Case study 7

River Glaven embankment removal - North Norfolk

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1. Catchment summary

Study location

The study was conducted at Hunworth Meadow on the River Glaven. The Glaven is a short (17km long), lowland (elevation is ~21 metres above Ordnance Datum), calcareous river in north Norfolk.

Catchment summary

The River Glaven has a catchment area of 115km2 and flows through agricultural land, deciduous and coniferous woodland, grazing meadows and former floodplain. The river has been modified by agricultural and flood management activities, which have included river channelisation, construction of artificial embankments, soil drainage, river diversion and realignment for weirs and mills, and the application of inorganic fertilisers.

Study summary

River embankments were removed from a 400m reach of the River Glaven in March 2009. The aim of the restoration was to:

- re-establish the hydrological linkages between the river channel and floodplain
- increase floodwater storage
- provide favourable hydrological conditions for floodplain biota
- help the cycling of nutrients

Hydrological, geomorphological, and biogeochemical sampling was conducted before and after embankment removal. Coupled hydrological/hydraulic models of pre-embankment and post-embankment conditions were developed using the MIKE SHE/MIKE 11 system.

Community involvement

Restoration of the River Glaven was carried out by the Environment Agency in collaboration with the River Glaven Conservation Group, local farmers, the landowner, the Wild Trout Trust and Natural England.

2. Data summary

Datasets and analysis techniques used

The original data were collected for academic research and are being used in Hannah Clilverd's PhD dissertation. The ownership of these data rests with UCL and any request for access to the data would be dealt with on a case-by-case basis by Hannah Clilverd and Dr Julian Thompson.

Other national datasets used were:

- Environment Agency –river discharge data
- UK Met Office meteorological data – supplemented by onsite weather station data

Onsite data collection included measurements of:

- river discharge
- precipitation
- temperature
- groundwater depth
- differential global positioning system (dGPS) surveys before and after the removal of river embankments

- fine scale botanical and soil chemistry sampling
- measurements of river and groundwater chemistry

For a detailed description of analysis techniques used see Clilverd et al. (2013).

Data restrictions

Licenses were needed from a range of organisations.

3. Model summary

Catchment processes investigated

This study looked at the removal of river embankments (longitudinal barriers) and the impacts on river–floodplain connectivity, flood water storage on the floodplain and downstream flood peak attenuation.

Model assumptions

Coupled MIKE SHE/MIKE11 hydrological/hydraulic models were used to quantify the hydrological responses to river embankment removal. This is a deterministic, physically-based, fully distributed comprehensive modelling system driven by daily air temperature, precipitation, evapotranspiration and gridded fields of physical properties (for example, topography, geology, soil properties and vegetation cover) and MIKE11, a one-dimensional hydraulic modelling system.

Dynamic coupling of the MIKE11 river model and the MIKE SHE model enabled the simulation of:

- river–aquifer exchange
- inundation from the river onto the floodplain
- the return of overland flow to the river

The model looked at the frequency of bankfull discharges, surface water depth and flood water extent on the floodplain during out of bank flood events.

Data and model outputs

Map outputs from the embanked MIKE SHE model and bankfull capacity measurements in MIKE 11 were used to identify sources of flooding on the floodplain such as groundwater flooding versus overbank flows. Water balance outputs from the models identified changes in storage components (for example, subsurface and overland storage). Simulated inflow and outflow in the MIKE 11 river model were used to calculate flood peak attenuation.

Modelled and data outputs included:

- mean daily climate data, and groundwater levels
- elevation data (from dGPS surveys)
- river, groundwater and soil chemistry (for example, anions, cations, pH, dissolved oxygen, conductivity)
- botanical data
- 2 MIKE SHE/MIKE 11 models of pre- and post-restoration conditions including their outputs:
- simulated groundwater levels
- maps of surface water depth and extent
- simulated water balance of the floodplain (Figure 1)

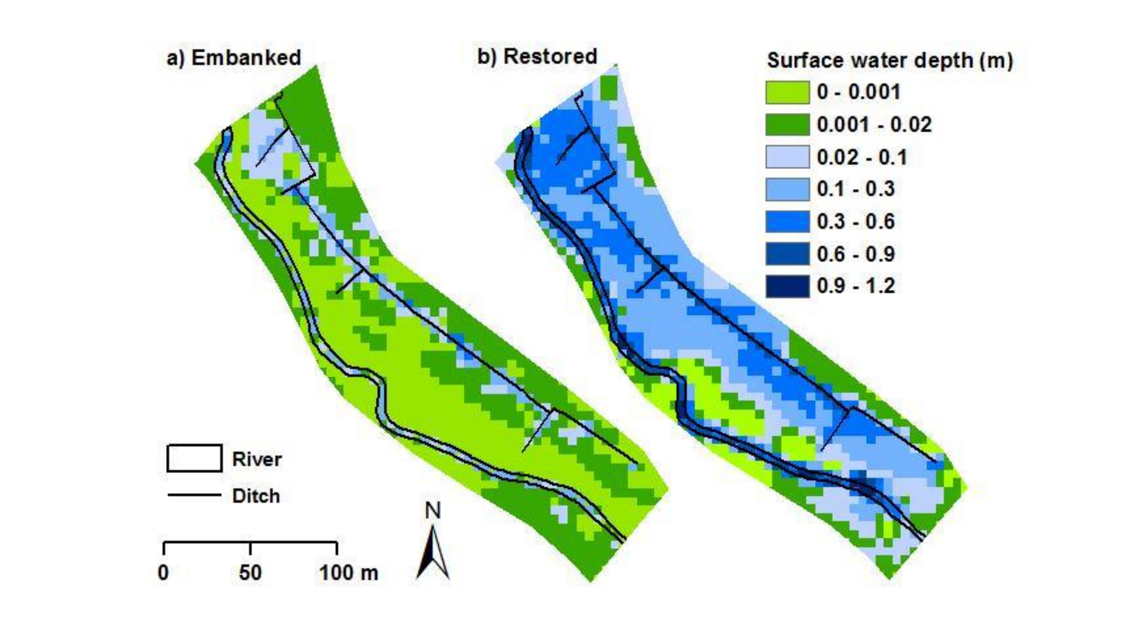

Figure 1: Model outputs before and after measures to reconnect watercourse with main river

Source: Hannah Clilverd

Groundwater levels on the floodplain and river stage data were used to calibrate and validate the MIKE SHE/MIKE 11 models using mean error, correlation coefficient (R) and Nash–Sutcliffe model efficiency statistics.

The aim of the embankment removal was to make space for water on the floodplain. A hydrological and chemical monitoring programme was conducted before and after the embankment removal to quantify the initial hydrological response to embankment removal. Hydrological/hydraulic models were required to directly quantify the effects (for example, groundwater storage) of embankment removal under identical climatic conditions.

The extent and depth of stored waters on the floodplain, along with duration of inundation, were simulated. Reductions in river discharge at the downstream end of the meadow were used to address the benefits of improved river–floodplain connectivity for downstream flood peak attenuation and floodplain biota.

A cumulative stress index, based on simulated groundwater levels, is being used to estimate aeration stress on floodplain vegetation and to predict plant community change following increased floodplain inundation resulting from embankment removal.

Model performance

The model performance statistics indicated an overall good ability of the model to reproduce groundwater levels across most of the meadow.

4. Lesson learnt

Choice of tools

The River Glaven is a dynamic hydrological system characterised by interaction of unsaturated and saturated zones, and surface and subsurface flows between the river and groundwater. Many different components and physical properties of the hydrological system were measured:

- precipitation
- potential evapotranspiration
- stream flow

- groundwater elevation
- topography
- hydraulic conductivity
- soil texture

MIKE SHE was selected as a suitably scaled model with the complexity and computational capability to represent surface–subsurface exchange at small spatial scales. It also had the flexibility to simulate hydrologic processes using a combination of distributed and semi-distributed methods, in line with the understanding of the processes at the site.

When selecting appropriate hydrological models, it is important to consider the complexity of the modelling system in relation to the availability of input data needed to parameterise and drive the models. Provided these requirements are met; similar projects might consider using the modelling tools employed in this case study. This study supports the use of coupled MIKE SHE/MIKE 11 models to simulate hydrological and hydraulic conditions following embankment removal. This is supported in a similar MIKE SHE river restoration study by Hammersmark et al. (2008) in the USA.

Catchment scale and typology

Although the contribution to flood peak attenuation reported in this case study was smaller than reported by other modelling studies, the length of the Glaven restored reach was also smaller. This project is part of a wider landscape approach to restoration being implemented along the River Glaven to reconnect and buffer an array of aquatic habitats of varying sizes such as rivers, streams, ponds and ditches. The removal of embankments along other reaches of the river could be expected to have a cumulative impact on flood peak recession. A hypothetical study could be conducted using the modelling approach described in this case study to quantify the hydrological impact of restoring larger sections of the river.

Relatively fine discretisation of the model was needed to characterise topographic variations across the floodplain accurately, including a blocked ditch and small scale features such as shallow depressions and raised hummocks. The relatively fast computational speed of the models allowed fine scale representation of hydrological conditions on the floodplain. This was necessary to model the microhabitats of differing soil water content that are important for fostering high species diversity.

Wider benefits

This case study addresses the improvements to river–floodplain functioning associated with enhanced hydrological connectivity, groundwater retention and flood peak attenuation. It also suggests the use of embankment removal as a tool for buffering the hydrological regime of wetlands and other aquatic ecosystems against some of the extreme climate variability predicted in the UK over the next century.

Another study on the River Glaven restoration, which will be submitted for publication shortly, uses the modelling results to address the long-term implications of embankment removal on floodplain plant biodiversity.

Future research needs

This study is one of few reported in the literature which presents both pre- and post-restoration hydrological data and directly assesses the hydrological effects of river restoration using modelling tools. The approach could be used in the planning stage of restoration projects to determine the site's suitability and whether desired hydrological conditions can be achieved.

The following results from the two models are consistent with those reported following embankment removal and 'pond and plug' meadow restorations by Acreman et al. (2003), Loheide and Gorelick (2007), and Hammersmark et al. (2008):

- increase in bankfull discharges and overbank inundation of the floodplain
- increased groundwater levels and subsurface storage within the floodplain
- increased overland storage on the floodplain surface
- modest declines in downstream flood peaks

5. Bibliography

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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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