# Case study 40. Afon Clwyd

## Author: Jacques Sisson

## Main driver: Flood risk management

## Project stage: Assessed; pending funding for implementation

**Photo 1: Clwyd catchment (source: Natural Resources Wales)**

## Project summary:

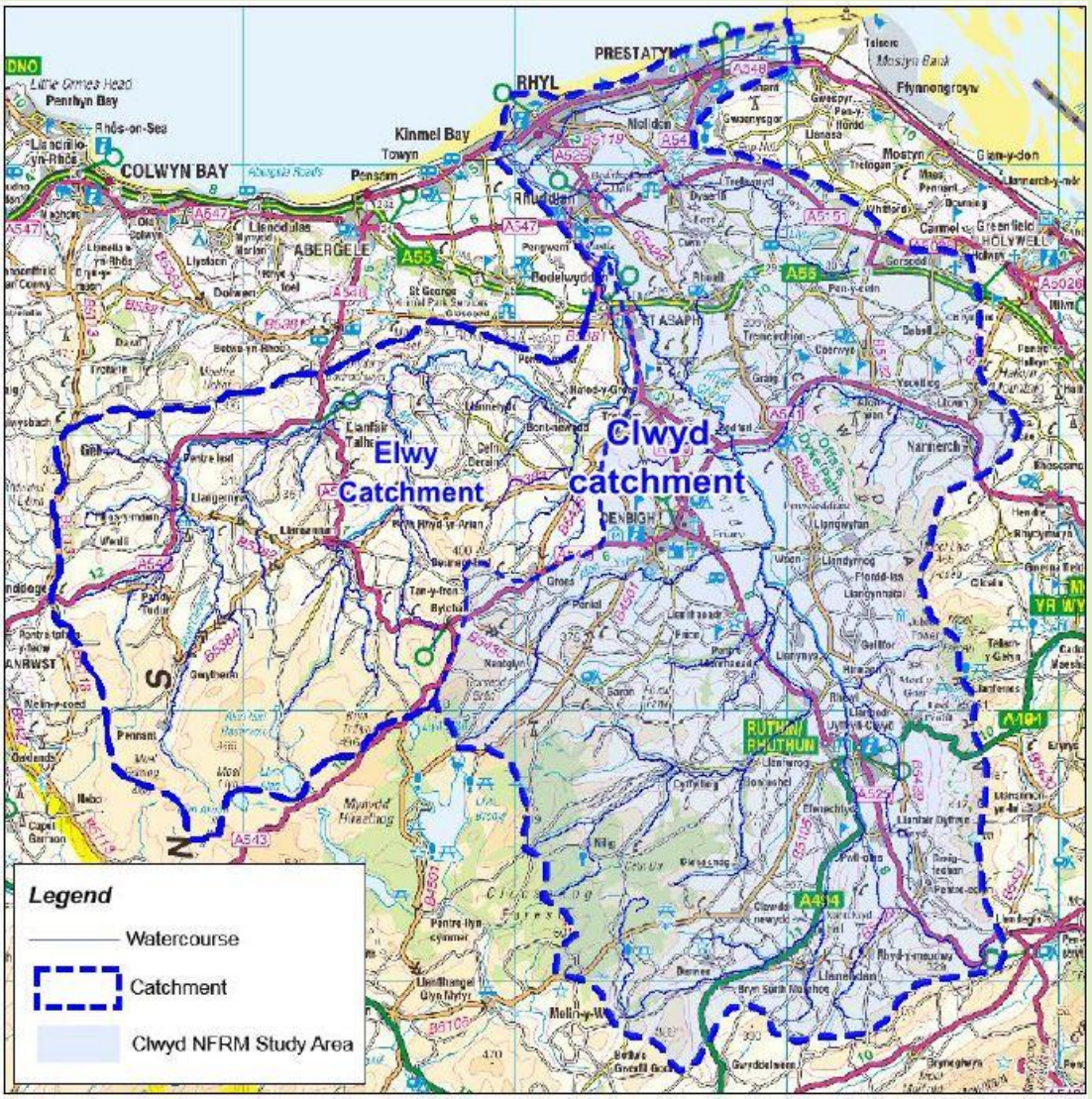
The Clwyd (Photo 1 and Map 1) is a large catchment in north-east Wales, discharging north into the Irish Sea. The confluence of the Afon Clwyd with the Afon Elwy is downstream of St Asaph, which in November 2012 was subject to severe flooding resulting in a fatality. The impact of flooding from the Afon Elwy, which flows through the town, was exacerbated by the backing up of flow at the confluence with the Afon Clwyd, which was also in spate.

In 2015, Natural Resources Wales commissioned AECOM Consultants to identify potential Working with Natural Processes (WWNP) in the Elwy catchment which would provide climate resilience to the proposed improvements to engineered flood defences in St Asaph (AECOM Consultants 2015). Following the study, AECOM wanted to develop techniques for rapid assessment of WWNP that could be applied to different types of catchments. AECOM used EU innovation funding to test techniques in a number of catchments, including this study of potential WWNP in the Vale of Clwyd.

A systematic review of the aerial imagery, Ordnance Survey (OS) mapping and flood zone/flood extent information was carried out to identify the most important morphological features in the catchment and to identify locations where the WWNP measures could potentially be implemented across the catchment. In contrast to the Elwy, the identification process included an assessment of implementation and shortlisting to streamline the process.

## Key facts:

The overall impact of the modelled WWNP is a reduction in peak flow and an increase in time-to-peak (TP). Peak flow reduction was approximately 6% for the 5-year design event and approximately 1% for the 200-year design event.




**Map 1**: **Afon Clwyd catchment (source: Ordnance Survey)**

## 1. Contact details

| Contact details | |
|---|---|
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## 2. Location and catchment description

| Catchment summary | |
|---|---|
| **National Grid Reference:** | SJ 09496 66240 |
| **Town, County, Country:** | Vale of Clwyd, Denbighshire/Flint, North Wales |

| | |
|---|---|
| **Regional Flood and Coastal Committee (RFCC) region:** | Not applicable |
| **Catchment name(s) and size ($km^2$):** | Clwyd catchment, 500$km^2$ (excluding Elwy catchment) |
| **River name(s) and typology:** | Afon Clwyd and associated tributaries, excluding Afon Elwy<br><br>In the upper reaches, the main river is step pool, becoming meandering through the central catchment with extensive flood plains and then becoming canalised through downstream urban areas. |
| **Water Framework Directive water body reference:** | GB110066059960 |
| **Land use, soil type, geology, mean annual rainfall:** | The catchment is largely rural. Agricultural uses are sheep grazing in the upper catchment, and dairy grazing and some arable farming in the mid to lower catchment.<br><br>The underlying geology of the main river is the Kinnerton Sandstone aquifer, which supplies as much as 10% of the baseflow in the lower reaches.<br><br>Average annual rainfall across the Clwyd catchment is approximately 900mm. However, this ranges from 750mm in the lower catchment to over 1,000mm in parts of the upper catchment. |

## 3. Background summary of the catchment

**Socioeconomic/historic context**

The Clwyd catchment includes the major towns of Ruthin/Rhuthun, Denbigh/Dinbych, St Asaph/Llanelwy, and Rhyl on the coast. There are numerous smaller towns and villages within the catchment. Land use is dominated by agriculture with a predominant vegetation classification of 'improved grassland'. Agriculture is pastoral in nature. It comprises mainly beef and some dairy farming on the floodplains in the lower catchment and sheep grazing in the upper catchment. There are also significant areas of arable farming, especially in low lying areas near the coast.

Agricultural land use class tends towards grades 4 and 5 (that is, suitable for grazing and dairy farming only). The upper part of the catchment to the south of the study area has substantial areas of woodland managed mainly by Natural Resources Wales (Clocaenog Forest). There is the potential for land management change to benefit WWNP within these areas.

Many of the upper tributaries flow through upland grazing land, above which there are significant areas of moorland (for example, Denbigh Moors) which have widespread drainage grips. Where the main river passes through urban areas (for example, Ruthin and Rhyl), it has been canalised.

Tourism is important to the local economy, especially around the coastal plains near Rhyl and Kinmel Bay. The area is important for both salmon and trout fishing, and the potential to enhance the recreation and tourism benefits associated with these rivers is significant.

In the lower reaches, there are large caravan parks and in summer the demand for water trebles. The main river flows over a large sandstone aquifer, which Dwr Cymru exploits to operate a scheme that augments the river in the summer (May to November) from boreholes in the upper catchment while abstracting for private water supplies takes place in the central catchment.

**Flood risk problem(s)**

The Afon Clwyd catchment has a long main channel surrounded by steeply sloping subcatchments that flow into the main channel along its length. The western part of the catchment is dominated by the Elwy catchment with the confluence in St Asaph. At the confluence of the Elwy and the Clwyd, the river becomes tidal and enters a narrow estuary before meeting the Irish Sea at Rhyl. Other moderately sized subcatchments such as the Ystrad and Clywedog flow in from the west. The last major inflow to the Clwyd is the Afon Ffyddion from the east.

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 an increased rate of run-off.

Despite some engineered alleviation schemes, there has been flooding in Ruthin and Denbigh during periods of intense rainfall**.** Damage to properties in the towns was widespread in the 2012 floods. In that instance**,** the volume of flow within the Clwyd held back flows in the Elwy resulting in devastating floods in St Asaph.

**Other environmental problems**

The Water Framework Directive **s**tatus of the main river is '**g**ood' in the upper reach to Pwll Glas where it then changes to '**m**oderate'. This is mainly due to the score for fisheries. Historically**,** there were several barriers to fish migration in the catchment (for example, man-made weirs**);** mitigation for these barriers is now being addressed.

There is increased run-off due to compaction; tree and hedge planting should improve infiltration and reduce soil erosion and thereby improve water quality in the main watercourses.

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

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

The Clwyd catchment includes the major towns of Ruthin/Rhuthun, Denbigh/Dinbych, St Asaph/Llanelwy and Rhyll on the coast. There are numerous smaller towns and villages within the catchment.

The Clwyd catchment and associated watercourses were analysed to define subcatchments and the key watercourses split into reaches based on geomorphological characteristics. This was used as a basis for the technical analysis. The primary watercourse data provided by Natural Resources Wales was reviewed and the watercourses within the catchment divided into a series of reaches that reflected the network of tributaries and various morphological features present. The river centreline data formed the basis of the reach numbering and each primary watercourse was assigned a number ranging from 1 to 13.

The final approach was based on 1D routing model and Revitalised Flood Hydrograph (ReFH) hydrological inflow boundaries. This provided a combination of representation of catchment response, the ability to simulate WWNP measures with efficient model development, and assessment of WWNP within the Clwyd catchment.

These watercourses were then further subdivided into individual reaches based on the location of tributaries entering the primary watercourse and key features. The point at which these tributaries joined the primary watercourse, and therefore the extent of each reach, was based on visual identification using aerial imagery and OS mapping. Each reach was then assigned a unique identifier. The primary watercourses were used to define the smaller subcatchments within the wider Clwyd catchment. (For example, the main branch of subcatchment 11 would be identified as Reach 11.1. At the first junction upstream, the tributary would be identified as Reach 11.1.1 and the main branch upstream would be identified as Reach 11.2.) These reaches and subcatchments form the basis of model development, carried out to identify key morphological features within the catchment.

A geomorphological classification of each reach was also carried out based on aerial imagery and verified through a site visit. Each reach was classified according to floodplain type and channel type with an associated baseline Manning’s n value. The baseline Manning’s n values were adapted from Chow (1959) and form the baseline on which the WWNP features were modelled.

An important aim of this study was to develop a rapid approach to assessing the potential benefits of identified WWNP measure opportunities within the subject catchment. Therefore the baseline model was not constructed by modifying or developing any existing model of the catchment. Instead the baseline model was developed using the ISIS 1D software package using ReFH boundary units and variable parameter Muskingum–Cunge (VPMC) cross-sections to route flow.

At the outset of the model development process, it was determined that the reaches modelled should generally match those of the supplied primary river centrelines geographical information system (GIS) layer. This baseline network was then combined with a hydrological model, in which appropriate inflow boundaries were derived to represent direct and lateral subcatchment inflows.

At the confluence of the Elwy and the Clwyd, the river becomes tidal and enters a narrow estuary before meeting the Irish Sea at Rhyl. The model has been extended part way along this section, terminating at the confluence with 'The Cut', which itself was not included as an explicit subcatchment inflow (no WWNP measures were identified on this reach).

*Direct inflows*

Direct inflow hydrological boundaries were applied at the upstream limit of reaches, with the catchment descriptors for the ReFH boundary extracted from the Flood Estimation Handbook (FEH) CD-ROM for the subcatchment draining to that point. For smaller reaches, the catchment descriptors were extracted at the downstream limit of the reach but applied at the upstream point. For non-modelled tributaries, direct inflows were connected into the modelled reach at the nearest cross-section.

*Intervening inflows*

Intervening inflow hydrological boundaries were derived for intervening catchment areas (that is, between an upstream direct inflow and the downstream limit of a reach). The catchment descriptors for the intervening catchments were derived using standard FEH methods. Detailed modelling would usually involve distributing the inflow generated from this intervening area laterally along the reach, or weighted by catchment area at specific inflow locations. Due to the simplification of the model schematisation, however, the lateral inflow for the intervening catchment was entered into the model at the upstream Elwy inflow.

**What was the design rationale?**

The Elwy Natural Flood Risk Management study (AECOM Consultants 2015) provided information on the efficacy of natural flood risk management measures within that subcatchment of the Clwyd. As this study focused on the Clwyd catchment, assumptions were made in respect of the Elwy inflows to the model.

There is a significant difference in timing of the hydrographs for the 2 catchments in terms of design storm event coverage. Therefore, it was assumed that the Afon Elwy would be running at baseflow only during design events on the Afon Clwyd. The associated natural flood risk management study on the Afon Elwy indicated that the baseflow from that catchment is in the order of $20m^3$ per second; this was therefore added to the model as a fixed flow time boundary.

Design event hydrology was developed for 2 return periods: 5-year and 200-year. The ReFH hydrological boundaries were generated for these 2 events based on a catchment-wide storm event, with a 50% winter design rainfall profile and a 15.5 hour storm duration, which was calculated to be critical based on the FEH approximation formula for design storms. ReFH model parameters were estimated from catchment descriptors in the absence of any event analysis being carried out as part of this study.

**Model limitations**

The coarse routing model of the Clwyd catchment has been developed using LiDAR (light detection and ranging) digital terrain data for the catchment. The limitations of the routing model are as follows.

- The cross-section shape has been simplified and the section depth estimated based on 'typical' morphological properties.
- The extent of the floodplain has been user-defined and is averaged over a reach.
- Structures within the Clwyd and its tributaries such as restricted culverts and bridges have not been implicitly included.

| Project summary | |
|---|---|
| **Area of catchment ($km^2$) or length of river benefitting from the project:** | 500$km^2$ |
| **Types of measures/interventions used (both WWNP and traditional):** | |
| **Numbers of measures/interventions used (both WWNP and traditional):** | |
| **Standard of protection for project as a whole:** | |
| **Estimated number of properties protected:** | |

**How effective has the project been?**

A long list of WWNP measures was derived based on morphological features identified through Google Earth, Bing aerial and digital imagery, and OS mapping. The long list of WWNP measures was then ranked based on scoring for opportunity and constraint as shown in the example in Table 1.

**Table 1: Opportunities and constraints for gully planting**

| Opportunity | | Constraint | | Overall Rank | |
|---|---|---|---|---|---|
| Score | Description | Score | Description | Rank | Description |
| 1 | Poor channel form, trees absent | 0 | No constraints | 1 | Very Good |
| 2 | Poor channel form, limited trees | 1 | Current land use | ↓ | ↓ |
| 3 | Good channel form, trees absent | 2 | Flood risk | | |
| 4 | Poor channel form, limited trees | 3 | Expense | | |
| 5 | Existing wooded gully | | | 8 | Very Poor |

A shortlist based on the effectiveness of each type of WWNP on roughness using a variable Manning's value was drawn up; for example, Adjusted Manning's n = Baseline Manning's n + (Manning's adjustment n × proportion of reach).

Some WWNP measures could not be modelled using roughness and instead were measured using their impact on run-off:

- dam storage
- gully planting
- land use management

Figure 1 will form the basis of a further study in the upper catchment headwaters to Pwll Glas by rural development agency, Cadwyn Clwyd, and local farmers who are applying for funding from the Rural Development Plan Sustainable Management Scheme to implement appropriate WWNP measures. Additional work will be carried out as part of the project to ensure all implemented WWNP will also benefit other ecosystem services.

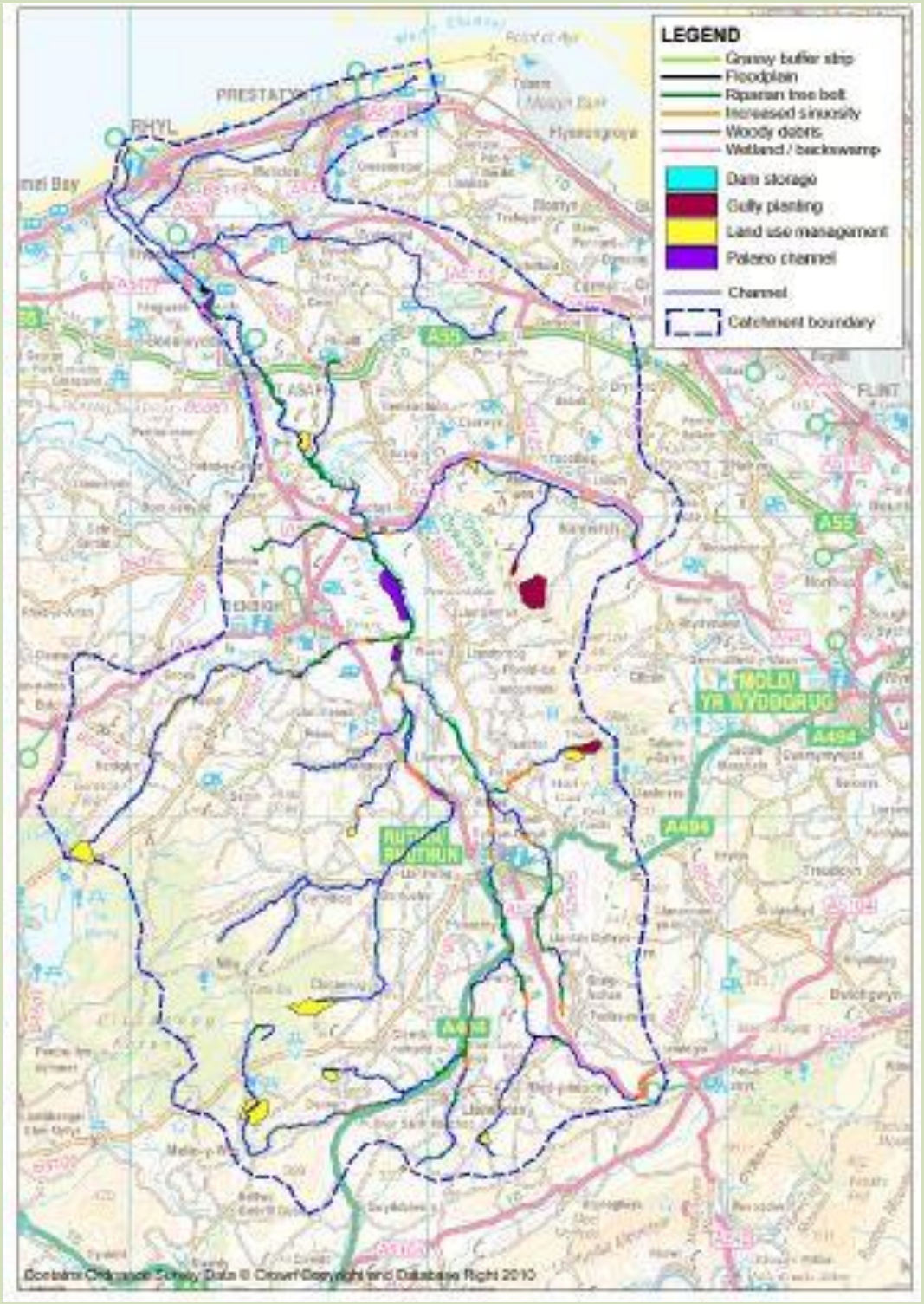


**Figure 1: Opportunities map for WWNP measures in Clwyd catchment**

## 5. Project construction

**How were individual measures constructed?**

Not yet known – construction not started

**How long were measures designed to last?**

WWNP measures will become part of some farm's management plans and their day-to-day operation.

**Were there any landowner or legal requirements which needed consideration?**

To be confirmed

## 6. Funding

| Funding summary for Working with Natural Processes (WWNP)/Natural Flood Management (NFM) measures | |
|---|---|
| **Year project was undertaken/completed:** | Clwyd Natural Flood Risk Study 2015<br>Clwyd WWNP Implementation Project 2017 to 2020 |
| **How was the project funded:** | Clwyd Natural Flood Risk Study 2015 – AECOM, EU Creative and Technical Excellence Council<br>Clwyd WWNP Implementation Project 2017 to 2020 – funding sources to be confirmed |
| **Total cash cost of project (£):** | Not yet known – project not completed |
| **Overall cost and cost breakdown for WWNP/NFM measures (£):** | Not yet known – project not completed |
| **WWNP/NFM costs as a % of overall project costs:** | Not yet known – project not completed |
| **Unit breakdown of costs for WWNP/NFM measures:** | Not yet known – project not completed |
| **Cost–benefit ratio (and timescale in years over which it was estimated):** | Not yet known – project not completed |

## 7. Wider benefits

**What wider benefits has the project achieved?**

It is anticipated that the project will improve grazing through the planting of shelter belts, with hedge restoration providing new habits for wildlife and plants. Other potential benefits include:

- economic benefits to farmers through improved stock health
- reduction in soil erosion through reduced run-off through increased percolation and evapotranspiration
- improved river ecology through reduction of sediment loading

**How much habitat has been created, improved or restored?**

No yet known – project not completed

## 8. Maintenance, monitoring and adaptive management

**Are maintenance activities planned?**

Maintenance of hedgerows will be carried out by farmers.

Improved management of woodlands will be undertaken by Natural Resources Wales

**Is the project being monitored?**

Monitoring will be carried out by a university or consultant.

**Has adaptive management been needed?**

To be confirmed

## 9. Lessons learnt

To be confirmed

**What was learnt and how could it be applied elsewhere?**

To early to say.

## 10. Bibliography

AECOM Consultants, 2015. *Clwyd Natural Flood Risk Management Study.* Cardiff: Natural Resources Wales.

CHOW, V.T., 1959. *Open-channel Hydraulics*. New York: McGraw-Hill.

## 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.