Case study 10

Clwyd Catchment Study - Denbighshire

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1. Catchment summary

Study location

This study is primarily concerned with on the Clwyd catchment (Figure 1) within Denbighshire in North Wales. The catchment has a large portion of high quality farmland that has been actively farmed since the Neolithic period. Remnants of ancient or semi-natural woodland can be found on the steeper hillslopes located in the southern and western side of the valley and to the south of Ruthin. Other areas of woodland exist within the catchment:

- small coniferous woodlands
- the 100km2 Clocaenog Forest
- areas of deciduous woodland on the floodplain between Ruthin and St Asaph

Catchment summary

The Clwyd catchment experiences rapid responses to rainfall events, in part due to the effects of intensive grazing and land drainage. It is believed that the removal of vegetation and compaction of soils through grazing has reduced the capacity of the soil to absorb rainfall resulting in increased rate of run-off.

Study summary

The study aimed to provide evidence for the potential benefits associated with natural flood Risk Management (NFRM) interventions in the Vale of Clwyd. NFRM is termed Working with Natural Processes (WwNP) in this case study for consistency with the main report. As part of the process, the impacts that WwNP may have on ecosystem services were considered alongside an analysis of changes in agricultural practices.

Like the Elwy case study, the investigation was undertaken as a result of the 2012 floods in St Asaph and Ruthin, and aims to reduce the flood risk to both locations. The study's objectives were to:

- quantify the potential for flood risk reduction associated with WwNP measures
- investigate the impact of WwNP solutions on other ecosystem services
- identify funding and delivery mechanisms to implement the potential solutions

Community involvement

A stakeholder exhibition/consultation was held at Ruthin Farmer's Market on 3 July 2014. The feedback and information were recorded and used to verify the project assumptions on current land use and extents of existing drainage and grips within the Clwyd catchment.

The willingness of some groups of farmers to undertake WwNP projects was also established at the exhibition. By engaging with local farmers it was possible to acquire knowledge on issues such as land compaction, experiences of flooding, and preferences and opinions on WwNP approaches.

Maps showing the assumed areas of drained land and land use were presented at the exhibition and feedback was given on these maps. Stakeholder involvement was used to vary the assumptions of the hydrological modelling and existing land use classifications.

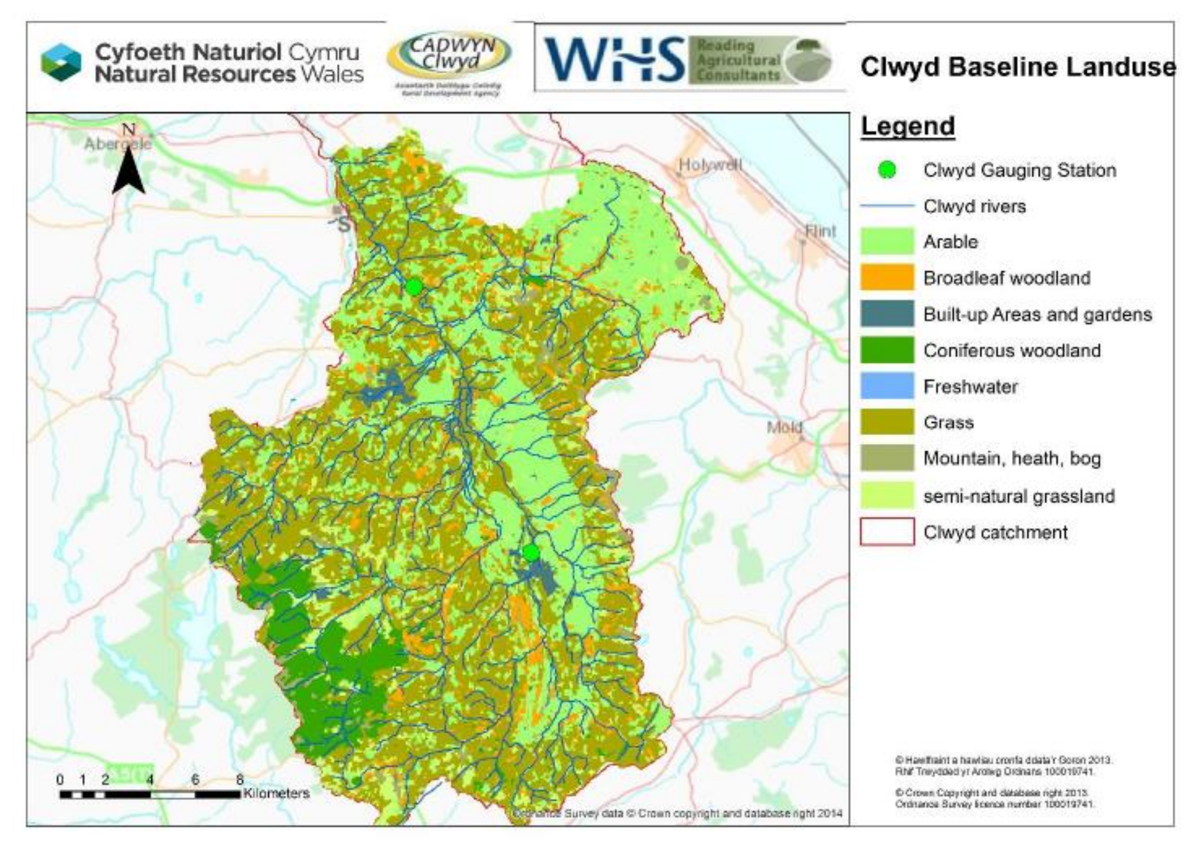

Figure 1: Current land use in the Clwyd catchment

Source: Natural Resources Wales

2. Data summary

Datasets and analysis techniques used

Flow data were used from 2 flow gauges located within the catchment: Clwyd at Pont-y-Cambwll (SJ 069 709) and Clwyd at Ruthin Weir (SJ 121 592). A Continuous Estimation of River Flows (CERF)/Hydrological Response Unit (HRU) model was set up based on the following datasets:

- Hydrology of Soil Types (HOST) soil dataset
- rainfall and evaporation data
- vegetation data – derived from the Centre for Ecology and Hydrology (CEH) Land Cover 2007 classification system
- land use data
- geology data
- topography data – 50m resolution Digital Elevation Model (DEM)

Datasets restrictions

Data licensing was required for HOST and the CEH Land Cover 2007 classification system (2007).

There is a CEH license for CERF. But although the Natural Resources Wales/Environment Agency hold national CERF outputs on a regular 1km grid, it is not clear how the changes to the model structure or thresholds could be implemented by others

3. Model summary

Catchment processes investigated

The following core catchment scale processes were investigated:

- run-off processes
- catchment/land use change

All processes were covered in varying degrees.

Model assumptions

The CERF model is capable of simulating the hydrological processes which determine how soils and vegetation influence run-off. CERF accounts for infiltration, interflow and groundwater storage and can model changes to overland flow and baseflow. These vary in different ways for catchments with different physical characteristics such as soil texture and land cover. These different properties are delineated through the definition of HRUs based on land cover and soil data. The parameters controlling the different modelled pathways can then be influenced through the WwNP measures investigated in this study, including afforestation, compaction relief and drain blockage.

The CERF model was used to:

- assess current and potential future flood risks using the change in peak run-off as a measure of flood risk reduction
- simulate the 1962 to 2010 daily flow record and thus include the full range of events over 48 years.

A relationship was developed between peak instantaneous flow and daily flow to derive a simulated ‘peaks over threshold’ (POT) series for flood frequency analysis.

The Flood Frequency Curves (FFC) derived from the simulated instantaneous annual maxima series were compared with the FFC derived from the gauged HiFlows instantaneous annual maxima series. The FFC for the site historic and simulated annual maxima series were fitted using the Pearson type III distribution for the Clwyd at Pont-y-Cambwll and the generalised logistic distribution for the Clwyd at Ruthin. The resulting CERF FFC were comparable in slope but offset to the single site historical FFC, although the event-based Revitalised Flood Hydrograph (ReFH) FFC were distinctly different (Figure 2).

Catchment processes were modelled in CERF as follows:

- To assess the influences of soil moisture and vegetation type, a loss model based on HRUs was used. Changes to antecedent soil moisture conditions due to the measures implemented were not explored.
- Three WwNP interventions were investigated by substituting the HOST soil classes and modifying the infiltration and drainage components of the model.
- Current and WwNP scenarios were modelled and the percentage changes to the winter and summer peak flows over the 48 year simulated period were reported.
- Compaction alleviation (Figure 3) and significant afforestation were found to have the potential to significantly attenuate summer peak flows within the Clwyd catchment. This is primarily because the catchment is predominantly saturated during winter as a consequence of the generally higher

rainfall and low evaporation rates.

- All interventions were found to have a smaller impact on winter floods. Saturation within the catchment during winter months as a result of higher rainfall and lower evaporation was deemed the primary reason for this.
- CERF modelling estimated that, if WwNP interventions were implemented across the Clwyd catchment, summer flood peaks could be reduced by up to 25% (maximum reduction of 250mm flood level at Ruthin for the modelled events) and the winter flood peaks could be reduced by up to 8%. This maximises the extent of the different WwNP measures, with Figure 3 showing, for example, extensive areas of proposed compaction relief.
- The impact of WwNP interventions on ecosystem services within the catchment is likely to be neutral or positive, with afforestation offering the greatest potential to benefit ecosystem services.

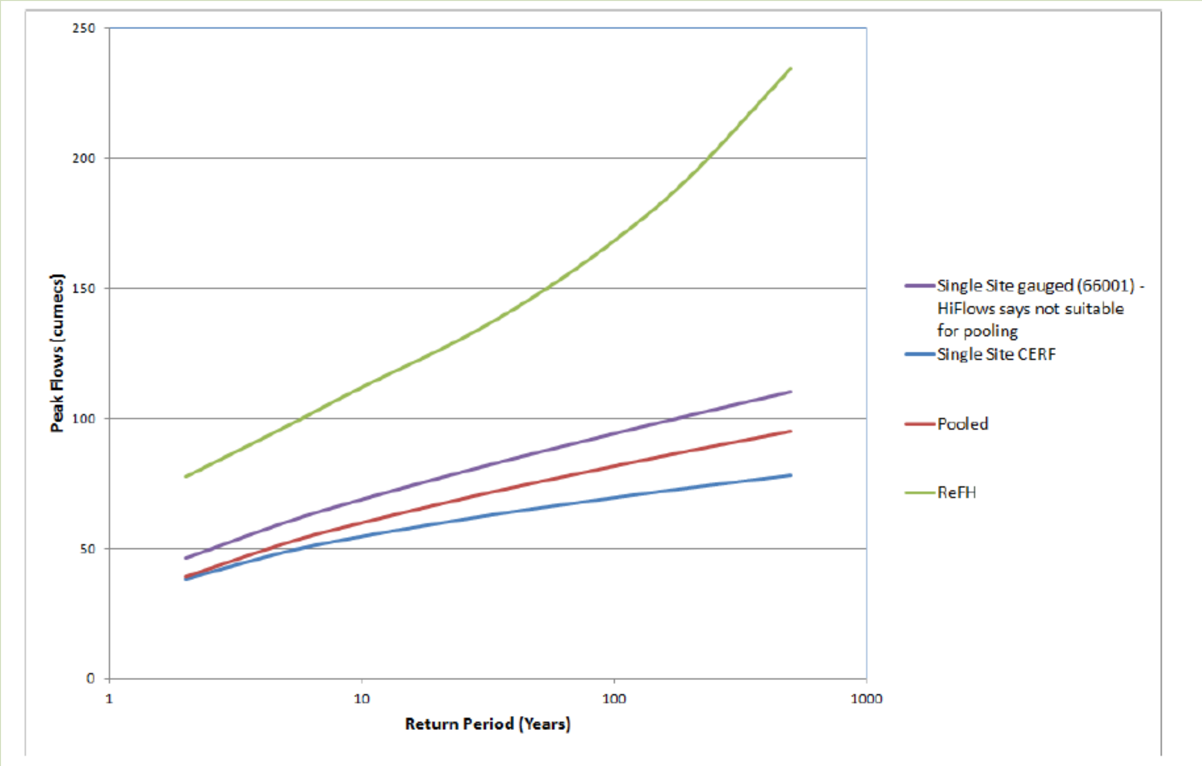

Figure 2: Flood frequency curves using the model and comparison with ReFH and FEH statistical parameters

Source: Natural Resources Wales

Using a daily time step, the potential benefit of three core WwNP measures was considered as follows.

- Tree planting was modelled by altering the HOST soil classes assumed in the CERF model in locations where such opportunities were possible.
- Mechanical compaction relief was modelled by revoking the infiltration excess algorithm. In the CERF model, it is assumed that precipitation up to a threshold rate (mm per day) can infiltrate into the soil column but that precipitation above this threshold cannot and therefore enters the routing of free water within the catchment. This is implemented as a simple bypass within the model structure diverting precipitation in excess of a defined threshold from the soil moisture accounting procedure and into the quickflow routing path for the grid cell in question. The thresholds for current and improved scenarios were estimated for different HOST classes based on the literature.
- Ditch and drain blocking was modelled by ‘revoking the drainage algorithm’ present for different land types.

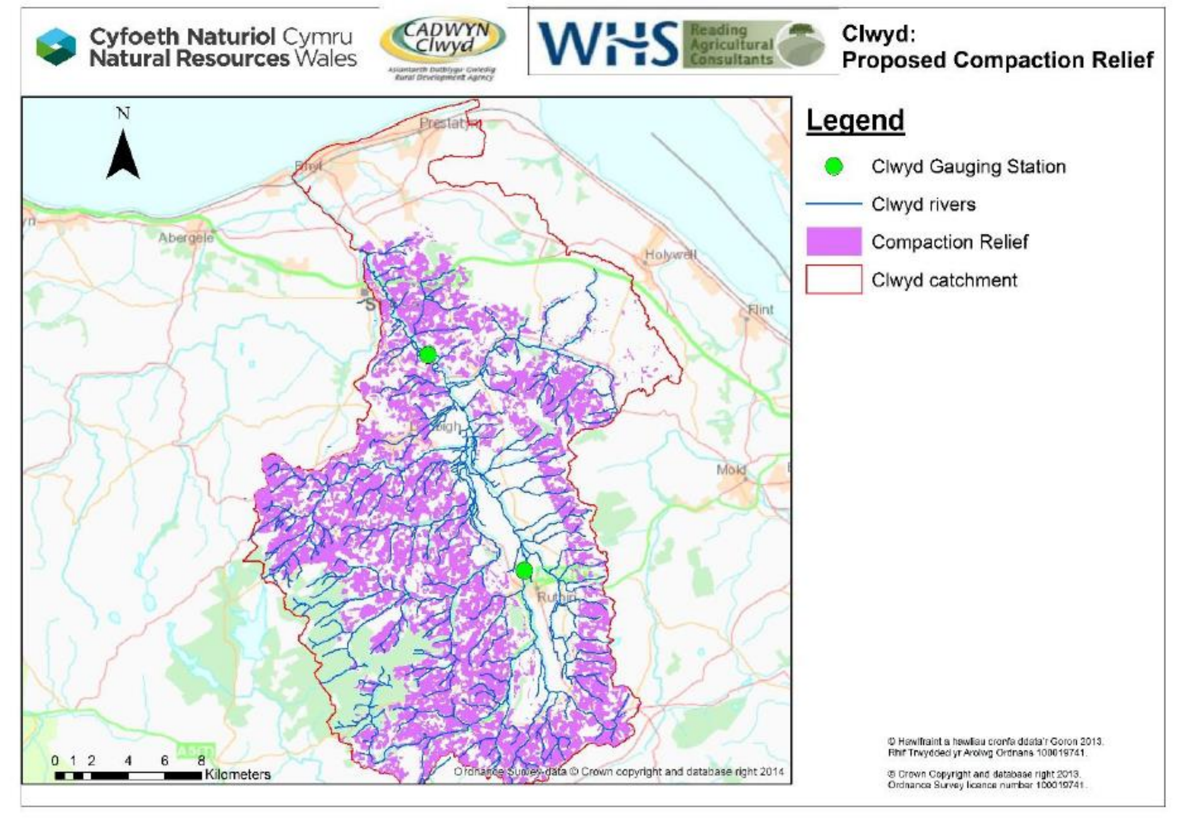

Figure 3: Areas of proposed compaction relief

Source: Natural Resources Wales

The following WwNP interventions were shortlisted:

- tree planting
- reducing stocking densities
- mechanical compaction relief (sub-soiling)
- contour ploughing – cessation of downslope ploughing
- reversion of arable fields (or part fields, for example, buffer strips) to pasture
- tree planting along the riparian zone
- moorland grip blocking, field drain blocking and ditch blocking

Data and model outputs

GIS was used to generate maps of:

- current HOST classes and how these would change given interventions
- the field drain network based on analysis of historic Ministry of Agriculture, Fisheries and Food (MAFF) data – 22% of the farmland was estimated to be historically drained

The outputs from the CERF model are a continuous daily estimate of flow partitioned into:

- overland flow
- interflow
- groundwater flow

As there were no existing survey data, geographical information system (GIS) analysis combined with a review of available MAFF data on the installation of drainage interventions (1980s and 1990s data) were used to confirm drainage locations.

Standard average annual rainfall data and slope classes, as calculated by the CEH Digital Terrain Model (DTM), were combined to determine the likely erosivity of the catchments surface (Figure 4).

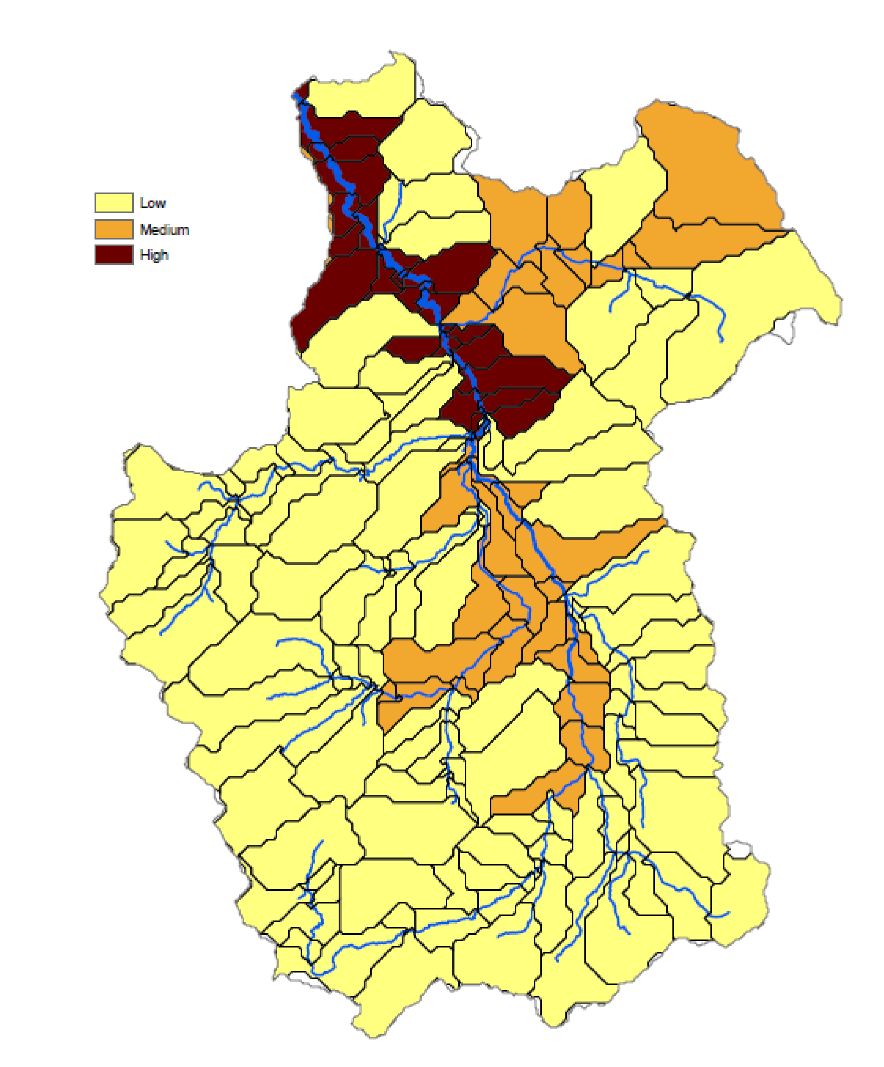

Figure 4: Fine sediment supply within the Clwyd catchment

Source: Natural Resources Wales

Model performance

The CERF daily modelled flows were compared with the gauge flows at Pont-y-Cambwyll (Figure 5) and Ruthin (Figure 6) for the entire historic record, 1962 to 2010. It was considered that the model was effective at simulating the annual daily maxima. The impacts of WwNP on the flood peaks were evaluated in terms of the changes to different flood events. Development of the CERF model allowed the use of distributed rainfall which is beneficial for modelling soil moisture status within the catchment and because of the strong west to east hydrological (decreasing) gradient.

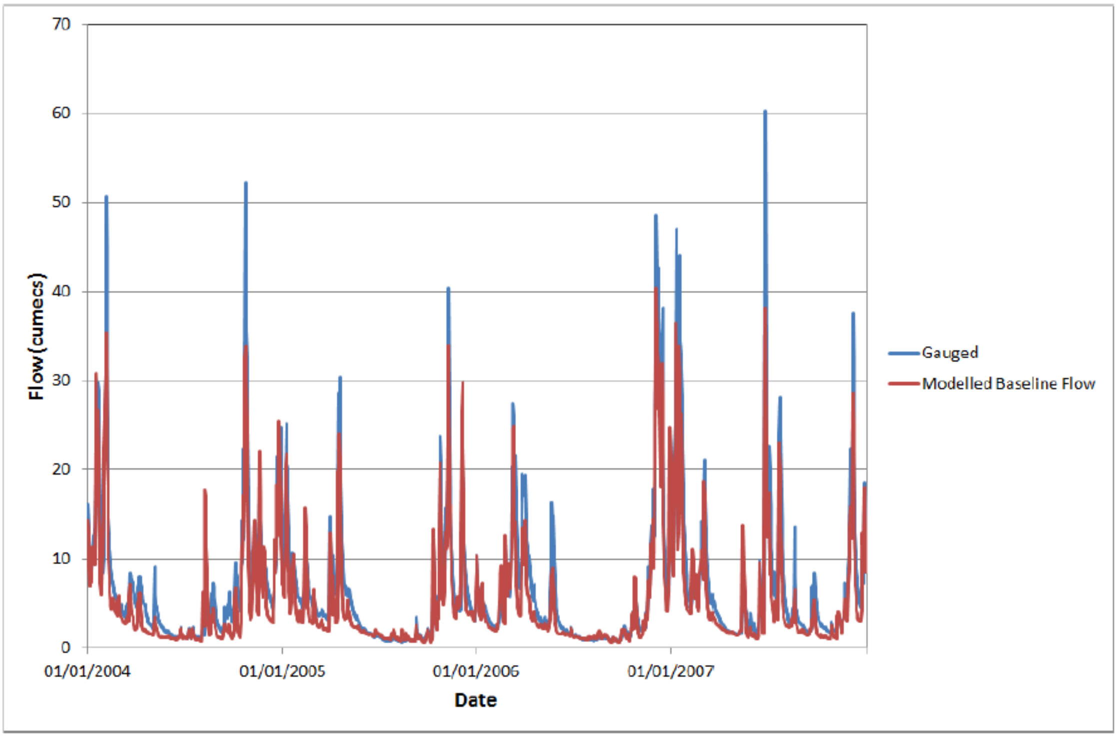

Figure 5: CERF model daily flows compared with observed flows over sample period at Pont-y-Cambwyll

Source: Natural Resources Wales

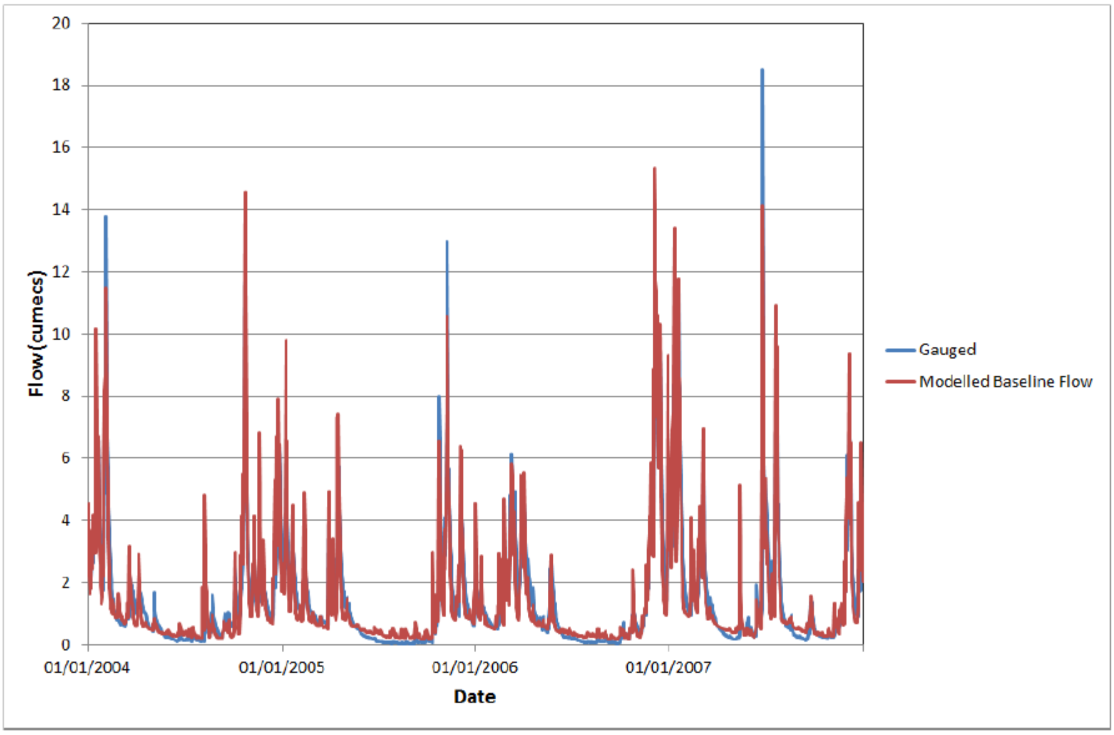

Figure 6: CERF model daily flows compared with observed flows over sample period at Ruthin

Source: Natural Resources Wales

4. Lesson learnt

Choice of tools

- The generic approach to using CERF-HRU, a Probability Distributed Moisture (PDM) type hydrological model, at a catchment scale is useful for experimenting with different WwNP or whole catchment approaches to flood risk management. This is especially the case for WwNP measures that consider land use change, such as the 3 core measures (afforestation, compaction relief and drain blockage) highlighted here.
- The study modelled daily annual flows and made a novel relationship between daily flow and instantaneous peak flow so as to be able to comment on specific events.
- The assessment of ecosystem services is straightforward. The study also identifies different funding mechanisms that might help with the implementation of the recommended measures.
- The approach demonstrates how WwNP measures associated with changes to land use (afforestation, compaction relief and drain blockage) can be modelled through changing effective parameters in a PDM type model.
- Such models can be accurate when calibrated using flow gauge data and are often used in flood forecasting, though their use at a broad scale may require a greater degree of correction or rescaling. However, the beneficial effects are assessed in terms of relative changes to flows and show in theory what could be achieved if there is belief in the model and the changes made to the model parameters are within realistic ranges.

Catchment scale and typology

- The approach is naturally a whole catchment approach, although it is ‘lumped’ with a 1km resolution grid.
- Ultimately, the influence of catchment scale changes has been investigated here rather than making a detailed examination.
- The case study was sensitive to scale and typology issues.

Wider benefits

The project considered the potential ecosystem services associated with the implementation of WwNP interventions (Figure 7). The ecosystem services were divided into four main categories:

- Provisioning services – supply of goods of monetary value which are of direct benefit to people (for example, food, timber, fresh water and fuel)
- Cultural services – non-material services with an important direct benefit to the wider social and cultural needs of society (for example, recreational space, tourism, spiritual enrichment, inspiration, reflection and employment)
- Regulating services – with no conventional monetary value, these services benefit people by regulating factors such as climate, flooding, erosion, water and air quality
- Supporting services – these services do not directly benefit people however they are essential for a functioning ecosystem (for example, water and nutrient cycling, soil formation and processes of plant growth)

A review of current funding options (Table 1) was conducted based on the following sources:

- Welsh Government Rural Development Programme 2014 to 2020
- agri-environmental schemes
- LIFE Natura 2000 (N2K) Programme for Wales
- Payments for Ecosystem Services
- Landfill Communities Fund including the Biffa award and the WREN biodiversity action fund

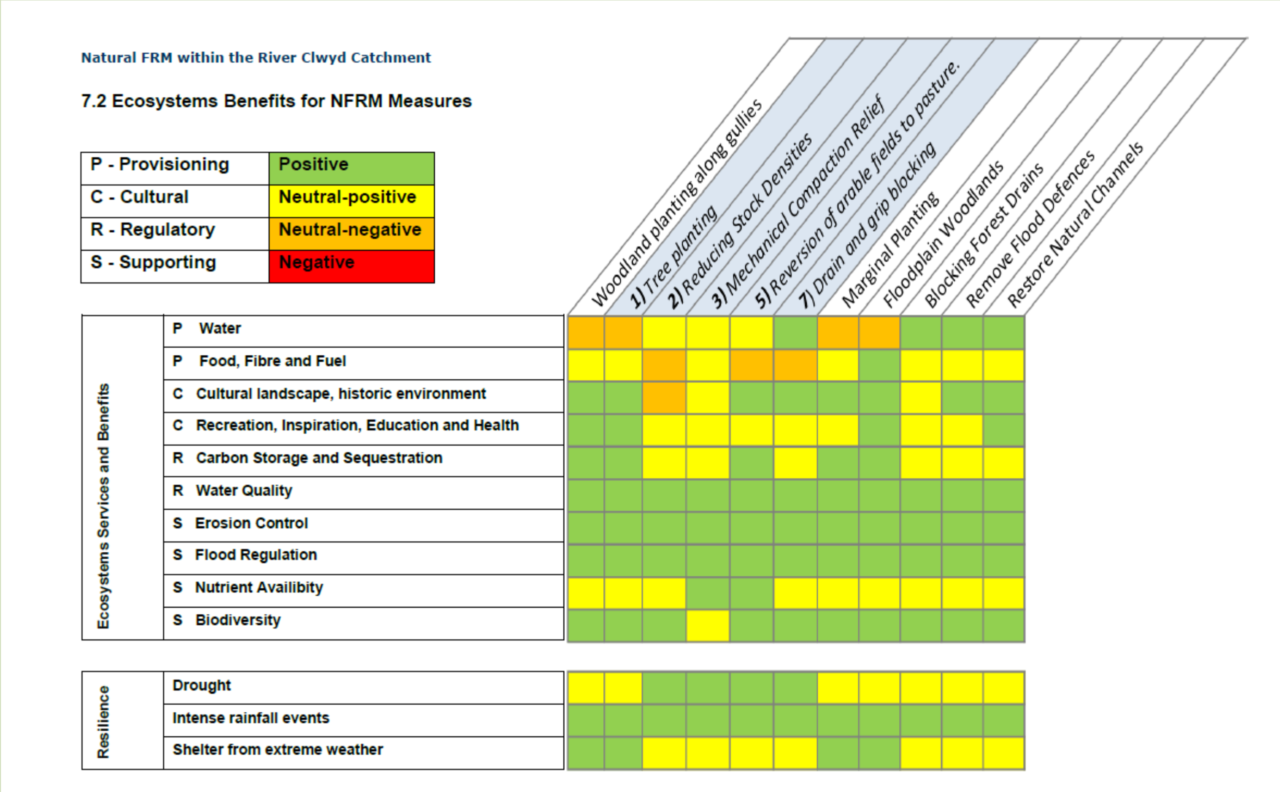

Figure 7: Matrix of pros and cons of different WwNP measures

Source Natural Resources Wales

Table 1: Funding options for different WwNP measures

Funding level	Rural Development Programme	LEADER	Glastir	LIFE (Natura 2000)	Payments for Ecosystem Services	Landfill Community Fund
European	×	×	×	×		
Central government	×	×	×	×	×	×
Regional government	×	×	×	×	×	×
Non-governmental organisations				×	×	×
Third party/ other				×	×	×

Source: Natural Resources Wales

Future research needs

The investigation used in-depth knowledge of how to model the effects of WwNP measures which influence soils and drainage and demonstrates how this can be done using the CERF model as opposed to event-based modelling. Continuous modelling allows the dynamic wetting up of soil and groundwater stores, which strongly influence flood risk and which are influential factors when considering WwNP measures.

Many of the modelling assumptions in terms of parameters are based on existing literature. Further investigation of flow monitoring and sediment sampling of the 3 sub-catchments are recommended to verify the benefits of WwNP interventions. Continued involvement of stakeholders and the creation of a framework created covering funding and future WwNP implementation are also recommended.

5. Bibliography

SISSON, J., 2015. Natural approaches to flood risk management within the River Clwyd catchment. HydroSolutions Ltd and Reading Agricultural Consultants.

Project background

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

It was commissioned by the Environment Agency’s Evidence Directorate, as part of the joint Flood and Coastal Erosion Risk Management Research and Development Programme.

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