Managing multiple non-point pressures on water quality and ecological habitat: Spatially targeting effective mitigation actions at the landscape scale

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Overview

Catchment systems deliver many benefits to society and ecology but also produce a range of undesirable externalities including flooding, non-point source pollution (from agriculture, forestry and urban areas) and the export of FIOs. These diffuse pressures are coupled with increasing stream temperature pressures on rivers from habitat change and projected changes to climate. These pressures can be reduced through actions at the landscape scale but are often tackled individually. Any intervention may have benefits for other pressures and hence the challenge is to consider all of the different pressures simultaneously to find solutions where one action has multiple benefits.

The general approach taken within this research has been to use simple, but spatially distributed, models to predict the pattern of each of the pressures at the landscape scale. These models follow a 'minimum information requirement' approach along the lines of the SCIMAP modelling approach (scimap.org.uk). This approach aims to capture the key features of the processes in relative rather than an absolute sense and hence the approach is good at determining key locations to act within a landscape for maximum benefit. The core of the approach is to define the critical sources areas for each pressure based on the analysis of the pattern of the pressure in the landscape and the connectivity from the sources areas to the rivers and lakes.

To identify the optimal locations within the landscape for mitigation actions, the benefit of a mitigation action at each location in the landscape needs to be considered. However, as one action has been made, it may change the suitability of other locations in the landscape. For example, as tree cover reduces the temperature in one river reach, the impacts of this cooling are transported downstream with the flow. Therefore, actions need to be considered in sets across multiple sites and objectives to identify action sets that deliver good environmental outcomes.

The River Ribble Catchment

The River Ribble catchment is located in north west England covering 1317 km^2. The land cover is a mix of urban, grassland and moorland. Currently 35% of the waterbodies are classified as 'good' under WFD. Key pressures on the system are:
- fine sediment impacting fish stocks
- FIOs impacting bathing waters
- flood risk effecting the urban areas
- the potential for elevated water temperatures effecting fish stocks.

Figure 1: Map of the River Ribble catchment, north west England, UK

The SCIMAP Approach

The approach taken to modelling the different distributed pressures is based on the SCIMAP framework. The SCIMAP framework identifies the critical source areas within the landscape by jointly analyzing spatial patterns of diffuse pollution risk at individual points and potential for a hydrological connection to be made to the receiving waters. The modelled impact of the exported material on the rivers is predicted by taking into account the potential for accumulation and dilution. These calculations are based on a 'minimal information' requirement approach and aims to identify the relative rank order of contributing locations rather than the absolute export of material in mg / l.

The SCIMAP results are generated at a 5m-pixel level or below, to give within field estimates of risk and connectivity, and applied to whole landscapes (from 1 to 2000 km^2 +) to give a broad overview of the potentially problematic locations. SCIMAP therefore gives a systematic approach to prioritizing areas within large landscapes for further, on the ground, investigations. SCIMAP is normally used with a land cover map, a detailed DEM (5m), in large catchments and information about the spatial pattern of rainfall. To assess the predictions, or to use SCIMAP Fitted, in stream measurements of water quality are needed. Therefore, SCIMAP uses a minimal dataset, making it simple to apply to new locations.

Hydrological Connectivity

Central to the SCIMAP approach is the spatial mapping of hydrological connectivity at the landscape scale, based on the Network Index. The hydrological connectivity describes how easy it is for water or water transported material to connect with rivers or lakes. The calculation is based on tracing each flowpath and finding how wet the catchment needs to be for each location to both generate and transmit runoff to the river or lake. In the figure:
- blue areas connect first and more frequently
- red areas connect last and least frequently.

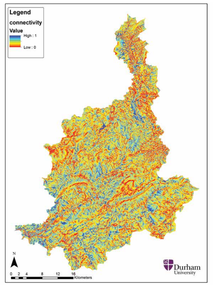

Figure 2: Map of predicted pattern of hydrological connectivity based on the Network Index

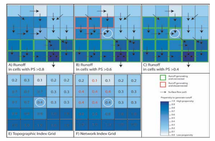

Figure 3: Approach to determining the hydrological connectivity based on the Network Index approach

Flood Risk

The representation of flood risk generation is focused on the generation of rapid overland flow. The local generation risk is calculated based on the land cover representing the differences in infiltration rates (lc), slope gradient effecting the soil depths and speed of transmission (B), local rainfall to capture differences across the catchment (rf) using:

$$Fr = lc * B * rf$$

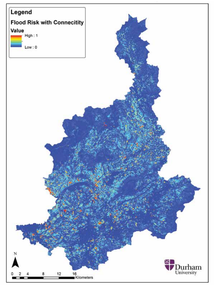

Figure 4: Map of predicted pattern of rapid overland flow generation and connection risk

These generate weightings which are then multiplied by the connectivity predictions to give Fig 4.
The highest flood risk weight is given to land covers with exposed soil surfaces, such as arable, and the lowest risk weight is given to woodland. Urban areas are not considered in the approach since the engineered drainage would not be effected by the proposed mitigation measures.

Fine Sediment Risk

The spatial pattern of the level of risk for fine sediment erosion in the landscape is determined by the balance of the energy available to erode the surface and the erodability of the soil. The driving energy is determined by the local stream power (p = UCA * Slope) and the erodability is related to land cover (lc) as a proxy for the amount of time that there are bare soil surfaces. Therefore, the fine sediment risk is determined by:

$$FSr = lc * sp * rf$$

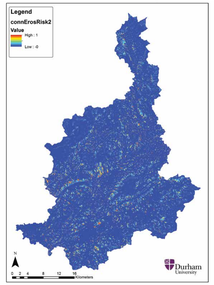

Figure 5: Map of predicted pattern of fine sediment erosion and connection risk

The weightings generated are then multiplied by the connectivity predictions to give Fig 5. This approach has been successfully tested across a range of UK catchments and is used by the Environment Agency and local Rivers Trust's.

Faecal Indicator Organism Risk

The level of risk for faecal indicator organisms (FIO) in the landscape is controlled by both the rate of application from livestock and the potential for die off during transport. The rate of application has been related to the amount of improved grassland and the die off is inversely rated travel time to the outlet of the catchment. Therefore, the local generation risk is calculated based on the land cover (lc), distance to the catchment outlet (d) and local rainfall (rf) using:

$$FIOr = lc * d * rf$$

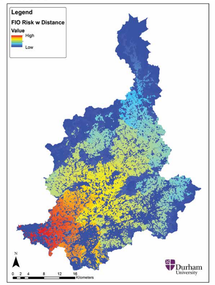

Figure 6: Map of FIO loadings and connectivity

These FIO risk generation values are then multiplied by the connectivity predictions to give Figure 6. A more detailed representation of FIO risk is currently being developed.

Stream Temperature Risk

The spatial pattern of water temperature was calculated as a rate equation process with the temperatures increasing towards an observed maximum value. This representation allows for the rate of increase in temperature to decrease with increasing catchment area. The rate of temperature change was related to the local amount of shading from vegetation, based on the Environment Agency (England) 'Keeping Rivers Cool' lidar dataset. Example output is shown in Figure 7. This representation does not currently account for cooler or warmer groundwater recharge to the channel effecting the in-stream water temperature. Riparian tree planting is being used as a mitigation measure for the reaches with elevation water temperatures. This measure has the additional benefit of disconnecting overland flow pathways and hence also reduces fine sediment, FIO and flood risk.

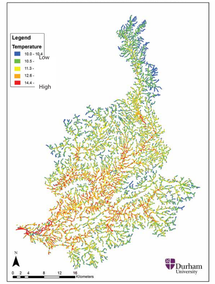

Figure 7: Map of predicted stream temperatures

Decision Support System

These modelling results are integrated into a web based decision support tool (Figure 8) which allows the user to explore the implications of considering an individual pressure as opposed to the set of pressures. This balancing of pressures is achieved by allowing the user to change the importance of different pressures to identify the optimal locations for a custom combination of pressures. For example, reductions in flood risk can be prioritized over reductions in fine sediment. This part of the analysis takes into account the restrictions on changing the land cover due to legal designations, such as RAMSAR sites or Special Areas of Conservation, Figure 9.

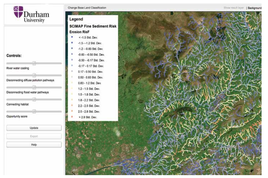

Figure 8: The web based decision support system that allows for the creation of mitigation scheme creation based on different weighting between the environmental pressures. Through exploring the different scenarios, it is possible to identify locations in the landscape where one mitigation action will have multiple benefits. Note: DSS is currently in development.

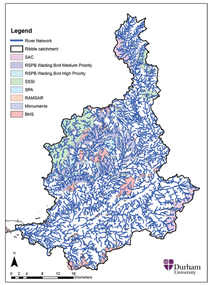

Figure 9: Map of constraints to woodland planting

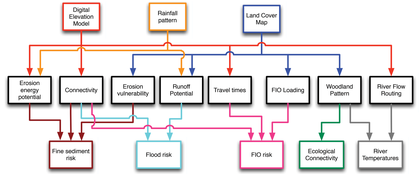

Figure 10: Flowchart showing how the information from primary datasets (DEM, rainfall and land cover) is converted into process representations, such as connectivity or runoff potential, and finally to risk maps.

Summary

The approach taken within this research is to consider a range of environmental pressures, which are normally managed separately, as single suite of problems that can be tacked with similar mitigation measures, such as tree planting. A set of reduced complexity models based on DEM analysis and simple physically based representation have been implemented. Based on the results of these models, it is possible to spatially target the mitigation measures at the landscape scale. To allow wide access to the tools, a web based GIS is being developed to allow users to experiment with a range of different priorities and identify locations where one measure will have multiple benefits.