivers will be reduced below the required limits, however, given the uncertainties, the total effectiveness will only be quantified by continued monitoring for SS in the river for a period before and after the introduction of the BMPs.

3.4 Matching BMPs with problem - Livestock on clay soils.

The source types in the River Sem catchment split into three different types: Maize growing; slurry disposal and run-off from farm tracks (see section 3.1) all of which are exacerbated by the steeply sloping land in the area and the clay soils, which limit infiltration and encourage surface run-off.

The problems resulting from maize growing are very similar to those caused by potato growing and the appropriate types of BMP are very similar, although implementation may be very different in practice. A casual inspection of the River Sem catchment immediately shows that the very steep slopes are not really appropriate for arable cropping and, hence, the most sensible BMP would be to turn the land back to permanent pasture, where the farmer has alternative land that could be used for maize. Conversely, in the River Sem catchment, conservation tillage to maintain ground cover between harvesting the maize and cultivation in the spring is not a practical option because all the vegetation, except for about 15 cm of stalk at the ground surface, is removed leaving the soil completely exposed. In this situation the use of either immediate rough cultivation to break up the compacted surface (as long as it does not leave channels up and down slope) or a rye grass or green manure cover crop would be appropriate. These however do have some costs associated with them, even though they are relatively small.

Because the soil is clay its structure would benefit from the incorporation of straw or farmyard manure, although slurry on its own would be less beneficial. Since maize is grown for silage to feed cattle, it is likely that some manure will be available but great care must be taken over the timing of the spreading / incorporation or pollution problems may occur. Again the use of buffer strips will be beneficial, although the steep slopes are likely to result in lower efficiencies compared to buffer strips on level ground.

An assessment of the usefulness of all BMPs was carried out in exactly the same way as for potato growing. This showed that only a small number were appropriate to counter the problems of (i) over dosing of fields with slurry at inappropriate times and (ii) run-off from farm tracks.

Animal waste management plans for each farm are the only appropriate BMP to combat over-dosing of slurry. Any assistance to the farmer required to develop a waste management plan would carry a small recurrent cost, alternatively a training course for the farmer would incur a one-off cost. However, a likely result of the plan would be the need to install increased storage for slurry, up to three months over the winter, in order to avoid the need for spreading in the periods when polluting run-off would occur, i.e. heavy rain/ high water tables or frozen ground. This is very expensive and a significant proportion of the total cost falls on the farmer, even though grants are available. Small farmers are likely to be resistant to these proposals unless additional incentives can be found. Manure sharing schemes may have benefits but the recipients would need to be outside the steep Sem catchment, which would incur high transport costs.

A number of BMPs are available to reduce run-off from farm tracks. These are identified in the Dictionary under Access track BMPs, Field boundary/ access point changes, vehicle movement controls and BMPs to reduce farm roadway run-off. Generally costs are small and can be done by the farmer himself with significant benefits. Riparian buffer zones may also be appropriate in specific circumstances.

Final comments

A qualitative methodology for reducing the effects of soil erosion in rivers has been presented and a number of examples have been worked through. However, the following limitations of the methodology should be noted:

1) The method can be operated with on little or no data. Under these conditions the conclusions can be self-justifying. It is always better, where ever possible, to base conclusions on sound field data than to draw conclusions on the basis of best guesses.
2) Any BMP which requires significant financial investment will have to be justified on the basis of appropriate quantitative field data.
3) Although the method focuses on low cost methods a significant effort (cost) will have to be put into visiting large numbers of farmers in the catchment and persuading them to change their practices with no obvious direct benefit to them, in most cases.
4) Diffuse pollution usually results from a number of different practices spread across farms all over the catchment. Hence working hard with one farmer to clear all the problems on his farm is unlikely to deliver a major benefit to the river. All the farms in a catchment will need to be improved.
5) The same BMP may well be applicable across the catchment to a generic problem, e.g. silage maize on sloping ground. However, it is unlikely that this one BMP will solve all the problems in a catchment. A range of BMPs will be needed, at least one for each type of problem.

Appendix 1 – Silt budget for the Hampshire Avon.

Suspended sediment data were supplied by the Environment Agency, through Dr. P Naden. Data for 188 sites were loaded into a Microsoft Access database. Flow data for the last 30 years for 8 gauging stations on the Hampshire Avon and its tributaries were obtained from the National Water Archive and loaded into Microsoft Access database. A number of sampling sites were found to be on small ditches and not on the main river or tributaries. These sample sites were excluded from further analysis. The most appropriate gauging station, generally the nearest gauge upstream of the sampling site was chosen by eye from mapped sites. Each suspended solids sample was linked with the flow for that day as measured at the most appropriate gauge. Sample sites with less than 12 samples were identified and exclude from further analysis.

A plot of the total number of days with flow below a given level as a percentage of the total measurement period (10 years, 1991-2000) was constructed for each gauging station (Figure A1) and the range of flows experienced at each sampling site (reported as gauging station values) was compared with the relevant ten year flow range. Analysis of individual yearly average flows at Knapp Mill, over the period 1975 – 2000 showed that the lowest maximum flow in these years was in 1997 and was equivalent to 87% of the 10 year maximum flow at the site. As a result any suspended solids data sets which covered a flow range with a maximum less than 80% of the 10 year maximum flow were excluded from further analysis. Table A1 gives the sampling points which were excluded from the data analysis, either because of limited sample numbers or limited flow range.

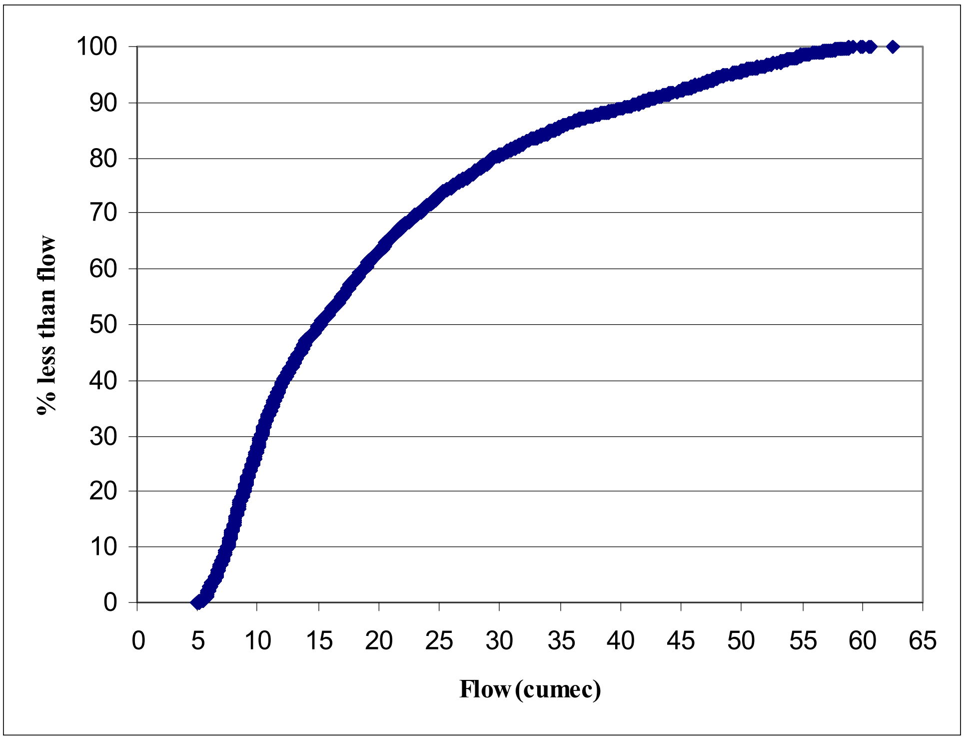

Figure A1.1 Cumulative flow at Knapp Mill gauging station over a 10 year period.

The catchment area of each sampling point and gauging station was calculated using a grid of 50m x 50m squares, each identifying the direction of flow (8 cardinal directions) of surface, run-off water out of each grid square. The grid was prepared by (and licensed from) the Centre for Ecology and Hydrology Wallingford (formerly the Institute of Hydrology) from a digital elevation map of Great Britain (Morris and Flavin, 1990, 1994; Moore et al, 1994) and installed within a GIS system operating under ARC VIEW version 3.2 (Environmental Systems Research Inc, USA).

The average suspended solids concentration over the sampling period was calculated at each sampling site using ACCESS and plotted using ARC VIEW (Figure A1.2). The average load (Figure A1.3) at each site was estimated by multiplying the suspended solids concentration at each site by the matched daily flow at that site and then taking a mean of all values. The load was corrected for flow differences between the sampling site and the gauging station by multiplying the average load by the ratio of the sampling site catchment by the gauging station catchment. Since the data are simply indicative no further attempt was made to refine the load estimate by multiplying by the ratio of mean flow over the whole period of sampling and the mean flow on the sample days alone.

Because of the much greater flow lower down the catchment, loads (Fig. A1.3) are much greater nearer the estuary. Conversely concentrations (Figure A1.2) are much higher near the river sources and are indicative of the source of silt pollution problems.

References.

Morris, D.G. and R.W.FIavin (1990) A digital terrain model for hydrology. Proc. 4th International Symposium on Spatial Data Handling, **1**, Zurich pp.250-262.

Morris, D.G. and R.W.FIavin (1994) Sub-set of UK digital 50m by 50m hydrological digital terrain model grids. NERC, Institute of Hydrology, Wallingford.

Moore, R.V., D.G.Morris, and R.W.FIavin (1994) Subset of the UK digital 1:50,000-scale river centre-line network. NERC Institute of Hydrology, Wallingford.

Table A1. Suspended sampling sites excluded from the calculations with reasons for exclusion.

Sample Point		Comment
50210488		less than 12 SS data
50280454		less than 12 SS data
50280460		less than 12 SS data
50240107		less than 12 SS data
50240310		less than 12 SS data
50231710		less than 12 SS data
50231869		less than 12 SS data
50231876		less than 12 SS data
50231883		less than 12 SS data
50231887		less than 12 SS data
50231894		less than 12 SS data
50240458		less than 12 SS data
50240474		less than 12 SS data
50240520		less than 12 SS data
50250605		less than 12 SS data
50250613		less than 12 SS data
50250655		less than 12 SS data
50250731		less than 12 SS data
50250752		less than 12 SS data
50250776		less than 12 SS data
50250788		less than 12 SS data
50250793		less than 12 SS data
50250797		less than 12 SS data
50250821		less than 12 SS data
50250836		less than 12 SS data
50250860		less than 12 SS data
50250884		less than 12 SS data
50250925		less than 12 SS data
50250929		less than 12 SS data
C0184000		less than 12 SS data
50230121		less than 12 SS data
50230128		less than 12 SS data
50211436		less than 12 SS data
50220429		less than 12 SS data
50220519		less than 12 SS data
50220780		less than 12 SS data
50220993		less than 12 SS data
50221146		less than 12 SS data
50222960		less than 12 SS data
C0037000		less than 12 SS data
50280251		max flow = 33% 10 year
50280217		max flow = 59% 10 year
50280221		max flow = 59% 10 year

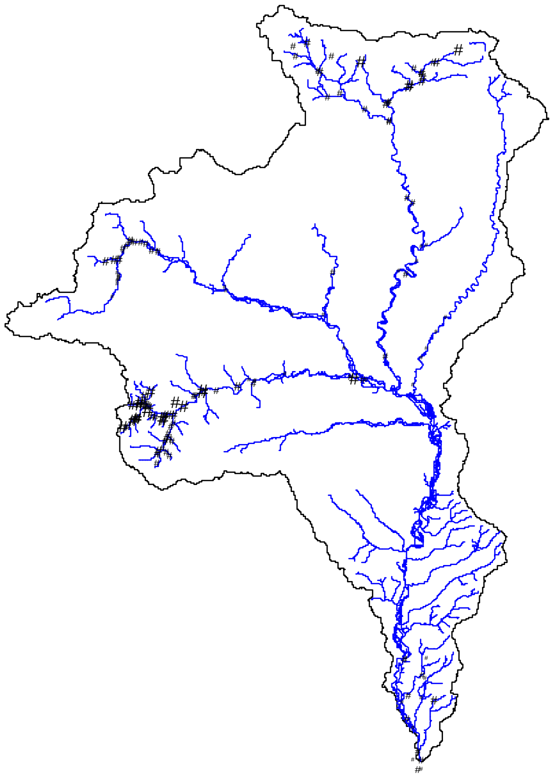

Figure A1.2. Average suspended solids concentrations at different sites on the Hampshire Avon and its tributaries.
3 • 10.5 • 17.5 • 27.5 ● 51.5 ● 85 mg /l.

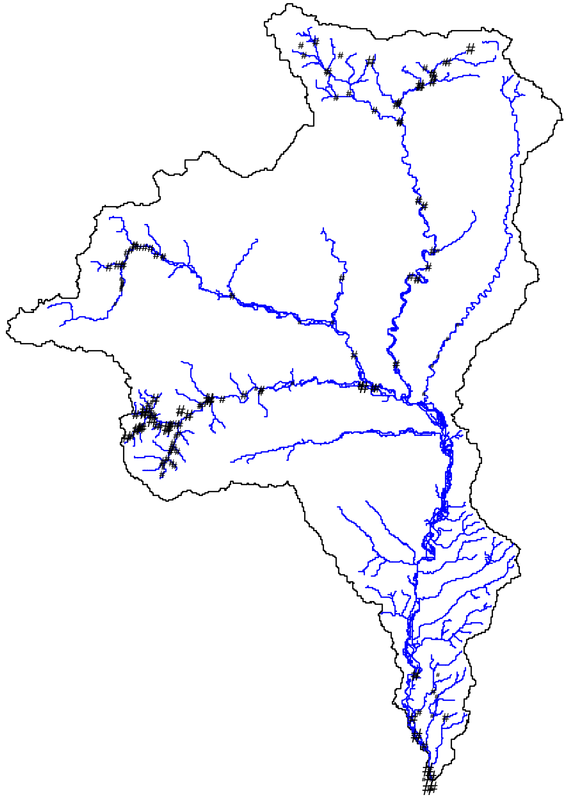

Figure A1.3. Average suspended solids load at different sites on the Hampshire Avon and its tributaries.
0 • 13 • 43 • 98 ● 231 ● 385 g /sec.

Appendix 2: BMP practicality checklist

Problem ……………………………………………………………………………………………………..
Annual cycle of crop/ process ……………………………………………………………………………….
Target concentration ……………………………….Target Efficiency ………………………………..

		Potential BMP	Not practical	Efficiency	Cost/ kg reduced	
A	**BMPs to reduce pollutant inputs**					
A-1	Use of soil P analyses to indicate over fertilisation					
A-2	Location of the fertiliser closer to the plant root					
A-3	Timing of fertiliser applications – “incidental losses”					
A-4	Timing of fertiliser applications - Split application of fertiliser/ slow release fertiliser					
A-5	Nutrient management plan					
A-7	Reduction in the dietary intake of P by livestock					
A-8	Liming of acid soils to utilise existing P reserves					
A-9	Reassess the need for continued maintenance dressings of P					
A-10	Waste management					
A-11	Farmyard run-off interception					
A-12	Roof run-off interception					
A-13	Prevention of misplaced fertiliser (spills)					
A-14	Pre harvest and harvest planning of timber felling					
B	**BMPs to reduce the amount of bare ground and, hence, particle dislodgement**					
B-1	Critical area planting					
B-3	Triple cropping					

		Potential BMP	Not practical	Efficiency	Cost/ kg reduced	
B-4	Green manure cropping					
B-5	Grassland rotation					
B-6	Cover crops					
B-7	Consideration of the time of planting					
B-8	Conservation tillage 1 - Crop residue management					
B-9	Conservation tillage 2 – till planting					
B-10	Conservation tillage 3 – strip rotary tillage					
B-12	Conservation tillage 4 – no-till planting					
B-14	Conservation tillage 5 – annual ridges					
B-16	Conservation tillage 6 – Chisel plough					
B-18	Conservation tillage 7 - Discing					
B-20	Eco tillage					
B-22	Compaction management					
B-23	Use bulky organic manures and/or incorporate straw residues					
B-24	Under sow cover crop					
B-25	Changing land use					
B-26	Irrigation management					
B-27	Livestock exclusion					
B-28	Feed/water trough location					
B-29	Livestock trails					
B-30	Grazing management					
B-31	Reduce strip grazing of fodder crops					
B-32	Location of outdoor pig units to minimise the risk of erosion					

		Potential BMP	Not practical	Efficiency	Cost/ kg reduced	
B-33	Access tracks/roads					
B-34	Field boundary/access points					
B-35	Vehicle movements					
B-36	Timber harvesting (traditional felling techniques)					
B-37	Tree felling - cut-to-length harvesting					
B-38	Reforestation / forest stand management					
B-39	Soil spreading					
B-41	Reduce run-off onto fields from farm roadways					
C	*BMPs to reduce run-off water speeds by reducing the angle or length of slope.*					
C-1	Strip cropping					
C-3	Contour cropping					
C-4	Hedgerow Planting					
C-5	Terracing (or contour bunds)					
C-6	Contour Cultivations					
C-7	Soil berms (low ridges to divert water flow					
C-8	Intersperse grass banks or ditches					
C-9	Ditch management					
C-10	Hedgerow management					
D	**BMPs to trap pollutants carried in run-off before it reaches the river.**					
	Riparian buffer zones (also called buffer strips, riparian filters, filter strips)					

		Potential BMP	Not practical	Efficiency	Cost/ kg reduced	
D-1	Riparian buffer zones – 1 – protection from machinery operation					
D-2	Riparian buffer zones – 2 – solids reduction					
D-4	Riparian buffer zones – 3 –dissolved pollutant reduction					
D-6	Wetland restoration					
D-8	Artificial reed beds					
D-9	Oxidation pond					
D-11	Intercept flow at the bottom of a slope by a grass buffer zone					
D-12	Focus run-off into buffer zones at critical places on a slope					
D-13	Water/sediment basin/retention					
D-15	Water diversions					
D-16	Grass waterways					
E	**In-stream amelioration techniques**					
E-1	Bank erosion prevention and consequent reduction in direct manure inputs to rivers					
E-2	Stream bank stabilisation					
E-3	Stream crossing					
E-4	Water jetting of sediments					
E-5	Bank width manipulation to increase flow rates					
F	**Miscellaneous**					
F-1	Minimising water table fluctuation					

Appendix 3 – Farm gate relocation as a practical BMP.

Background

During heavy rainfall events, it is not uncommon for soil to wash off sloping land and be carried out through farm gates to either deposit on the road or be transported at increasing velocities down the road to end up in a river. Although there is little quantitative information on the frequency of occurrence of these events, there are a number of very well documented, spectacular occurrences in Great Britain. As a result there is general perception amongst Environment Agency staff and other river managers that the repositioning of vulnerable farm gates to the top of a slope on the same exit side is a very cost effective BMP. This is based on the assumption that the gap left by the gate would be filled with a hedge on top of a small ridge to form a semi-permeable barrier, behind which any run off would pond and not spill over into the road. Since no attempt has been made to quantify the scale of the problem and the resulting cost of any consistent programme of gate movement a pilot project was developed to identify vulnerable gates in a small catchment and, by scaling, make an estimate of the cost of moving all vulnerable gates in the larger Hampshire Avon catchment as part of a planned programme of reducing suspended solids concentrations in the river.

Methods

Following advice from the Environment Agency, the River Sem catchment was chosen as a test area since problems with suspended solids in the river were known to occur there. The River Sem is a small tributary of the Hampshire Avon, with a catchment area of approximately 5.31 km^2. The catchment is almost exclusively Kimmeridge clay and is steeply sloping, which makes it prone to soil erosion, particularly on arable areas following the harvesting of silage maize crops.. The annual average rainfall is estimated to be between 826 and 888 mm / year. The catchment is exclusively agricultural with a high proportion of dairy farms in the area. The Hampshire Avon has a total catchment area of 1701 km^2.

Using 1:10,000 scale tiles of raster data supplied by Ordnance Survey, the field boundaries were digitised on screen in ARCVIEW and stored as polygons. The centre-line of all roads and tracks in the catchment were also digitised on screen and stored as vector data. Field gates were located visually on 1:10,000 scale aerial photographs of the catchment (supplied by the Environment Agency). The position of the gate was then re-located on screen on the digitised field boundary and recorded on the GIS as a point. Visual identification of gates from aerial photographs will not identify those under trees. Even for gates not under trees, this method cannot locate all the gates in the catchment, but gates showing wear in the adjacent area were clearly visible. Hence the method tended to be biased towards the gates which are most likely to be a problem. Gates opening directly onto either a road or track were identified as a separate subset of all gates by visual observation of the GIS screens, selecting the points and creating an additional field in the database which was marked true for gates leading onto roads. No attempt has been made to differentiate between gates that actually have connectivity with the river via tracks and roadways and those that do not, since clearing roads of deposited field soil is also an undesirable cost to the community.

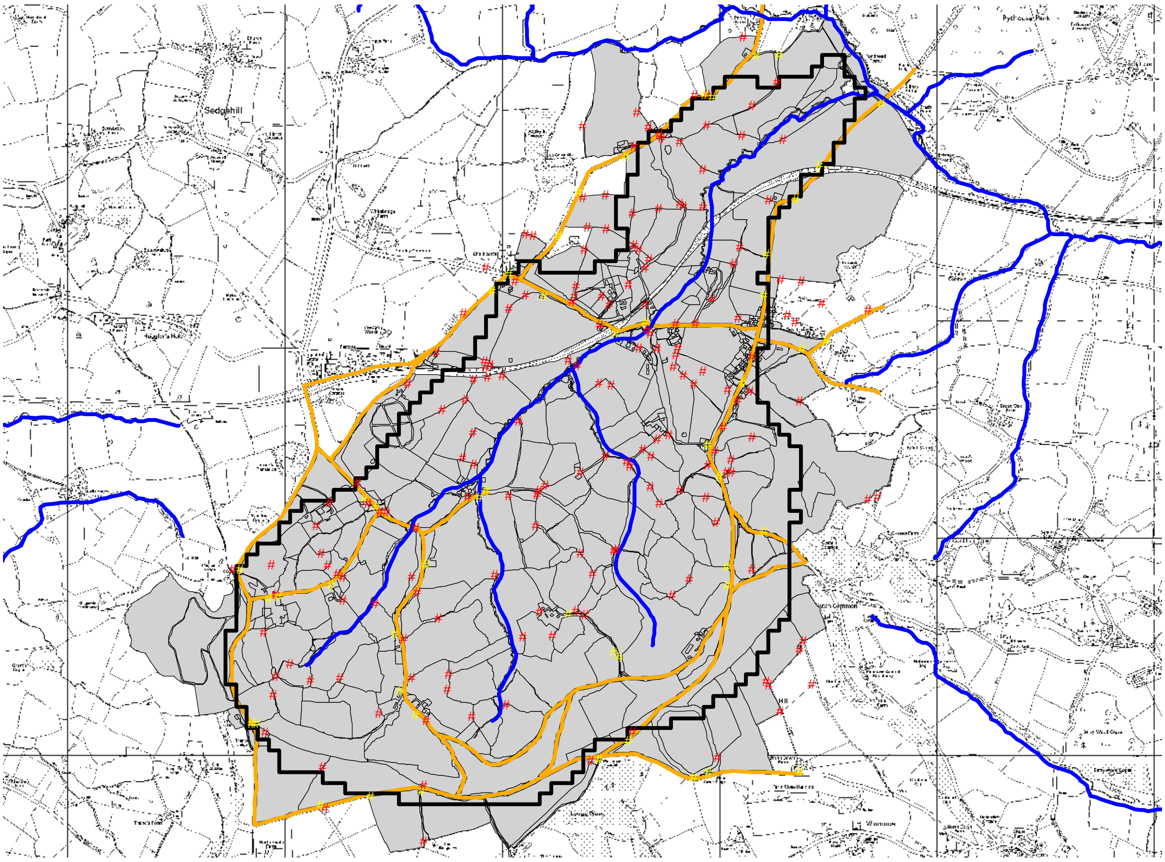

Figure A3.1 The location of gates in the River Sem catchment. Gates adjacent to roads are indicated by yellow points. Other gates are indicated in red. The backdrop is reproduced from 1:10,000 Panorama® dataset by permission of Ordnance Survey® on behalf of The Controller of Her Majesty's Stationery Office. All rights reserved.

Using the ARCINFO function TOPOGRID, a digital elevation map (DEM) grid with a pixel edge of 10m was created for the catchment from the digitised 1:10,000 OS contour (and spot point height) data layer. A flow direction grid was produced from this DEM in ARCINFO using the FLOW_DIRECTION command. A catchment boundary was then derived from the flow direction grid for every gate individually using the WATERSHED function in ARCVIEW and the catchment area was recorded. Since no data were available on the type of boundary between each field, it was not possible to identify whether the boundary was impermeable (wall, bank or ditch), semi-permeable (hedge) or completely permeable, e.g. fence. As a result no attempt was made to limit the contributory catchment area to each gate to just the within field areas.

The maximum and minimum heights in each gate catchment were derived using an ARC extension prewritten script "Surface tools for point, line and polygon". v.1.3 (J.Jenness) downloaded from the ARCSCRIPT web site. This script identified the highest and lowest pixels in the DEM, which were within a specified polygon (in this case the catchment boundary). The altitudes of the highest and lowest points for each gate's catchment were recorded (Table A3.1). The ARCVIEW function FLOW_LENGTH was used to derive the distance along the flow direction, to the furthest pixel from the gate. 7 m was added to all values to allow calculations to be made for cell values that had zero distance to source, i.e. a single celled catchment. [In a 10m x 10m pixel, half the length of the diagonal is 7m.] This distance was recorded for every gate (Table A3.1). The point in the catchment which is furthest away from the gate need not be the highest point but a series of quality control checks suggested that, in fact, for almost all cases, the most distant pixel was also the highest pixel. Using these data an average slope was calculated by dividing the maximum height difference in each gate catchment by the maximum length along the direction of flow. The slopes are tabulated in Table A3. 1. A piece of software was written to identify the centroid pixel of the catchment for each gate and the Land Cover

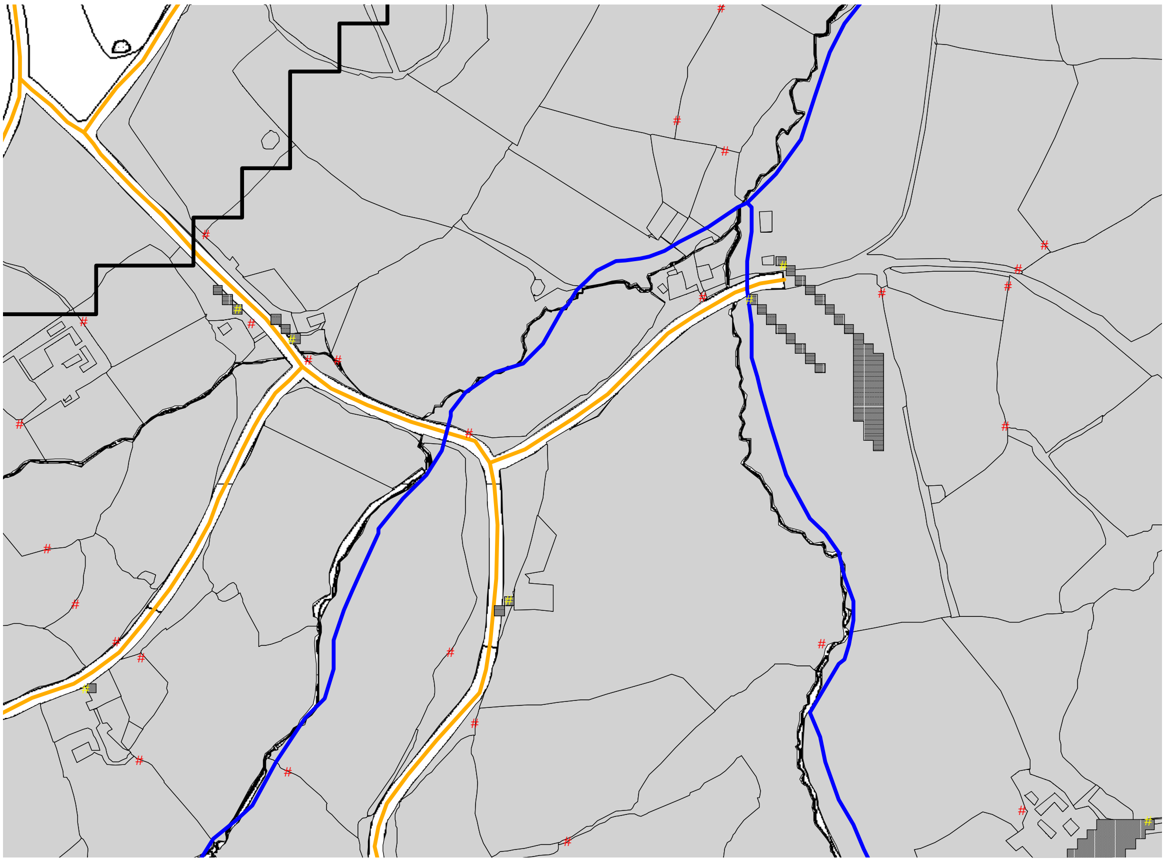

Figure A3.2 A map of a part of the River Sem catchment showing examples gate catchments which cross the road (centre right) and intersect the road centre line (centre left). The map also gives examples of long, single-pixel-chain type, gate catchments. The backdrop is reproduced from 1:10,000 Panorama® dataset by permission of Ordnance Survey® on behalf of The Controller of Her Majesty's Stationery Office.

(Fuller et al., in press; Smith et al., 2001) type underlying this pixel was recorded as the land cover type of the gate catchment. The cover types were reduced to three types by combining all grassland types to "grass" and all cultivated types to "tilled" arable. One field was classified as broad-leaved woodland and all others were classified as bare ground.

Results

229 gates were identified in the 5.31 km^2 River Sem catchment (fig A3.1). Of these 75 opened onto either metalled roads or unmetalled tracks. However, it was clear from the

GIS screen that the catchment for some of these gates was actually on the other side of the road to the gate, i.e. the field was down slope of the road. In these circumstances the field would be unable to deliver erosion products onto the road. By selecting catchments which intersected a road, 33 catchments were identified as potentially crossing the road (Figure 3A.2). A further visual selection was then carried out to separate fields where the majority of the catchment was the opposite side of the road to the gate and those where the gate sloped towards the road but one or two pixels had overlapped the road but almost all of the catchment was in the field. 25 gates, where the catchment crossed the road, were deselected. Eight gates were found to have catchments which cut, but did not cross the road, these gates were retained. For a larger river catchment, this operation could be automated by linking a gate with the field polygon (or polygons) that it opened into and selecting those gates where the majority of the catchment was in the correct field. The total set of gates at risk (50) was obtained by adding the gates near roads, which did not cross roads, and the gates which touched roads but where the majority of the catchment was in the field(s) on the same side of the road as the gate.

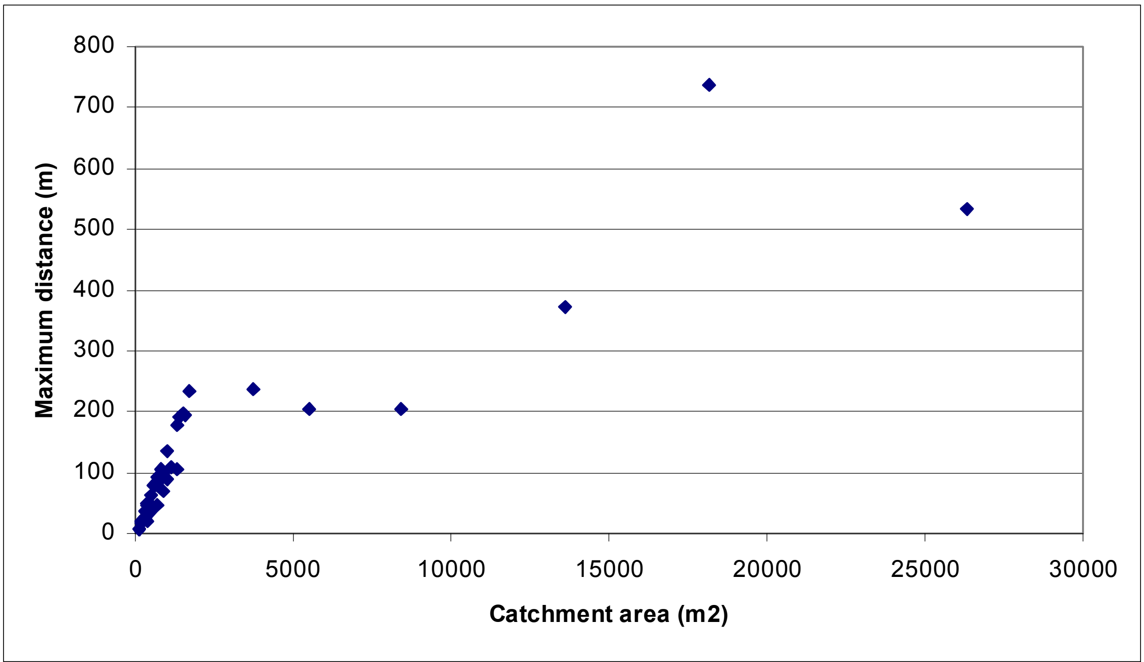

Figure A3.3 A plot of maximum distance from the gate to the furthest point in the gate catchment versus the catchment area size.

A large number of the derived catchments are single pixel wide lines perpendicular to the contours (Figure A3.2). Although they appear to be rather artificial, they are reasonable estimates of the smoothed catchment created by the DEM. In reality, they probably under-estimate the true contributing catchment which will be focussed by soil depressions caused by farm traffic, etc., particularly around gates, but the height data are not sufficiently detailed to include these areas in the catchment calculations. A consequence of these long thin catchments is that a plot of maximum length along the direction of flow versus the catchment area for all gates opening onto roads (Figure 3A.3) shows a very strong relationship at small to medium catchment areas. Conversely, in the small number of larger catchments, the relationship between maximum length and area is much more variable with a smaller overall increase in maximum distance with catchment area. This

is a result of the broadening of the catchments rather than an elongation, i.e. the hill slopes have a similar length but the catchment area is wider. As a result the maximum distance increases but the maximum height difference remains about the same as for the smaller catchments resulting in a lower calculated mean slope.
Excluding the soil type, three physical factors are known to influence erosive potential on slopes: a) the contributing area; b) the slope and c) the length of slope. All other things being equal, a large contributory catchment is more likely to develop high overland water flows and, hence be more prone to erosion that a small one with the same slope. A catchment with a steep slope is likely to erode more strongly than a catchment with a low slope, and, above a certain slope threshold (about 3%), long slopes are likely to be more eroded than short slopes. Unfortunately, the inter-relationships between these three

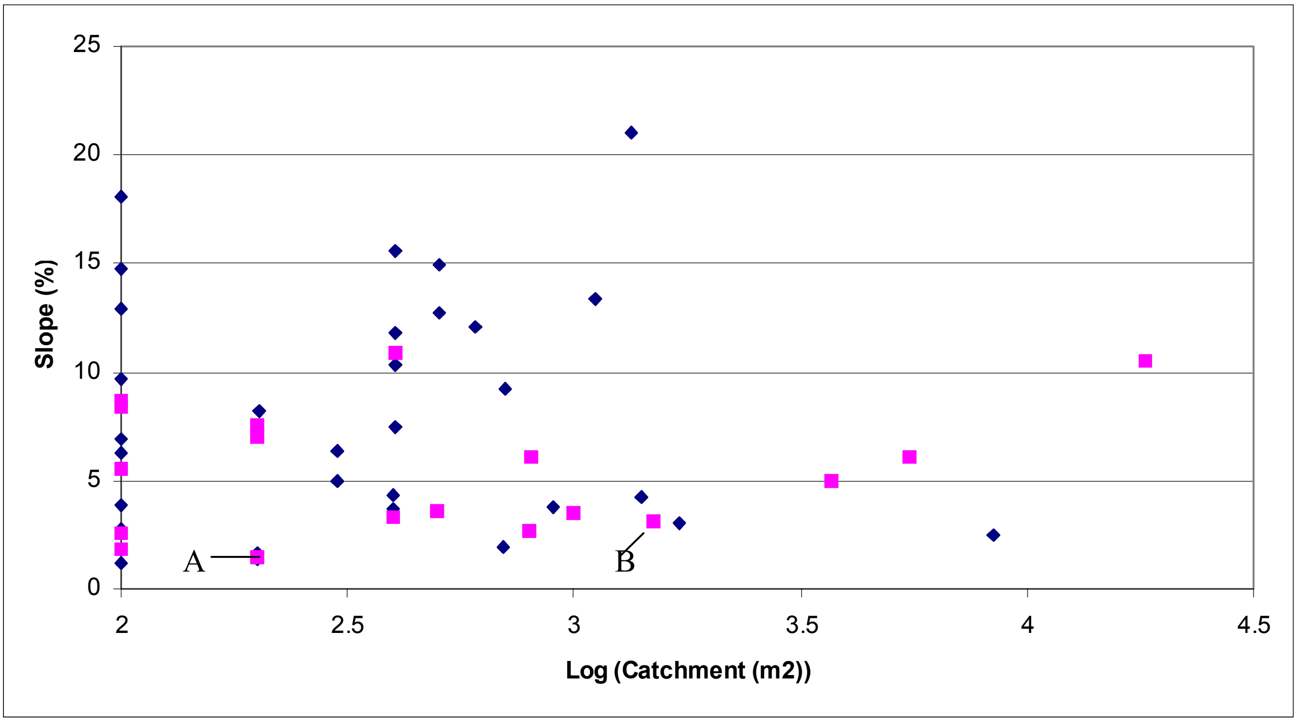

Figure A3.4. A plot of average slope (m/m) against area (m^2) for catchments which could potentially contribute eroded soil run-off through field gates onto roads in the River Sem catchment. Grassed (or broad leaf woodland – one point) are indicated by diamonds. Tilled or bare land is indicated by grey squares. Point A has tilled soil but a very low slope. Point B is the farm gate through which a soil loss event has been observed.

factors are not simple and, among other things, depend on the type of erosion which is dominant at the site. However, the strong relationship between catchment area and maximum distance, except at the largest catchment areas, suggests that a combination of catchment area and slope should be sufficient to differentiate the gates most susceptible to large erosive flows onto roads.

A plot of average slope against catchment area is shown in figure A3.4 for the 50 gates which open onto a road and are up-slope of the road. The 15 gates with very small catchments (single pixel = 100 m^2) are unlikely to be at risk, even when the slope is steep. Of the residual (35) gates, 22 with grassed fields are unlikely to erode significantly, but an alarm should be triggered if a land use change were being considered. Of the remaining gates, one (number 88) has a very low slope of 1.5%. The slope of all the other twelve gate-catchments is very close to or greater than 3% and has some potential to discharge erosion products into the road.

Discussion

Comparison with actual events.

All the fields with very high slopes are currently down to grass, which reduces their potential to erode significantly. The highest slope in cultivated fields is 10.9%, although it has a relatively small area (400 m^2). The field clearly at most risk of depositing erosion products on the road is gates 143 with a slope of 10.5% and an area of 1.82 ha. However, no recorded events have been located for this gate. In the recent past only one run-off event has taken place, through gate 16, following the harvest of a silage maize crop Figure A3.4. Gates, in the River Sem catchment, with contributing catchments discharging directly onto the upstream side of a road. (N. Smith, personal communication). This is one of the gates highlighted by this project as being at risk, which adds some credence to the methodology. The Environment Agency are currently awaiting data from the County Council highways department which should provide more information on the location of past run-off events.

Costs of gate replacement on a catchment wide scale.

Hilton et al. (2000) identified the costs of £550 for moving a gate and replacing with a fence. Replacing the gate with a hedge, rather than a fence, would incur additional costs. However, the extra work in creating a small bank to plant on (the cost of planting is approximately equivalent to the cost of posting for the replacement fence. As a result the cost would only increase by about £50 for the cost of the plants, resulting in a total cost of £600 per gate removal. In the 5.13 km^2 of the Sem catchment there are 12 gates at risk, giving a total cost of £7,200 to move all the gates at risk. Simple scaling to the rest of the Hampshire Avon catchment (1701 km^2) suggests that the total cost would be approximately £2.378M for the high-risk gates. This is not a small sum!

The scaling process makes some major assumptions, e.g. similar field size distribution, density of roads, geology / soil type and steepness of slopes in the Avon catchment and the Sem subcatchment. The road density is very similar in the two catchments (Hitchman, 1993). Much of the Avon catchment is covered by chalk and greensand, rather than the Kimeridge clay of the Sem catchment. As a result, the latter is much more likely to develop erosive flows of run-of water, although this was not taken into account in our model. However, the average slope in the Avon catchment is 6.0% whereas the Sem has an average slope of 9.2%, which suggests that less gates will be at high risk in the Avon. Conversely a much greater proportion of the Sem catchment (19%) has slopes less than 3%; a slope below which erosion rates will be low. Only 2% of the whole Avon catchment has slopes less than 3%.

The general impression is that the model is likely to have of the right order of magnitude of total cost. However, it is highly likely that a large proportion of the proposed relocations would be impractical and not allow the farm to continue to operate effectively. Even so, the sums of money involved per river catchment are likely to be very high (£1M-£100k for a catchment the size of the Hampshire Avon). This suggests that the cost of relocating farm gates at a catchment scale is so expensive that it is unlikely to be an acceptable blanket policy to implement. However, the limited evidence does suggest that the GIS approach highlights the most vulnerable gates and could be used as a preliminary tool to direct farm inspectors to the gates with the most potential to discharge. A targeted survey could then identify a much smaller subset of gates, giving the highest return for a much more limited investment.

References

Fuller, R.M., Smith, G.M., Sanderson, J.M., Hill, R.A., & Thomson, A.G. (in press). The UK Land Cover Map 2000: construction of a parcel-based vector map from satellite images. Cartographic J.

Hitchman, J. (1993) A methodology for the identification of extended river networks linking critical source zones to the riverine environment. Unpublished MSc thesis. Silsoe College, University of Cranfield.

Hilton, J., G P Irons, S McNally (Sept 1999) Pilot Catchment Study of Nutrient Sources – Control Options and Costs. pp.107+ Environment Agency. Technical report P345.

Smith, G.M., Fuller, R.M., Sanderson, J.M., Hill, R.A. and Thomson, A.G., 2001. Land Cover Map 2000: a parcel-based map from satellite images. Proceedings of the 1st Annual Remote Sensing and Photogrammetry Society Conference, Remote Sensing Society, Nottingham. CDROM

Table A3.1
Location of field gates in the River Sem catchment, which open onto either roads or tracks, and data related to potential soil loss through the gates.

Gate ID	NGR	X-Coordinate	Y-Coordinate	Catchment Area (m2)	Min elevation (m)	Max elevation (m)	Elevation range (m)	Maximum Distance (m)	Slope ((max - min) / dist)	Intersects Road	Combined - at risk	Land cover group
62	ST881271	388199	127119	8404	123.145	128.27	5.1248	204	0.025	TRUE	TRUE	Grass
18	ST894277	389465	127719	1701	119.846	126.901	7.055	233	0.03	FALSE	TRUE	Grass
44	ST883275	388360	127595	1401	123.122	131.087	7.965	191	0.042	FALSE	TRUE	Grass
170	ST876251	387605	125190	1334	191.968	213.775	21.8074	104	0.21	FALSE	TRUE	Grass
109	ST892260	389214	126036	1110	160.847	175.189	14.3415	107	0.134	FALSE	TRUE	Grass
68	ST879271	387961	127139	901	124.99	128.581	3.5913	95	0.038	FALSE	TRUE	Grass
176	ST875255	387513	125567	703	158.673	163.004	4.3315	47	0.092	FALSE	TRUE	Grass
215	ST871247	387169	124777	700	243.245	244.715	1.4701	79	0.019	FALSE	TRUE	Grass
191	ST869257	386979	125735	604	184.603	194.031	9.4285	78	0.121	FALSE	TRUE	Grass
149	ST885254	388522	125479	505	175.335	182.351	7.0161	47	0.149	FALSE	TRUE	Grass
179	ST875252	387539	125297	504	180.476	188.579	8.1033	64	0.127	TRUE	TRUE	Grass
192	ST869257	386931	125724	404	189.332	196.967	7.6346	49	0.156	FALSE	TRUE	Grass
98	ST890262	389009	126286	402	149.708	154.738	5.0298	49	0.103	FALSE	TRUE	Grass
148	ST885254	388547	125457	402	177.117	182.893	5.7759	49	0.118	FALSE	TRUE	Grass
186	ST868251	386854	125153	401	243.42	244.987	1.5668	21	0.075	TRUE	TRUE	Grass
32	ST893268	389388	126872	400	123.237	124.889	1.6528	45	0.037	FALSE	TRUE	Grass
51	ST882273	388269	127393	400	126.237	127.846	1.6086	37	0.043	FALSE	TRUE	Grass
205	ST874261	387427	126149	300	137.704	139.954	2.25	35	0.064	FALSE	TRUE	Grass
206	ST873261	387372	126181	300	141.052	142.792	1.7398	35	0.05	FALSE	TRUE	Grass
152	ST888249	388890	124904	201	221.035	222.75	1.7152	21	0.082	TRUE	TRUE	Grass
36	ST885277	388577	127758	200	123.942	124.294	0.3522	21	0.017	FALSE	TRUE	Grass
174	ST876258	387651	125881	200	140.711	140.996	0.2848	21	0.014	FALSE	TRUE	Grass
143	ST883256	388310	125655	18188	153.218	231.139	77.9217	739	0.105	TRUE	TRUE	Bare
194	ST867258	386797	125863	402	188.929	194.266	5.3376	49	0.109	TRUE	TRUE	Bare
210	ST876248	387635	124838	400	237.643	239.26	1.6173	49	0.033	FALSE	TRUE	Bare

153	ST889249	388958	124923	5514	218.056	230.52	12.4636	204	0.061	FALSE	TRUE	Tilled
132	ST879262	387934	126226	3705	127.897	139.694	11.7969	238	0.05	FALSE	TRUE	Tilled
16	ST897280	389751	128000	1501	106.789	112.87	6.0811	197	0.031	TRUE	TRUE	Tilled
20	ST893275	389356	127561	1001	125.303	129.996	4.693	134	0.035	FALSE	TRUE	Tilled
131	ST878261	387899	126190	801	128.474	134.964	6.4896	106	0.061	FALSE	TRUE	Tilled
1	ST892282	389279	128228	800	116.298	118.69	2.3925	89	0.027	FALSE	TRUE	Tilled
150	ST885250	388587	125073	500	229.823	231.098	1.2745	35	0.036	TRUE	TRUE	Tilled
3	ST891282	389178	128224	200	117.844	119.313	1.4686	21	0.07	FALSE	TRUE	Tilled
75	ST886270	388666	127000	200	117.031	118.636	1.6045	21	0.076	FALSE	TRUE	Tilled
88	ST891267	389112	126719	200	127.569	127.882	0.3125	21	0.015	TRUE	TRUE	Tilled
6	ST889280	388940	128044	100	121.034	121.119	0.0856	7	0.012	FALSE	TRUE	Grass
31	ST895269	389500	126908	100	122.129	122.399	0.2699	7	0.039	FALSE	TRUE	Grass
80	ST885269	388529	126949	100	119.024	119.147	0.123	7	0.018	FALSE	TRUE	Grass
161	ST893249	389376	124929	100	219.207	219.69	0.4831	7	0.069	FALSE	TRUE	Grass
162	ST884249	388454	124987	100	224.935	225.613	0.678	7	0.097	FALSE	TRUE	Grass
188	ST868251	386874	125151	100	243.951	244.983	1.0325	7	0.148	FALSE	TRUE	Grass
197	ST872257	387215	125790	100	166.788	168.055	1.2671	7	0.181	FALSE	TRUE	Grass
212	ST873248	387399	124813	100	241.42	241.618	0.1976	7	0.028	FALSE	TRUE	Grass
219	ST890257	389043	125790	100	189.757	190.662	0.9047	7	0.129	FALSE	TRUE	Grass
220	ST890258	389039	125874	100	184.479	184.919	0.4399	7	0.063	FALSE	TRUE	Grass
97	ST889264	388952	126432	100	136.881	137.492	0.6105	7	0.087	FALSE	TRUE	B-L wood
23	ST892273	389223	127312	100	131.398	131.527	0.1288	7	0.018	FALSE	TRUE	Tilled
25	ST892271	389207	127123	100	129.774	130.365	0.5902	7	0.084	FALSE	TRUE	Tilled
66	ST880272	388038	127221	100	127.859	128.247	0.3883	7	0.055	FALSE	TRUE	Tilled
228	ST889280	388975	128034	100	120.551	120.733	0.1817	7	0.026	FALSE	TRUE	Tilled
144	ST883256	388390	125651	26301	150.509	224.941	74.4316	532	0.14	TRUE	FALSE	
208	ST874261	387445	126128	13624	136.653	158.864	22.2103	373	0.06	TRUE	FALSE	
72	ST888269	388895	126989	1600	122.107	126.202	4.0959	194	0.021	TRUE	FALSE	
73	ST888269	388806	126991	1300	121.088	125.292	4.2046	177	0.024	TRUE	FALSE	
221	ST891258	389159	125859	1126	181.647	205.772	24.1249	107	0.225	TRUE	FALSE	
30	ST896270	389691	127052	1000	121.019	121.582	0.5625	89	0.006	TRUE	FALSE	
7	ST888280	388892	128040	900	120.961	121.511	0.5504	69	0.008	TRUE	FALSE	
214	ST871247	387192	124758	900	242.712	244.567	1.855	99	0.019	TRUE	FALSE	
169	ST876251	387658	125164	821	190.873	215.372	24.4982	106	0.231	TRUE	FALSE	

96	ST889263	388952	126342	805	141.573	153.371	11.7984	106	0.111	TRUE	FALSE
69	ST878270	387829	127039	801	125.824	130.605	4.7808	106	0.045	TRUE	FALSE
190	ST869257	386964	125747	707	183.387	197.162	13.776	92	0.15	TRUE	FALSE
92	ST890265	389023	126514	701	131.383	135.975	4.5921	92	0.05	TRUE	FALSE
199	ST872258	387247	125838	603	160.532	169.603	9.0706	78	0.116	TRUE	FALSE
130	ST878261	387851	126194	600	128.682	131.622	2.9398	78	0.038	TRUE	FALSE
211	ST876248	387644	124865	600	237.12	239.655	2.5357	78	0.033	TRUE	FALSE
207	ST873261	387386	126165	401	139.867	142.67	2.803	49	0.057	TRUE	FALSE
227	ST891268	389157	126842	400	126.487	127.062	0.5751	45	0.013	TRUE	FALSE
58	ST884269	388456	126986	301	119.698	121.468	1.7697	27	0.066	TRUE	FALSE
65	ST880271	388066	127185	300	126.247	127.785	1.5381	35	0.044	TRUE	FALSE
175	ST876260	387610	126053	300	135.105	135.94	0.8344	27	0.031	TRUE	FALSE
151	ST886251	388607	125114	200	230.979	231.315	0.3363	17	0.02	TRUE	FALSE
163	ST884249	388413	124982	200	225.227	226.381	1.1544	21	0.055	TRUE	FALSE
5	ST889280	388946	128045	100	120.814	120.868	0.0539	7	0.008	TRUE	FALSE
11	ST887278	388732	127860	100	121.8	121.833	0.0331	7	0.005	TRUE	FALSE