AN EARTH SYSTEMS ENGINEERING APPORACH TO THE DIRECT MANAGEMENT OF RUNOFF FLOW PATHS AND NUTRIENT REMEDIATION AT SOURCE

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ABSTRACT

Rural land use and management is a well studied subject, however there is a need for tools that will support policy making, that will empower local experts and educate farmers towards sustainable farming activity. Earth Systems Engineering and Management is a new approach that accepts that the Earth is already highly engineered and that there are a range of proactive interventions that can take place within the landscape that can create an environment that benefits everyone. Here, two recently developed tools are used to visualise and prioritise the opportunities we have to both understand the sources of nutrient enriched runoff and also control runoff flow pats. Strategic locations within the landscape afford us many opportunities to target and remediate flows under varying conditions. Hence, a high resolution terrain analysis toolkit is presented, TOPMANAGE, that can highlight likely runoff flow paths, the operation of Critical Source Areas and depict the potential locations to control nutrient runoff loss whilst maintaining the economic viability of the farmer. Equally, a policy tool is presented that integrates many hydrologic/agronomic/policy factors into a clear problem solving framework. Thus, a Decision Support Matrix is presented that allows both farmers and policy makers to visualise and prioritise strategies to reduce nutrient pollution through proactive land management.

Keywords: terrain analysis, runoff management, decision support.

INTRODUCTION

Despite the abundance of knowledge available to scientists regarding land management there is still a lack of momentum in solving the nutrient pollution problem. Equally, frustration and conflict exists between policy makers and stakeholders in setting convincing and workable land use change initiatives and best management practices. To this end, two decision making tools are presented that are currently being implemented in a number of ongoing research projects that are pursuing an Earth System Engineering and Management (ESEM) agenda.

METHODS

The first ESEM tool is TOPMANAGE (www.ncl.ac.uk/TOPCAT/Topmanage), a topographical/hydrological toolkit that uses high resolution digital terrain analysis to highlight the likely runoff flow paths seen on farms. The tool operates at a grid resolution of 50 cm – 2m, which can also include observed man made features such as tramlines, land drains, tyre tracks and hedgerows. It is also important that a rudimentary hydrological analysis is also carried out to establish the principal components of the hydrological runoff mechanisms (e.g. overland flow, drain flow or flow subsurface flow). Cheap and rapidly acquired evidence for the source of polluting flow can be assessed on farmers' fields either during or shortly after medium and large storm events. Basic supporting knowledge of likely nutrient loading, soil analysis and grab samples taken in recession and baseflow periods gives more insight to the nature of the pollution problem. Often Universities and Institutes instrument sites at large cost to achieve this knowledge, however, it is local farmers and agronomists who can easily supply this type of information. Moreover, the key evidence of storm related polluting events already exists in the memory of the farmers and usually only requires a simple visual prompt to identify whether or not their fields are causing pollution (for examples using photographs of erosion on bare fields, sediment fans and sediment filled ditches with fresh deposits). It is therefore possible to suggest obvious opportunities to abate pollution without using TOPMANAGE but just hydrological common sense alone. TOPMANAGE and instrumented research catchments are demonstrations to the wider community that we understand runoff, pollution and hoe to prioritise the locations best suited to engineer the land.

A complementary tool to TOPMANAGE is the Decision Support Matrix (DSM). The DSM seeks to integrate and prioritise the key factors controlling the environmental problem, in this case nutrient pollution (Quinn 2003). The DSM targets the farm scale as the key scale where the greatest impact of nutrient pollution loss can be achieved (it is assumed that farms and catchments can be treated the same way, i.e. hillslopes feeding channel networks). It becomes clear that many farming practises are targeted towards crop and soil management that give high yields with the lowest soil nutrient surplus. The secondary and less understood factor is how nutrient pollution reaches the larger receiving channels. In the ongoing rural management projects, despite the complexities of the farming activities and runoff variability it is possible to communicate both how runoff mobilises available nutrients and how it moves them on and through the fields to the ditches and hence to the larger receiving waters. Pollution risk can often be assessed just by asking informed questions relating to farming intensity and practise. This simple information must then be combined with the concept of runoff management, which points towards obvious mitigation strategies. Even with improved crop and soil management the problem of rainfall falling on some farmers' bare soils with high nutrient levels will always remain. Equally, it is assumed that farmers will always require sound economic returns form their crop and livestock. It is also likely that higher level of environmental standards will be required in the future, hence ESEM may offer the best hope of reducing pollution for the near future.

RESULTS AND DISCUSSION

The acquisition of accurate high resolution terrain data is now relatively easy and cheap. Global Position Systems and LIDAR data are often used in scientific research. In the current ESEM studies shown here (such as the CHASM project, Quinn et al., 2003 and SEAL Burke et al., 2003), a Leica 500 series GPS is mounted onto the CHASM 'Green Machine' (Quinn et al., 2003, Hewett and Quinn 2003). Complementary data for ditches and the location of drain outfall are mapped separately on foot using the same GPS. Terrain analysis, is a well established subject and has often been used to study surface and subsurface flow paths (Quinn and Beven, 1993). The terrain analysis used here is based on the multiple flow direction algorithm (Quinn et al., 1995) and is not the same algorithm as those commonly present in existing GIS packages.

Figure 1 shows a 2m map of a farmers field studied in the SEAL project (Burke et al., 2003). The site grows cereal crops, has silty clay soils, steep slopes and is often prone to overland flow in the early winter period. Hence the storm events are falling on bare soil with high nutrient loading. Even though some sedimentation/infiltration occurs on the floodplain zone, clear evidence of the overland flow connectivity to the stream is evident. Also, the flood plain becomes a nutrient source during flooding events. Stage 1, of TOPMANAGE is to study how the overland flow is leaving the field. A flow accumulation map is then produced for figure 1, N.B. the track in the field has been added to the map and is known to control flow during storms (see figure 2 A). It is also known that the farmer cultivates the field along the steepest gradient. It is possible to add the effect on this cultivation techniques to the maps (see figure 2 B) – this is stage 2 of the TOPMANAGE analysis.

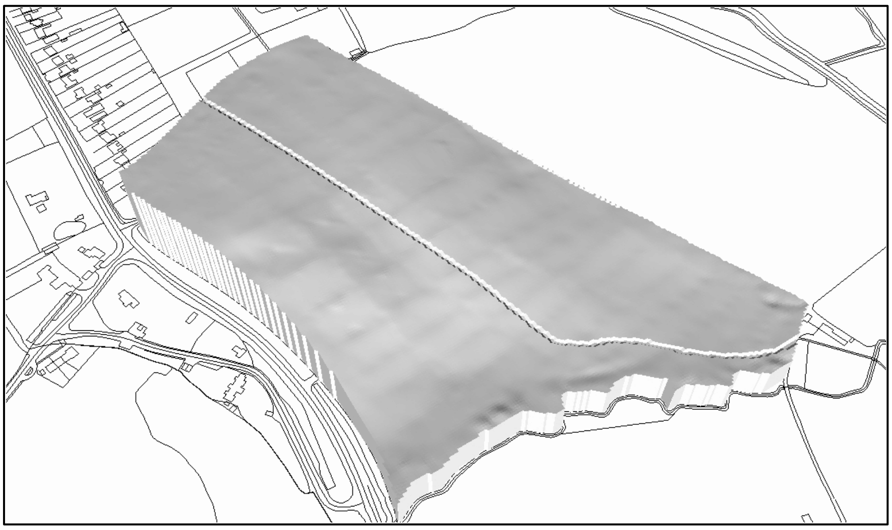

Fig 1. A high resolution terrain map (2m grid cells) for a site vulnerable to overland flow losses (n.b. the main track is included on the map)

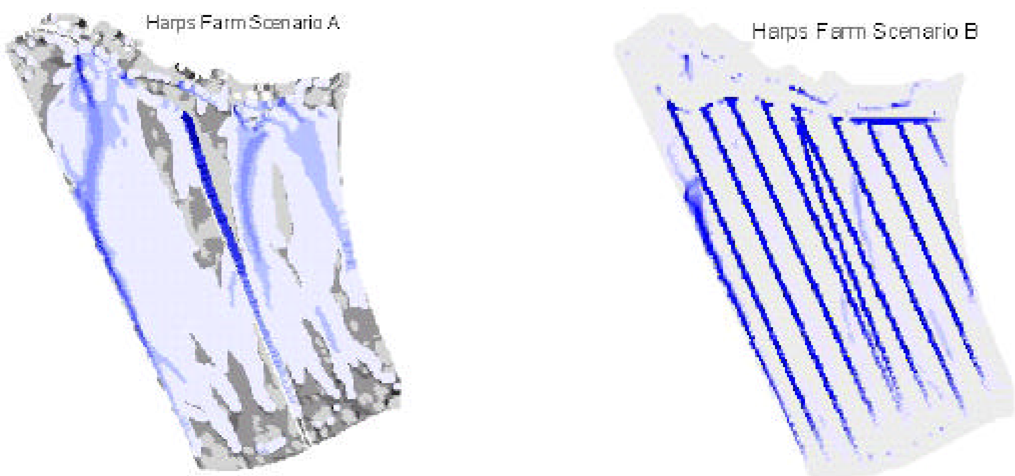

Figure 2 A. A flow accumulation map for the terrain in figure 1 (darker shades indicate locations where overland flow is concentrating). Figure 2 B. Is the flow accumulation including the effects of tramlines.

By understanding the interaction of the natural and the man made gradients, it is possible to visualise and quantify the likely volumes of overland flow reaching certain locations. Stage 3, of the TOPMANAGE analysis is thus to propose a direct engineering intervention to disconnect most if not al the overland flow from the receiving channel. Further to this, low technological remediation strategies can be implemented to guarantee that phosphorous stripping and denitrification will take place. The proposed ESEM strategy for this field is thus threefold:-

1. To create a tramlines that deliver flow to the natural gradient of the land (see figure 3 A)
2. To create a temporary storage/infiltration/remediation pond that will store overland flow during a design storm event (in this case 10mm of overland flow will be stored), see figure 3 B.
3. Switch crop production on the flood plain only.

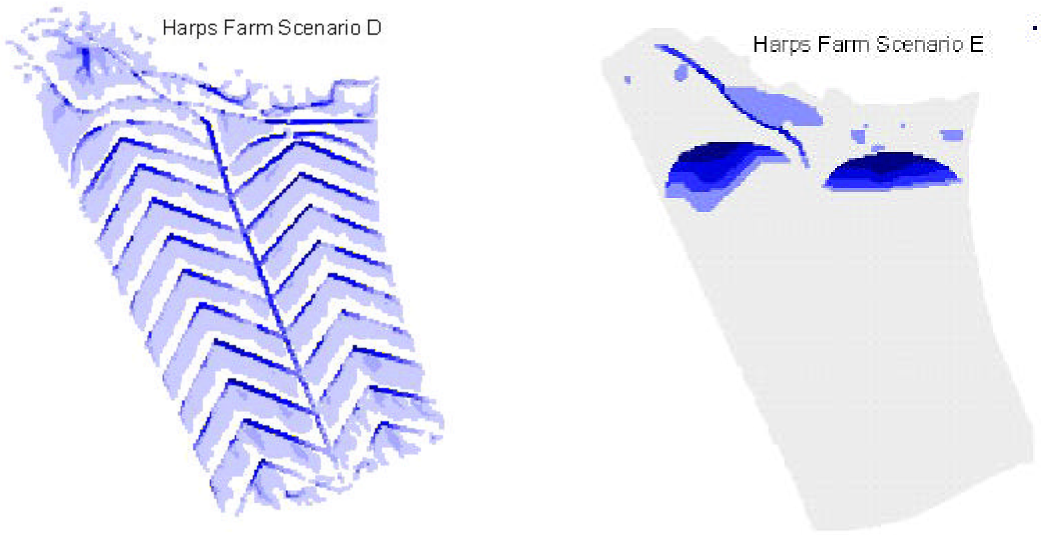

Fig 3A, The flow accumulation map where the tramlines pattern work with the natural terrain to guarantee that overland flow moves towards the desired location. Fig 4B is a depth of storage map showing the size, location and depth of the overland flow within a low cost temporary storage pond.

The above TOPMANAGE process needs to be communicated to both farmers and local land use policy makers. Hence the DSM approach is used. As an example of the management of phosphorous losses will be depicted in a simple form, despite the complexity of the P problem. Figure 4 shows the DSM P loss matrix, where the value on the map is the total P loss for a typical year. The structure of the matrix relates to crop/livestock/soil management on the vertical axis (which also includes soil type). A series of questions are answered that must be expressed in terms of their relative risk to mobilising the P available in the soil. The horizontal axis, uses a series of questions relating to natural and man made features that are controlling the runoff and buffering processes in the field. The two sets of question lead to the plotting position for the current sites (figure 5), here the field studied above (figure 1) has been added to the matrix.

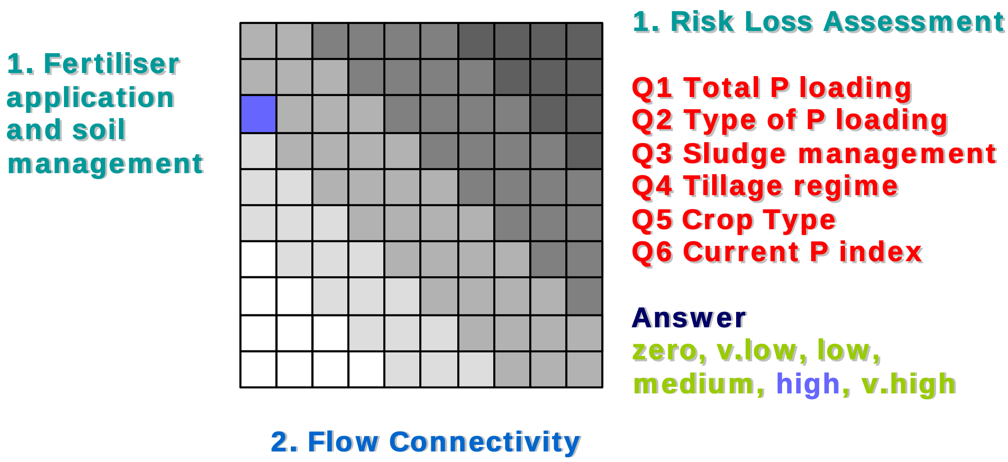

Figure 4 The DSM for P risk loss – showing questions relating to the vertical axis (the blue square is an estimate of the risk for the study field)

It is now possible to use the same matrix in mitigation mode and suggest a number of land use recommendations. Some ESEM options are clearly not possible, for example stopping cereal production. However some strategic ESEM options can have a very large impact on the nutrient pollution risk (see figure 6). Even though all the estimates of P availability, P transport and the impact of P management and remediation are all subject to very large uncertainty, it should be clear that a range of options are available to move to a lower P loss level from this site. The TOPMANAGE recommendations how a clear opportunity to greatly reduce the pollution risk whilst the farmer can maintain profit on 85-95% of their field.

CONCLUSION

Two tolls are presented, the first shows a GIS tool that can reflect how runoff can mobilise and transport nutrient to receiving water, through terrain analysis, local evidence and hydrological common sense. The tool offers the opportunity to target flows that pose a pollution risk, to manage that flow and also suggest engineering recommendations to abate pollution.

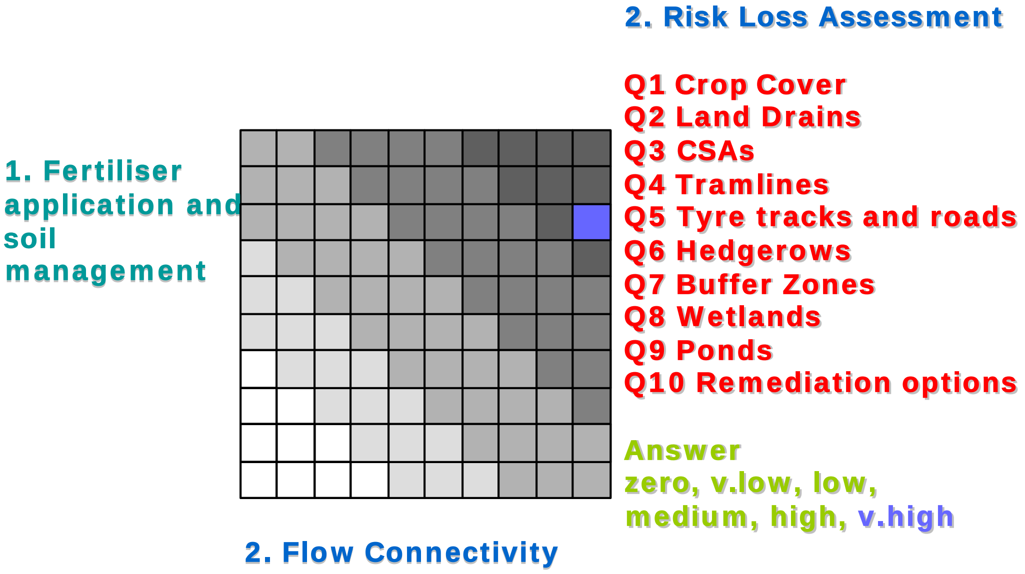

Figure 5 The DSM for P risk loss – showing questions relating to the horizontal axis (the blue square is the final estimate of the risk for the study field, have answered all questions)

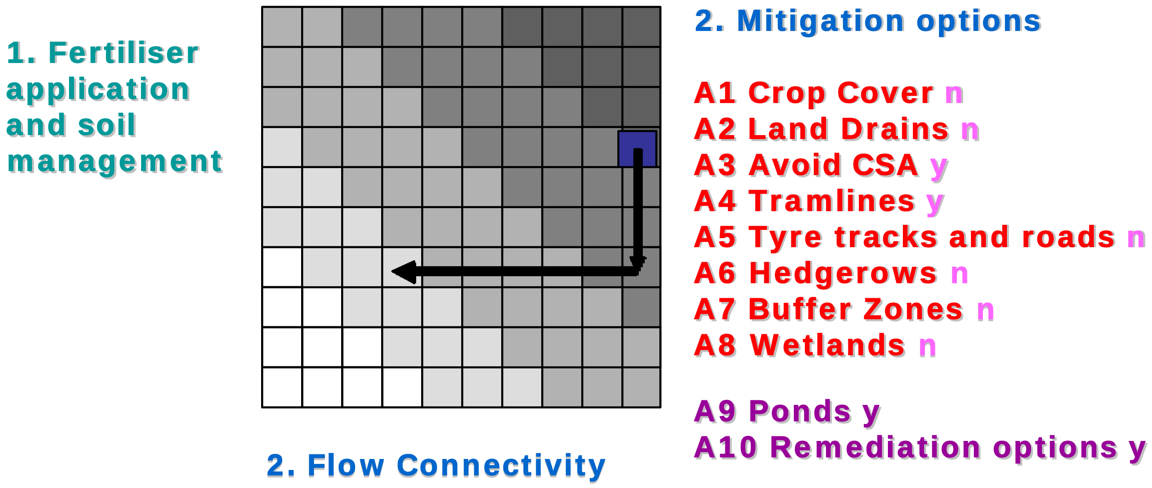

Figure 6. The DSM in mitigation mode. The various questions represent whether or not a mitigation option is to be followed. The blue square was the original position of the study field. Te two arrows reflect the likely impact of firstly controlling the amount P available to mobilisation (vertical arrow) and secondly the impact of the proposed ESEM approach to runoff management (horizontal arrow)

The second tool seeks to integrate many factors that control nutrient pollution risk through a simple Decision Support Matrix. The DSM for nutrient loss can reflect:-

1. the nutrient available to the transport processes,
2. the mechanisms by which the flow propagate though and off the farm.

Hence, the DSM encourages a range of viable mitigation strategies to control, intercept, buffer and remediate polluting runoff.

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