Case study 5. River Glaven, North Norfolk

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Main driver: Improve river corridor habitat and reconnect river and floodplain

Project stage: Constructed, sections of river and floodplain are restored (works conducted 2009 to 2010)

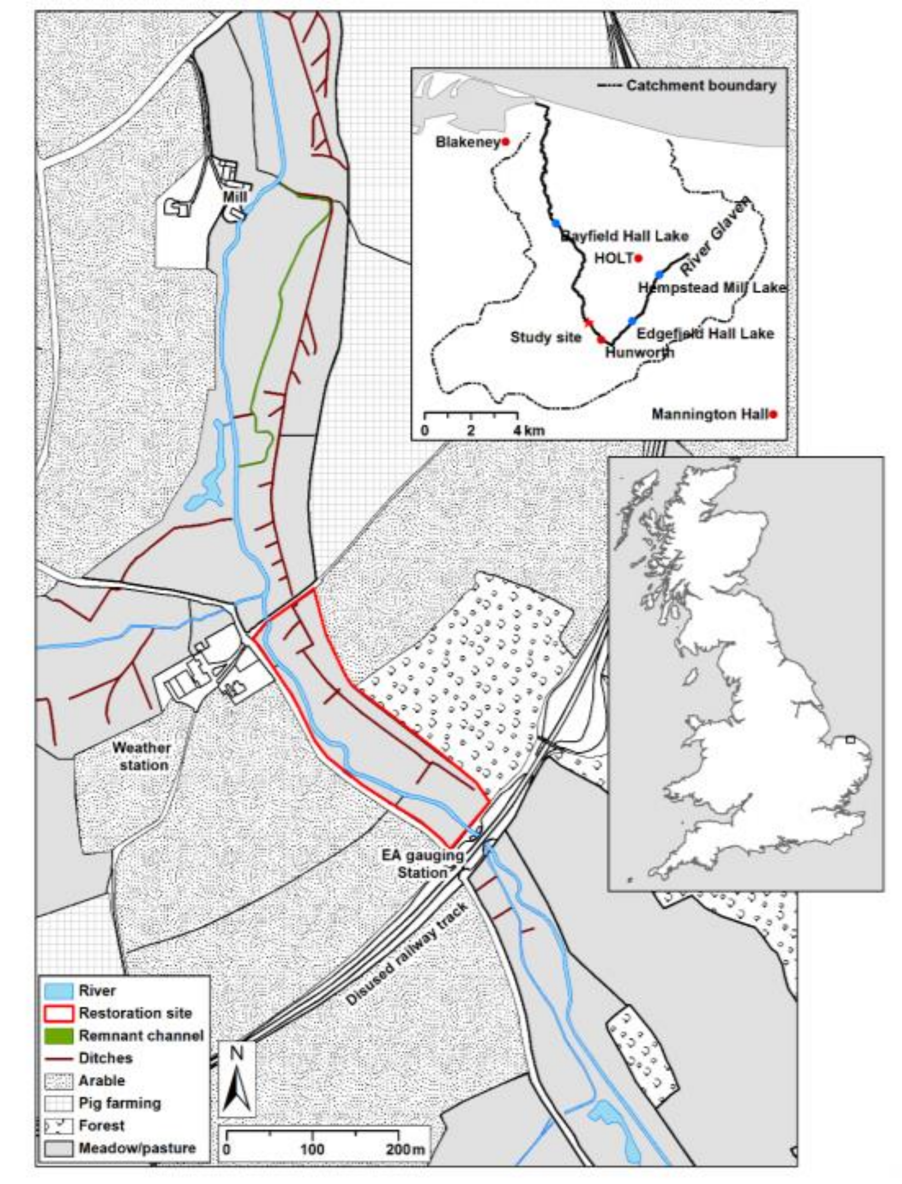
Photo 1: Embankment removal work in progress, 2009 (source: Clilverd 2016)

Project summary:

The River Glaven in north Norfolk (Map 1) has been historically modified, for example, through the creation of water mills. Coupled with this, widespread dredging has occurred and flood embankments have been created to protect agricultural land. The project's objectives were to improve the river corridor habitat by restoring river processes and reconnect the river and its floodplain and to develop an experience base that would serve the River Glaven Conservation Group (RGCG) well on other projects. The project provides a unique opportunity to monitor and model river and floodplain interactions.

Key facts:

A MIKE SHE/MIKE 11 coupled hydrological/hydraulic model was employed to assess the impact of floodplain reconnection. Using data from 2007 to 2010, the study found that the removal of the embankment permitted widespread inundation of the floodplain at high flows (>$1.7 m^3 s^{-1}$) as well as enhancing flooding of the immediate riparian area during lower magnitude events. Removal of embankments has found to have reduced the channel capacity by approximately 60%, suggesting that overbank flooding was the most dramatic hydrological effect following the restoration project (Clilverd et al. 2013).



Map 1: Restoration site at Hunworth Meadow, River Glaven (source: Clilverd 2016)

1. Contact details

Contact details	
Names:	Ian Shepherd
Lead organisation:	River Glaven Conservation Group (RGCG)
Partners:	Wild Trout Trust, University College London (UCL), Queen Mary University London (QMUL), Environment Agency, Richard Hey, local farmers and landowners, Natural England, Norfolk Wildlife Trust
e-mail address:	See the RGCG website (www.riverglaven.co.uk) for contact details

2. Location and catchment description

Catchment summary	
National Grid Reference:	TG 062 361
Town, County, Country:	Hunworth, Norfolk, UK
Regional Flood and Coastal Committee (RFCC) region:	Anglian
Catchment name(s) and size (km^2):	Glaven, 115km^2
River name(s) and typology:	River Glaven
Water Framework Directive water body reference:	GB105034055780
Land use, soil type, geology, mean annual rainfall:	Agricultural land, deciduous and coniferous woodland, grazing meadows and former floodplain Calcareous (Chalk) Mean annual rainfall: 600–650mm (Clilverd 2016)

3. Background summary of the catchment

Socioeconomic/historical context

The River Glaven has historically been modified for industrial purposes through the creation of water mills. With the exception of Letheringsett Mill, these mills are no longer in use. However, water control structures such as weirs and sluices remain, and these impede the natural river flow. The River Glaven has been severely modified with canalisation, over-deepening and impoundment common along most reaches. Embankments were historically created to protect the adjacent floodplain farmland. Therefore a large area of floodplain is disconnected from the main river system. Coupled with this, some floodplains have been drained to further improve agricultural productivity.

The dredging that occurred throughout the 1970s to 1980s in many parts of the channel resulted in the lowering of the channel bed and further disconnections between the river and its floodplain (Wild Trout Trust, 2006). The spoil from the river was used to create embankments. Surveys by the RGCG have shown that several sections of the middle and lower part of the Glaven have been significantly widened and deepened to improve floodplain land for farming.

Flood risk problem

An Environment Agency database indicates 57 properties at risk of flooding in the River Glaven catchment from Thornage to Cley. These 'at risk' properties are dispersed throughout the catchment.

Other environmental problems

The River Glaven has a high biodiversity value. Therefore ecological restoration was the main driver for improvements to the river. The nutrient concentrations in the Glaven are moderate while dissolved oxygen concentrations are high (Clilverd 2016). Seasonal patterns of macrophytes growth and recession are common in the water body (Clilverd 2016). The catchment falls under the Freshwater Fish Directive, Natura 2000, Nitrates Directive and Shellfish Waters Directive. The Glaven has been given a 'moderate' status for fish, 'good' status for invertebrates, 'good' status for chemistry and 'poor' status for flow dynamics under the Water Framework Directive classification system. The river may hold the largest remaining river population of white-clawed crayfish in southern England (RGCG 2013). Historical modifications to the channel have severely affected the ecological value of the river by reducing the density and diversity of habitats.

4. Defining the problem(s) and developing the solution

What evidence is there to define the flood risk problem(s) and solution(s)

Improvements in river and floodplain biodiversity were the primary driver. However, flood peak attenuation was also a goal within the overall objective to improve natural river–floodplain connectivity and associated ecosystem services. The Glaven is thus a key learning site to understand these processes on a chalk fed river.

The properties at risk of flooding are dispersed along the River Glaven. Most settlements are small in size and therefore the 'at risk' areas occur across the catchment. Flood risk management was not the main driver of the restoration work.

What was the design rationale?

The aim of this restoration project was to increase hydrological connectivity between the over-deepened, embanked river and its long abandoned floodplain to improve flood storage capacity and ecological diversity within the river and floodplain. Restoration took place at locations that were severely modified and disconnected from the floodplain. Therefore measures that improved the form of the river and connectivity to the floodplain were considered. The RGCG consulted with a number of different stakeholders and experts to develop a fit-for-purpose restoration plan.

Project summary	
Area of catchment (km^2) or length of river benefitting from the project:	Length of river restored/reconnected: 400m reach at Hunworth Meadows (2009 to 2010)
Types of measures/interventions used (Working with Natural Processes and traditional):	Restoration at Hunworth Meadows: embankment removal resulting in a 40–80m wide (3ha) floodplain area (2009) and remeandering (2010)
Numbers of measures/interventions used (Working with Natural Processes and traditional):	River restoration: embankment removal, remeandering, riffle creation
Standard of protection for project as a whole:	Not applicable – the primary purpose of the project was to improve ecological impacts while assessing the hydrological functioning
Estimated number of properties protected:	Not assessed

How effective has the project been?

Work by Clilverd (2016) investigated the implications of river embankment removal on river–floodplain hydrological connectivity in a chalk setting (see Figure 1). This study is rare as it uses an empirically driven hydrological/hydraulic modelling approach and has data from before and after restoration.

The restoration work at Hunworth Meadows had a moderate effect on flood peak attenuation and improved free drainage into the river. MIKE SHE/MIKE 11 was utilised to analyse the impact of the floodplain reconnection before and after restoration. Using data from 2007 to 2010, the study found that the removal of the embankment resulted in widespread inundation of the floodplain at high level flows (>$1.7m^3s^{-1}$). Restoration also promoted regular inundation of the immediate riparian area during lower magnitude flood extents. However, the restoration had only a small impact on flood peak attenuation (maximum 5% peak reduction) owing to the limited length of restoration and improving drainage back into the river (Clilverd et al. 2015). The removal of embankments was found to have reduced the channel capacity by approximately 60% (Clilverd et al. 2013), suggesting that overbank flooding was the most dramatic hydrological effect following the restoration of the site. In addition, groundwater levels were slightly higher and subsurface storage was greater.

Embankment removal alongside the River Glaven at Hunworth has created a more natural flood-pulsed hydrological regime, characterised by regular, short duration inundation of the floodplain meadow. This is likely to result in improvements to river–floodplain ecosystem functioning (for example, enhanced habitat connectivity and heterogeneity) (Clilverd 2016). This study found a change in the quality of flooding (that is, from long-term, stagnated inundation with oxygen-poor groundwater prior to the restoration to short-term pulses in oxygen-rich river water following restoration), which should help to:

- reduce aeration stress for meadow plants during submergence
- create flood conditions that are much more easily tolerated by a variety of wet meadow plant species

Indeed, recent vegetation surveys at Hunworth Meadows recorded a significant increase in plant species richness following the 2 phases of restoration (Carl Sayer, personal communication).

Remeandering at Hunworth had no significant impact on stream invertebrate biodiversity, but when invertebrates in backwaters (left over from non in-filled parts of the old channel) were included, a significant increase in invertebrate diversity was detected, due to the addition of several 'pond-associated' species (Sayer 2014). The remeandering had no significant short-term (>4 years) impact on fish populations, aside from brown trout (*Salmo trutta*) for which density and biomass both increased (Champkin et al. forthcoming).

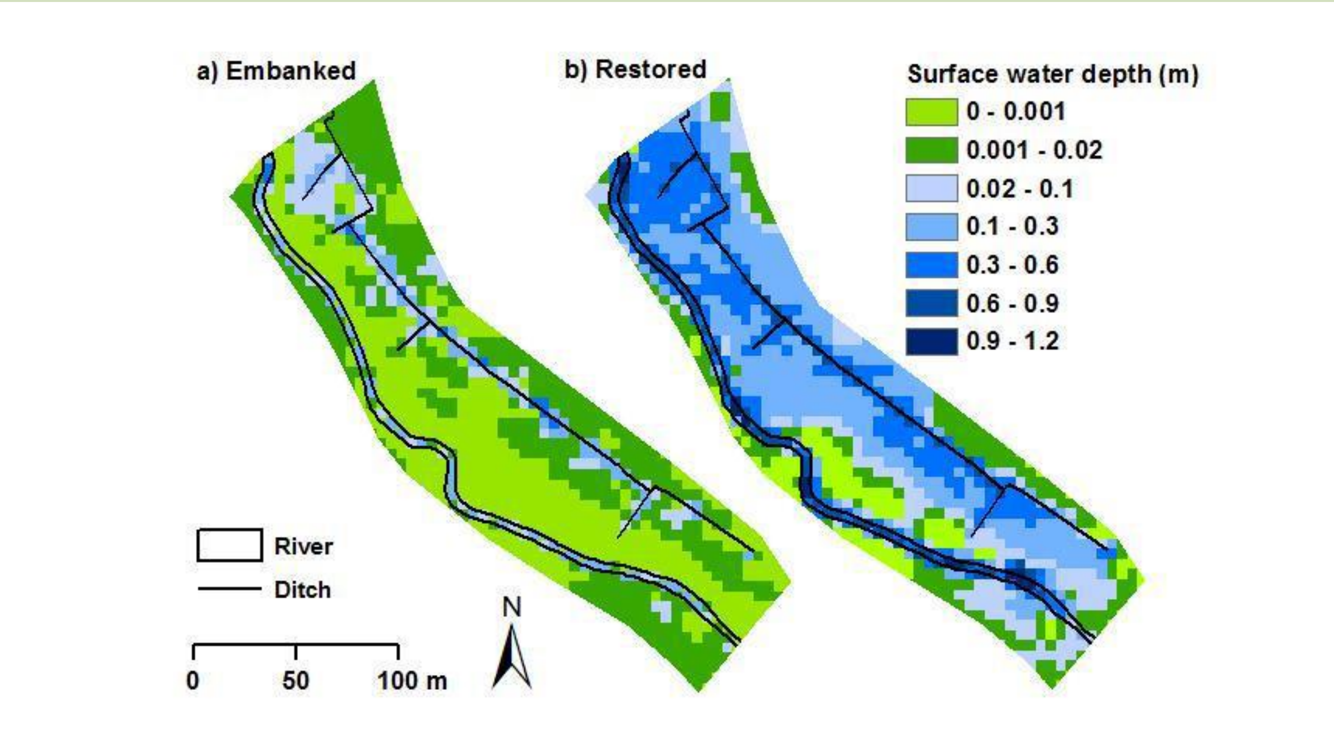


Figure 1: Model outputs before and after measures to reconnect watercourse with floodplain during a large overbank (post restoration) event (18 July 2001; flow = $3.1 m^3 s^{-1}$) (adapted from Clilverd et al. 2016)

5. Project construction

How were individual measures constructed?

The work at Hunworth Meadows took place in 2 phases. During the first phase in 2009, around 400m of embankments were removed (Photo 1) with the aim of:

- reconnecting hydrological processes between the river and floodplain (Figure 2)
- maximising the amount of floodwater that can be stored on the floodplain
- providing other ecosystem services such as improving water quality and habitat

Heavy machinery was used to remove the embankments and these works encroached 10m into the floodplain (Clilverd 2016). The work resulted in the removal of ~1,400 tonnes of soil from the site, which resulted in the river banks being at the same height as the neighbouring meadow (Clilverd 2016). During the first phase, no work took place within the river to alter the channel geomorphology. An ecological survey noted a water vole population within one section of river embankment and so no work took place to remove this section.

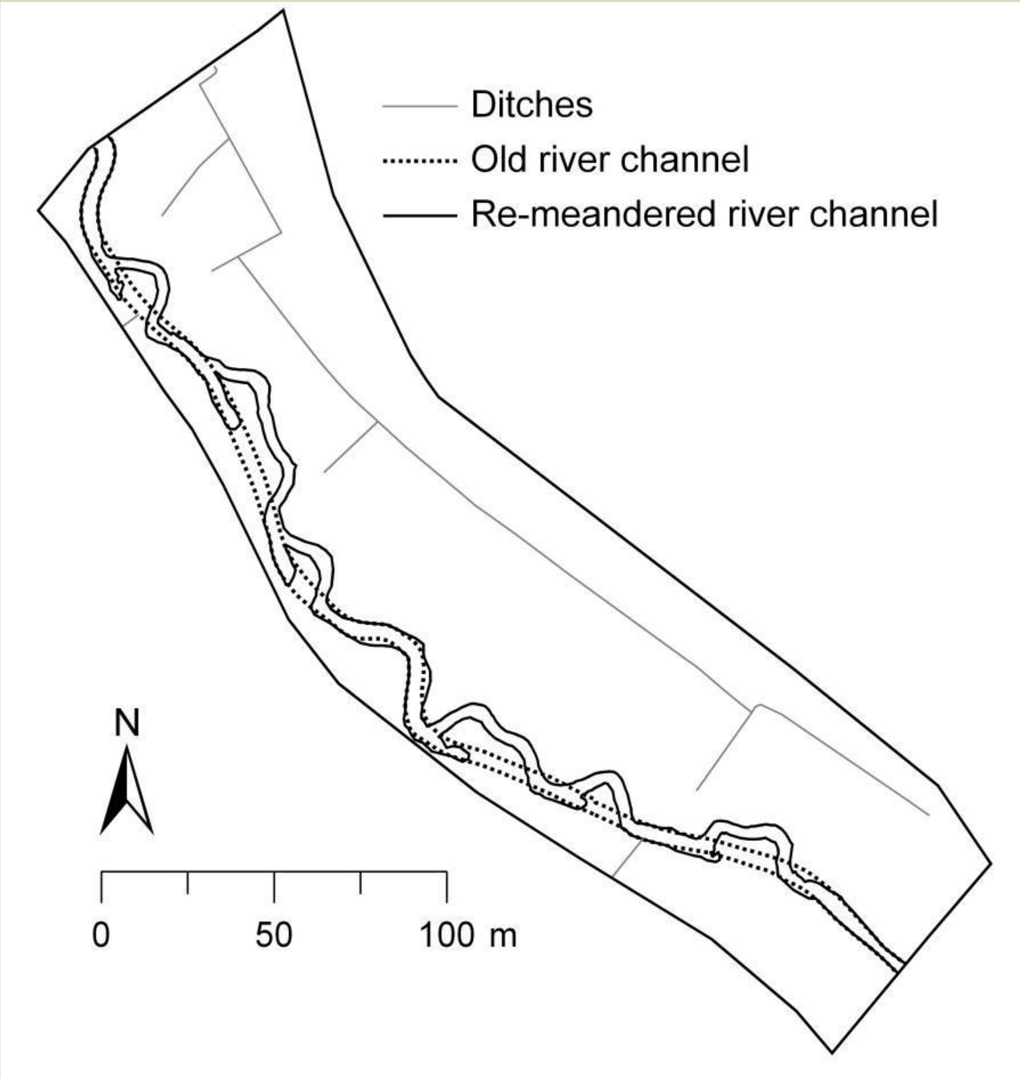


Figure 2: Remeandered river channel at Hunworth Meadows (source: Clilverd 2016)

A second phase of work was conducted in 2010. The aim of this phase was to improve the in-stream habitat/ecology and to improve floodplain connectivity further. To improve the river morphology, the work created a narrower and more geomorphically diverse meandering channel. River sinuosity increased by 16% (Clilverd 2016). The work was delivered in partnership with the landowner (Stody Estate), Wild Trout Trust, Environment Agency, Norfolk Wildlife Trust, RGCG, UCL, QMUL, Professor Richard Hey and the Centre for Environment Fisheries and Aquaculture Science (Cefas).

How long were measures designed to last?

The river restoration measures were designed in a way to allow the re-establishment of natural processes. Therefore these measures could change in their current form (for example, river sinuosity may develop further and channel bars will change over time), but they are designed to be self-sustaining and allow the river to establish a more natural form.

No seeding of the river margins was carried out and vegetation was left to develop naturally.

River embankment removal is permanent.

Were there any landowner or legal requirements which needed consideration?

A Flood Defence Consent to carry out the works was required, which was obtained from the Environment Agency.

6. Funding

Funding summary for Working with Natural Processes (WWNP)/Natural Flood Management (/NFM) measures	
Year project was undertaken/completed:	2009 to 2010
How was the project funded:	Part funded by the Environment Agency, co-ordinated by RGCG
Total cash cost of project (£):	£10,000–50,000
Overall cost and cost breakdown for WWNP/NFM measures (£):	
WWNP/NFM costs as a % of overall project costs:	Not applicable
Unit breakdown of costs for WWNP/NFM measures:	As above
Cost–benefit ratio (and timescale in years over which it has been estimated)	Not applicable

7. Wider benefits

What wider benefits has the project achieved?

The 2 Glaven restoration projects have yielded a range of other benefits. The driving aim was to improve the channel morphology to provide new habitats and enhance the habitat (for example, for brown trout). Since the restoration was completed at Hunworth Meadows, the Water Framework Directive classification of the water body has improved from moderate ecological potential to good. Improvements to in-stream habitat heterogeneity, but weak responses in fish from 2010 to 2014 (except for brown trout which increased in density and biomass after the restoration) have been detected (Champkin, forthcoming).

How much habitat has been created, improved or restored?

A 400m reach of river was restored at Hunworth Meadows. This involved embankment removal resulting in a 40–80m wide (3ha) floodplain area (2009) and remeandering (2010).

8. Maintenance, monitoring and adaptive management

Are maintenance activities planned?

The schemes have been designed to be self-sustaining so as to minimise the need for future maintenance.

Is the project being monitored?

A 3-year hydrological monitoring programme was established to assess the hydrological connectivity post restoration. This work was led by UCL and QMUL; its findings are presented in Clilverd (2016) and other scientific papers by the teams at UCL and QMUL – see Section 10 Bibliography. Groundwater depth and river stage monitoring, measurements of groundwater chemistry and surveys of topography were carried out to assess the hydrological impacts of river and floodplain restoration. Before and after control intervention (BACI) studies of floodplain plants, aquatic macrophytes (2007 to 2012), invertebrates (2009 and 2012) and fish (2009 to 2014) were all carried out (Sayer 2014, Champkin et al. forthcoming, Sayer unpublished data). Some of this work is still to be published.

Future surveys to assess the longer-term response of this system are likely. Ongoing research will also investigate the potential impacts of climate change on hydroecological conditions within Hunworth Meadows.

Has adaptive management been needed?

The ditch running parallel to the River Glaven at Hunworth along the base of an arable/woodland hillslope was excavated during the remeandering stage of the restoration in 2010. The aim was to reduce waterlogging during the growing season.

Remeandering of the River Glaven channel at Hunworth Meadows has affected the Environment Agency's gauging station immediately upstream. The new channel configuration has enhanced the impact of macrophytes growth (that is, it has reduced the channel volume and increased flow resistance during the summer, which causes water to back up over the weir – a minor problem before the restoration). Consequently, from August 2010 onwards the rating curve was no longer valid at the gauging station and the data are questionable. Remedial measures involving lowering the crest height of 3 of the riffles and a cattle crossing have since been implemented. These have partly, but not completely, resolved the issue.

Reinstatement of traditional grazing to balance additional nutrient supply from river floodwater and sediments during periodic flooding has been reinstated at the site.

9. Lessons learnt

What was learnt and how could it be applied elsewhere?

The reconnection of the river and floodplain did not change the aeration stress of the floodplain meadow because of pre-existing, very wet conditions, except for the river embankments where the habitat changed from dry grassland to wet meadow/fen (Clilverd 2016). The restoration works also altered the local groundwater regime, thus encouraging more diversity in plant ecology. Data from Hunworth Meadows suggest that embankment removal can increase river and floodplain connectivity to form a more natural flood-pulsed wetland ecotone, which favours conditions for enhanced flood storage, plant species composition and nutrient retention (Clilverd 2016). In terms of biological response, the Hunworth project revealed the importance of reinstating backwater habitat to lowland streams. In this case, 6 backwaters (left from sections of non in-filled sections of old channel) significantly enhanced invertebrate biodiversity in the river–floodplain system, as well as affording new habitat for amphibians (Sayer 2014).

A collaborative and community driven approach was crucial to the success of this project.

10. Bibliography

CHAMPKIN, J., COPP, G.H., SAYER C.D., CLILVERD, H.M., GEORGE, L., VILIZZI, L., GODARD, M.J. AND CLARKE, J., forthcoming. Responses of fishes and lampreys to re-meandering work in a small English chalk stream. *River Research & Applications* [submitted November 2016].

CLILVERD, H.M., 2016. *Hydroecological monitoring and modelling of river-floodplain restoration in a UK lowland river meadow*. Doctoral thesis, University College London.

CLILVERD, H.M., THOMPSON, J.R., HEPPELL, C.M., SAYER, C.D. AND AXMACHER, J.C., 2013. River-floodplain hydrology of an embanked lowland Chalk river and initial response to embankment removal. *Hydrological Sciences Journal-Journal Des Sciences Hydrologiques*, 58, 627-650.

CLILVERD, H., THOMPSON, J., HEPPELL, K., SAYER, C.D.AND& AXMACHER, J., 2015. Removal of river embankments and the modelled effects on river-floodplain hydrodynamics. *Geophysical Research Abstracts*, Volume 17, EGU-2015-12974.

CLILVERD, H.M., THOMPSON, J.R., HEPPELL, C.M., SAYER, C.D. AND AXMACHER, J.C., 2016. Coupled hydrological/hydraulic modelling of river restoration impacts and floodplain hydrodynamics. River. *River Research and Applications*, 32 (9), 1927-1948.

ENVIRONMENT AGENCY, 2010. *Ecosystem services assessment of sea trout restoration work on the River Glaven, North Norfolk*. Bristol: Environment Agency.

HOLT-WILSON, T., 2014. *The Glaven river catchment. Links between geodiversity and landscape. A resource for educational and outreach work*. Norfolk Geodiversity Partnership

RGCG, 2013. Glaven crayfish transfer III [online]. River Glaven Conservation Group. Available from: http://www.riverglaven.co.uk/index.php/2013/09/25/glaven-crayfish-transfer-iii/ [Accessed 24 March 2017].

RGCG, 2014. *Restoration works on the Gunthorpe stream at Thornage: a tribute to Nigel Holmes.* Unpublished internal document. River Glaven Conservation Group.

RRC, 2006. *River Glaven Restoration Project*. RRC Case Study Series. Cranfield, Bedfordshire: River Restoration Centre. Available from: http://www.therrc.co.uk/case-studies-project [Accessed 24 March 2017].

SAYER, C.D., 2014. Conservation of aquatic landscapes: ponds, lakes, and rivers as integrated systems. *WIREs: Water*, 1 (6), 573-585.

THOMPSON, J. AND CLILVERD, H., 2015. *Case study 7: River Glaven embankment removal – North Norfolk*. A case study for the Environment Agency project SC120015 'How to model and map catchment processes when flood risk management planning'. Bristol: Environment Agency.

WILD TROUT TRUST, 2006. A Cinderella river. The River Glaven Conservation Group (RGCG) in river habitat improvement 2006. In *The Chalkstream Habitat Manual*, Chapter 12. Waterlooville, Hampshire: Wild Trout Trust. Available from: http://www.wildtrout.org/content/wtt-publications [Accessed 24 March 2017].

Project background

This case study relates to project SC150005 'Working with Natural Flood Management: Evidence Directory'. It was commissioned by Defra and the Environment Agency's Joint Flood and Coastal Erosion Risk Management Research and Development Programme.