Case study 4

River Wensum sediment study - Norwich

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1. Catchment summary

Study location

The Wensum is one of the most important chalk river habitats in the UK. It originates between the villages of Colkirk and Whissonsett and stretches for 78km through the east of England (Figure 1). It is a low gradient, groundwater-dominated river which flows through a number of nature reserves, towns and cities before reaching its confluence with the River Yare in Whitlingham.

Human activities have altered the natural state of the Wensum through impoundments by watermills and weirs, and the modification from multiple channels to a single channel. The river and its tributaries are now classified for Water Framework Directive purposes as heavily modified water bodies (Collins et al. 2013). The development of agricultural land on the floodplains has also altered the natural drainage conditions of the catchment, greatly influencing its storage capacity.

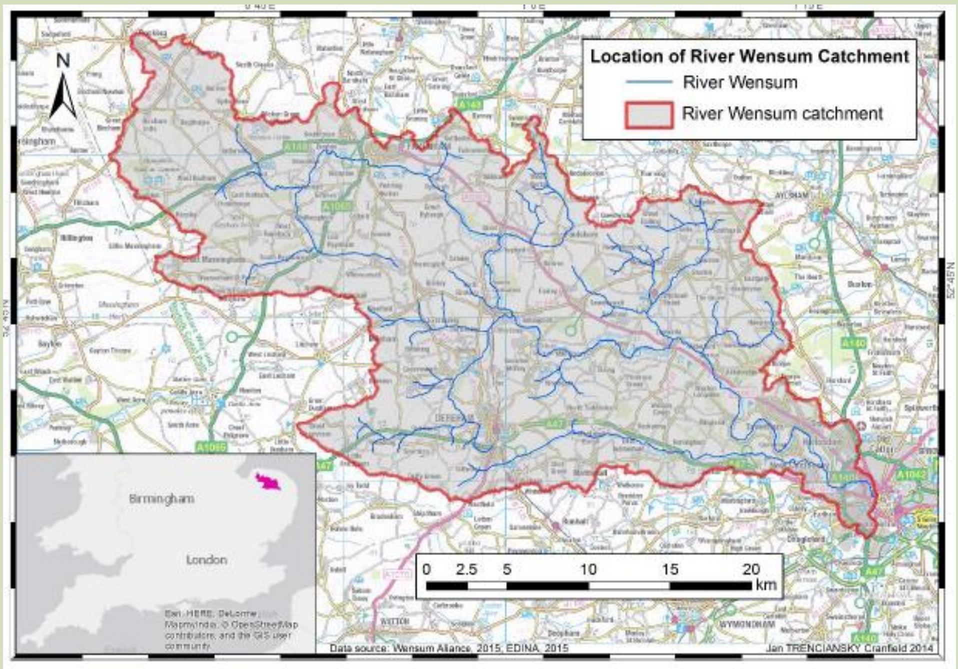

Figure 1: Wensum catchment

Source: Wensum Alliance

Catchment summary

Soil erosion and sediment accumulation within river channels is particularly problematic in the River Wensum catchment (Sear et al. 2006). In 2001 the entire stretch of the Wensum was designated a Site of Special Scientific Interest (SSSI) and a Special Area of Conservation (SAC) to conserve species such as the bullhead, brook lamprey, white-clawed crayfish, Desmoulin's whorl snail, and crowfoot and water starwort vegetation (Collins et al. 2013). However, sediments, bank poaching and diffuse water pollution mean that the Wensum has a 'poor ecological' potential under the Water Framework Directive with 99.4% of the SSSI habitats considered unfavourable or declining (Wensum Alliance 2015a). A catchment walkover survey carried out for this case study highlighted channel poaching by livestock, channel clearance and arable run-off as the main pathways of sediment to the river (Figure 2).

The city of Norwich, located just before the confluence of the rivers Wensum and Yare, is the largest development in the catchment with a population of approximately 376,500. It is one of a number of settlements in the catchment at risk of flooding from the River Wensum. Agricultural areas within the catchment are also at risk of widespread and relatively frequent flooding. Flood damage to urban infrastructure is a timely and costly process to repair and recover. Between May and October 2014, Norwich incurred estimated flood damage costs of over £1.5 million to 51 residential buildings and 29 commercial and public buildings (Brown 2015).

The current flood management strategies for the Wensum catchment involve the construction, strengthening, raising and protection of river embankments and flood walls (Environment Agency 2009). As illustrated by the Pitt Review (2008) these engineering techniques are not considered sustainable in the future. Therefore the Catchment Flood Management Plan (CFMP) for the Wensum aims to reduce the risk by focusing on storing water or managing run-off (for example, by reducing run-off from agricultural land (Environment Agency 2009). This links in with the report’s aim to introduce WwNP strategies that will improve the condition and water storage potential of agricultural areas so as to protect cities such as Norwich against flood damage.

Figure 2: Catchment walkover and identification of sediment sources

Source: Cranfield University

Study summary

This case study demonstrates how a spatially distributed soil erosion and sediment delivery model can be used to identify areas of high sediment production and deposition in a river catchment that is experiencing excess fine sediment pressure.

This investigation incorporated a review of flood risk and water quality strategies, a catchment walkover and the setting up of a screening level geographical information system (GIS) tool to help identify locations of high deposition and erosion. A sensitivity analysis of the model was conducted on 3 core factors:

- land cover
- crop factor
- rainfall erosivity

The GIS-based WaTEM/SEDEM model was applied to the Wensum catchment to investigate how the implementation of various Working with Natural Processes (WwNP) measures affects sediment delivery to the channel. The model identified areas of potential high sediment production and delivery based on topography, land use, soil erodibility and rainfall erosivity.

A walkover survey was carried out across the entire catchment to identify activities and land management practices that might be contributing to sediment production and delivery, and to propose suitable WwNP measures to address them.

The findings demonstrate how land management practices and WwNP measures such as buffers strips, riparian woodlands and crop rotation can reduce soil erosion and sediment delivery to the River Wensum. Targeted buffer strips were shown to be the most effective strategy to minimise sediment delivery. Although uniform buffer strips along the entire network reduced delivery by 16%, targeted buffers strips located on river sections with the greatest sediment delivery (the op 30%) proved to be almost as effective and reduced sediment delivery by 11%.

Community involvement

In terms of communicating with communities and stakeholders, the CFMP currently provides flood warning and forecasting services and increases preparedness by promoting the awareness of the risk of flooding (Environment Agency 2009). However, there is little mention in the CFMP of disseminating knowledge on the causes of flooding in the area and ways in which communities and stakeholders can help alleviate the risk of flooding. Going forward, it is hoped to reduce the consequences of flooding by improving awareness (Environment Agency 2009).

This project developed an approach for communicating the outputs from the GIS model at three different levels:

- communicating to land owners to help them manage soil losses
- a decision support tool for erosion policy development
- making the public aware of erosion concerns

2. Data summary

Datasets and analysis techniques used

The project used the following data:

- catchment Digital Terrain Model (DTM) (OS Terrain 5 DTM)
- land cover data:
- CORINE Land Cover 2006 (spatial accuracy 25m, converted in 20m raster)
- NERC 2007 (spatial accuracy 5m converted in 20m raster))
- crop data (computation of a crop factor)
- soils data
- annual average rainfall
- a river definition (Wensum Alliance 2015b)

Data analysis included a catchment walkover and sediment budget analysis (Figure 3).

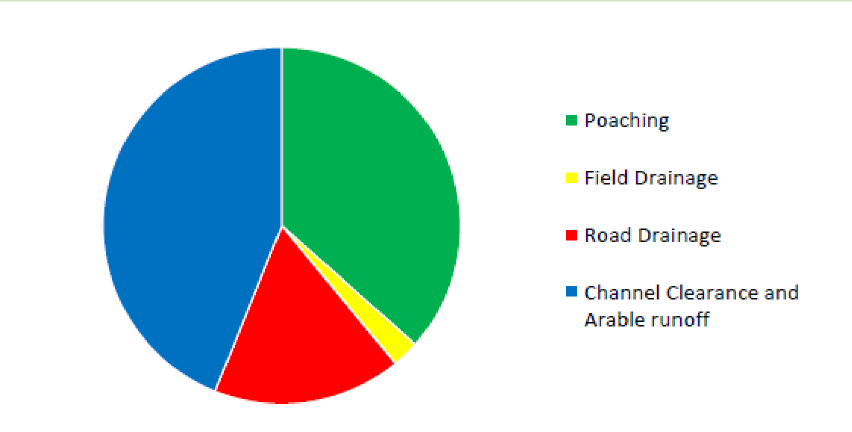

Figure 3: Proportions of identified areas of 'high' sediment inputs into the river Wensum

Source: Cranfield University

Data restrictions

The data and licensing were readily available through project partners and the use of EDINA/ academic datasets.

3. Model summary

Catchment processes investigated

This case study looked at a catchment's sediment sources, pathways and receptors.

Model assumptions

A spatially-distributed soil erosion and sediment delivery model WaTEM/SEDEM has been set up for the River Wensum and can be used to identify areas of high sediment production and deposition within its catchment.

WaTEM/SEDEM is an empirical model that estimates the spatial distribution of soil erosion and sediment delivery in a river on an annual basis. It was chosen for this study because:

- it requires a reasonable amount of input data to calculate sediment transport and sediment yield
- it is suitable for small catchments as it can be run with datasets of 5 or 20m resolution
- it does not require an expert modeller with GIS experience and is relatively user-friendly.
- it is suitable for identifying strategies for reduction of sediment loads which in turn would reduce long-term maintenance budgets and flood risk

The model can be used to identify where measures to control soil erosion and sediment delivery could be taken and to test their effect at small scale (Van Oost et al. 2000, Van Rompaey et al. 2001).

The model's calculations are carried out by dividing the catchment into cells of 20m × 20m. The two main parts of the calculation are erosion and transport. Erosion rates are calculated for each cell based on the online soil erosion assessment tool, RUSLE, developed by Michigan State University. The sediment generated is either deposited or transferred to the next cell based on the local transport capacity.

Data and model outputs

WaTEM/SEDEM outputs the following numerical values in tonnes per year:

- total sediment production over the study area (Figure 4)
- total sediment deposition over the study area
- total sediment export (sediment yield): the total amount of soil leaving the study area equals sediment production minus sediment deposition; ponds are also taken into account for the calculation of the sediment export value
- total river export: total sediment leaving the study area via rivers only
- total pond deposition: total sediment leaving the study area via pond deposition

Model performance

The model was used to assess different WwNP measures. To do this, assumed changes were made to the crop factor to simulate, for example, the effect of buffer strips. Table 1 lists the resulting potential sediment reductions for different WwNP strategies.

The approach developed in this case study helps to target locations where more detailed hydrological and hydraulic models should be focused. Through scenario modelling, it also identified two core strategies for the reduction of sediment production by:

- improving agricultural practices such as crop rotation
- reducing sediment delivery via buffer strips and riparian planting

The two most effective scenarios modelled were:

- implementation of '30% targeted buffer strips'
- a crop rotation including winter wheat, sugar beet and winter barley

The identification of targeted buffer strips as an effective sediment reduction strategy is in line with other research findings.

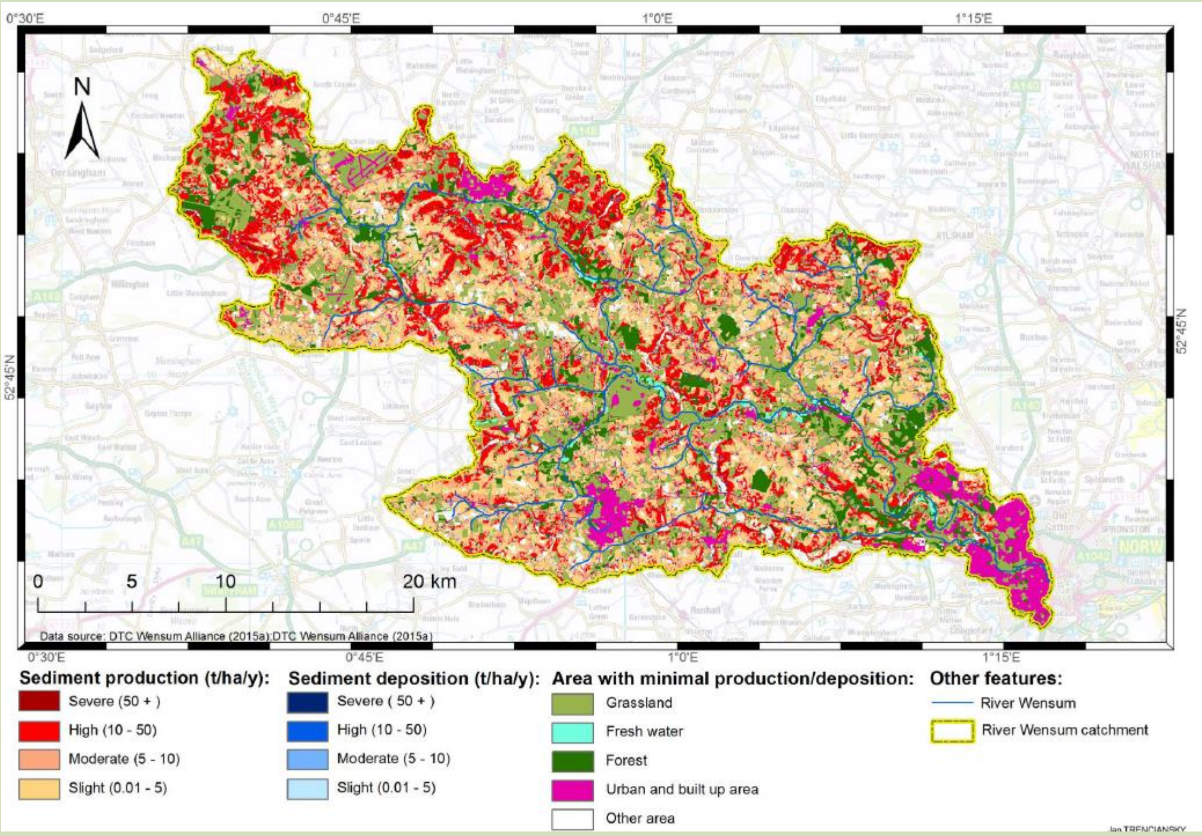

Figure 4: WATEM/SEDEM modelled sediment production and deposition in the Wensum catchment

Source: Cranfield University

Table 1: Sediment reduction for different WwNP scenarios

Strategy	Scenario	Total sediment export reduction (%)
2	Do nothing	0
2	Uniform pasture buffer	16.0
	Uniform woodland buffer	17.3
3	Target 10% pasture buffer	4.3
	Target 10% woodland buffer	4.4
	Target 20% pasture buffer	8.7
	Target 20% woodland buffer	9.0
	Target 30% pasture buffer	11.9

	Target 30% woodland buffer	11.6
4	Crop rotation 1 Crop rotation 2 Crop rotation 3	8.9 12.9 1.1

4. Lesson learnt

Choice of tools

The WaTEM/SEDM model is a relatively simple approach that:

- generates spatially explicit estimates of sediment production and delivery
- allows the testing of alternative management strategies
- provides clear map outputs which are well suited to communicating information about agricultural soil erosion and sediment delivery risk to stakeholders and the public

In this study, the model was applied to the entire Wensum catchment. However, it could easily be applied to subcatchments using higher resolution datasets, which would permit modelling of more complex sediment pathways, barriers and WwNP measures. It appears to be a useful tool that could complement more detailed hydrological and hydraulic modelling of flood risk.

It is likely that the sensitivity to crop factor and rainfall erodibility will need to be explored in new investigations and highlights the need for accurate data. The uncertainty over the coefficients used could be propagated to the model predictions in the GLUE (Generalised Likelihood Uncertainty Estimation) framework as in the Wyre Case Study.

The study showed it is also important to make use of field-based assessments of soil erosion as well as modelled delivery rates else important processes that are at submodel scale may be missed (for example, cattle poaching).

Catchment scale and typology

The GIS model was applied to the whole catchment and the issue was the need to scale the model down to understand the smaller scale features that influence erosion or deposition rates. Suggested amendments to the model resolution or coefficients were made to overcome this.

Regarding typology, the model tends to predict a high erosion rate in croplands where high slope is present. A low erosion rate is usually predicted in areas where pasture, forest or an urban area are present. When a pathway is available for a transfer of sediment from an eroded land to the river (for example, an area without vegetation around the river), the model predicts a high sediment input of sediment in the river. Thus, the presence of an area of high erosion does not necessarily lead to a high sediment delivery in the nearby river – a pathway for sediment transfer is required.

Regarding scale, owing to the model’s 20m resolution and focus on soil erosion, it does not recognised some sources of sediment delivery to the channel. For example, urban areas are known to be significant sources of fine sediment, but the sediment product is considered negligible for this land use in WaTEM/SEDEM. In addition, small scale land management features/practices (for example, poaching of riverbanks by livestock) were not recognised by the model even though they may have a strong influence on sediment production and delivery to the channel.

These issues could be addressed by, for example, reclassifying urban or pasture cells with a higher erodibility coefficient where high road traffic or bank poaching was observed using values from the scientific literature. Small scale practices could be better dealt with at a subcatchment scale using a higher resolution model (for example, 5m × 5m). This would also allow the inclusion of other parameters and landscape features such as tillage direction, field drainage, hedgerows and bank vegetation.

Wider benefits

The case study highlighted the importance of the multiple benefits of better sediment erosion management in terms of water quality, flood impacts and biodiversity.

Fine sediments in rivers can exist in two forms – deposited and suspended – and each can have their own effect on the aquatic environment. The deposition of fine sediment in rivers can alter the channel dimensions, decreasing the storage capacity and increasing the risk of flooding. Sediment deposition can also have an effect on the ecology of a water body by degrading spawning grounds through the burial and suffocation of eggs and larvae (US EPA 2012a, Collins et al. 2013). Suspended sediments within the water can lead to a decline in water quality and aquatic ecosystems. For instance, it can cause clogging of gill mucus, leading to asphyxiation and traumatisation of gill tissue in fish (US EPA 2012a). High concentrations can also elevate and prolong turbidity levels, reducing the penetration of sunlight to submerged aquatic species and lowering productivity (US EPA 2012a, Collins et al. 2013). In addition, increased turbidity can severely affect a fish's ability to see prey or feed normally (US EPA 2012a).

Sediments from arable land can carry with them harmful contaminants and excess nutrients, such as phosphorus and nitrates from fertilisers, which can affect water quality. The sources of contaminated sediments in the Wensum catchment arise from damaged road verges and bank channels, most likely from poaching by livestock, and an increase in run-off generation from the compaction of farm tracks (Collins et al. 2013). Reducing the inputs and pathways of sediments through WwNP strategies will significantly reduce the potential for these harmful nutrients to enter the River Wensum. Subsequently, water quality will improve along to help counter the presently 'declining' SSSI and SAC habitats.

Future research needs

The WaTEM/SEDEM model is sensitive to assumed crop factors and rainfall erosion rates.

The scale issues identified and the need for finer resolution to capture some pathways require further study.

Small scale land management features/practices (for example, poaching of riverbanks by livestock) were not recognised in the model, even though they may have a strong influence on sediment production and delivery to the channel. These could be addressed by, for example, reclassifying urban or pasture cells with a higher erodibility coefficient where high road traffic or bank poaching was observed using values from the scientific literature.

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Project background

This case study relates to information from project SC120015 'How to model and map catchment processes when flood risk management planning'.

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