Dinas Powys Flood Risk Management Scheme

Cyfoeth Naturiol Cymru
Natural Resources Wales

Five Case Model: Outline Business Case

Revision	Date	Originator	Checker	Approver	Description
1.0 DRAFT	11/2/20	Jba / MG	GTJ	GTJ	Draft issue to public
2.0	4/5/20	MG	GTJ	GTJ	Final issue to FRM BB(June)

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1. The Strategic case

1.1. Introduction

A catchment wide study of the Cadoxton in south Wales considered flood risk from its headwaters near Michaelston-le-Pit and Wenvoe, through Dinas Powys to the Sully Moors at Palmerstown, as illustrated in Figure 1-1**Error! Reference source not found.**. This Outline Business Case (OBC) is c oncerned with managing fluvial flood risk to Dinas Powys, shown below as Upper Catchment. A recent business case 'Cadoxton Outfall business case' and resultant capital scheme was concerned with managing flood risk at the Industrial Area in Palmerstown and is now independent of this project.

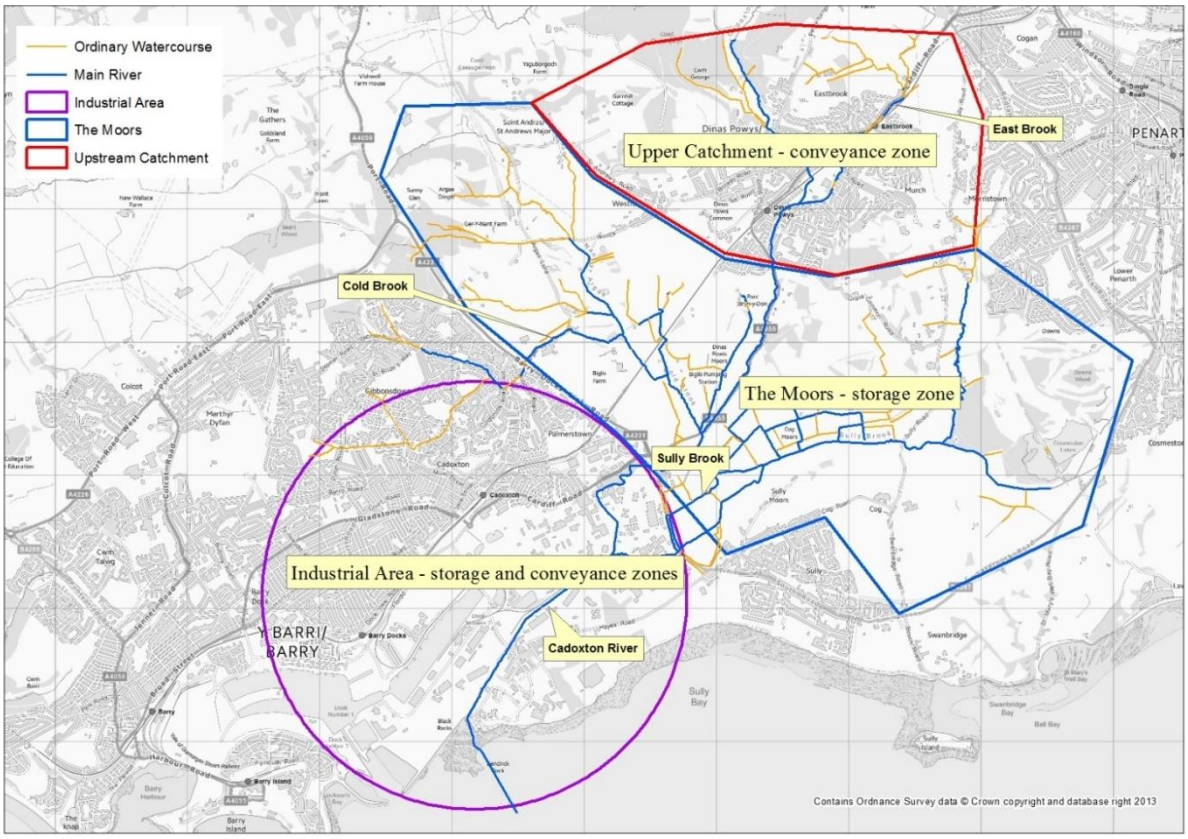

Figure 1-1: Map showing the study area

1.2. How strategic Flood and Coastal Erosion Risk Management is considered

1.2.1. National Flood and Coastal Erosion Risk Management Strategy

The Welsh Government **National Flood and Coastal Erosion Risk Management Strategy** objectives set the framework for flood and coastal erosion risk management work within Wales:

- Reducing the consequences for individuals, communities, businesses and the environment from flooding and coastal erosion;
- Raising awareness of and engaging people in the response to flood and coastal erosion risk;
- Providing an effective and sustained response to flood and coastal erosion events;
- Prioritising investment in the most at-risk communities.

Every flood risk management action undertaken in Wales has the National Flood and Coastal Erosion Risk Management strategy objectives as the overarching deliverable.

1.2.2. Flood Risk Management Plans

Sitting under the National Strategy objectives, Natural Resources Wales has three regional **Flood Risk Management Plans** (FRMP). The Cadoxton catchment is located in the Western Wales FRMP region. The Plan gives an overview of the flood risk in the Western Wales River Basin District and sets out NRW's priorities to manage and reduce flood risk from 2015 to 2021 and beyond. The plan sets several high-level objectives relevant to the project:

- Objective 1: Reduce the risk of harm to life from flooding to people and communities from main rivers, reservoirs and the sea.
- Objective 2: Increase resilience of services, assets and infrastructure to current and future risk of flooding.
- Objective 4: Improve community awareness and resilience to current and future flood risk.
- Objective 6: Allocate funding and resources for all sources of flooding on a risk basis.
- Objective 7: Incorporate natural resource management into the delivery of flood risk management.
- Objective 8: Seek opportunities to deliver River Basin Management Plan measures through flood risk management.

The study area is located within the Tawe to Cadoxton area of the Western Wales FRMP. Within the FRMP, Dinas Powys is identified as a key community where NRW "feels there is still more to be done to manage and reduce the risk of flooding". The community has been given 'very high' priority measures to further investigate the flood risk. This has resulted in flood modelling studies to predict where flooding might occur and how severe it might be, and the development and appraisal of options to reduce the risk of flooding. The objectives of the FRMP were used during the development of the project's critical success factors, to enable the long list options to be assessed against the flood risk management plan for the catchment.

1.2.3. Flood Risk Assessment Wales (FRAW) Communities at Risk Register (CaRR)

The Wales-wide Communities at Risk Register (CaRR – 2019) ranks communities across Wales based on their flood risk, informed by a high level, national scale, model prediction. This helps NRW start to understand flood risk across all of Wales and where the priorities are, so we can begin investigating. Dinas Powys is the 55th ranked community in Wales for river flood risk.

1.2.4. Local Flood Risk Management Strategy

The project complements Vale of Glamorgan Council's Local Flood Risk Management Strategy (2012). The Council's strategy outlines high level management actions to manage local flood risk from ordinary watercourses, surface runoff and groundwater.

1.3. How strategic Sustainability and Well-being is considered

A summary of the local sustainability and well-being strategic framework is presented below. Through considering the study area and nature of the project, we've identified the objectives and priorities within those strategies that are of relevance to the project. The listed sustainability and well-being objectives and priorities will be discussed further within the Economic Case, where they will be considered as part of the options appraisal.

1.3.1. Wellbeing of Future Generations (Wales) Act 2015

The Well-being of Future Generations Act requires public bodies in Wales to think about the long-term impact of their decisions, to work better with people, communities and each other, and to prevent persistent problems such as poverty, health inequalities and climate change.

In response to the Well-being of Future Generations Act and its associated goals, we've produced a Well-being Statement – "Managing today's natural resources for tomorrow's generation" 2017-18. The statement sets out seven well-being objectives, those that are of particular relevance to this project include:

- Champion the Welsh environment and the sustainable management of Wales' natural resources.
- Ensure land and water in Wales is managed sustainably and in an integrated way.
- Improve the resilience and quality of our ecosystems.
- Reduce the risk to people and communities from environmental hazards like flooding and pollution.

- Help people live healthier and more fulfilled lives.

The Vale of Glamorgan Public Service Board (PSB) brings together public and third sector organisations from across the Vale of Glamorgan tasked with working together to improve services and well-being across the county. In response to the Well-being of Future Generations Act, the PSB has produced a local Well-being Plan that includes its long-term vision and priorities for improving local well-being for people of all ages and across all areas of the Vale. The local Well-being Plan sets out four objectives, the two that are of particular relevance to this project are:

- To enable people to get involved, participate in their local communities and shape local services.
- To protect, enhance and value the environment.

Minimising flood risk is part of the PSB's objective 'to protect, enhance and value the environment' within its 2050 vision document.

1.3.2. Environment (Wales) Act 2016

The Environment Act puts in place a process to help plan and manage Wales' natural resources in a more sustainable and joined up way. It focuses on building resilience into our ecosystems and recognising the benefits they provide if we manage them in a smarter way. The Act places a specific duty (Section 6) on public bodies:

- Seek to maintain and enhance biodiversity….and in doing so promote the resilience of ecosystems, in particular the diversity, connectivity, scale, condition and adaptability of ecosystems.

The Environment Act sets out an iterative framework for delivery, which includes the State of Natural Resources Report (SoNaRR), Natural Resources Policy and Area Statements. Published in 2017, the Natural Resources Policy sets out three national priorities, all of which are relevant to this project:

- Delivering nature-based solutions.
- Increasing renewable energy and resources efficiency.
- Taking a place-based approach.

Dinas Powys is located within the South Central Wales Area Statement boundary. The Area Statement is currently being produced and is due to be published in 2020. Any objectives or priorities being put forward by the Area Statement will be considered by the project at the point information becomes available.

1.4. The flood problem and current management arrangements

1.4.1. The Problem

The Cadoxton River has an extensive history of fluvial flooding, although the nature of this flooding varies across the catchment. Dinas Powys is one of the key areas of concern, specifically in relation to residential flooding.

There is a lengthy flood history for the village, with properties on St Cadoc's Avenue, Greenfield Avenue, Elm Grove Place and Cardiff Road at Eastbrook having been affected. Internal property flooding was reported in 1903, 1913, 1948, 1986, 1998, 1999 and 2008. External flooding was also reported in 1965, 1968, 1976, 1995, 2007, 2012,2013 and most recently in March 2020.

In the 1% (1 in 100) annual exceedance probability (AEP) present day event (ie a flood event with a 1% chance of happening in any year following heavy rainfall) (Figure 1-2**Error! Reference source not found.**), there are 197 residential properties and 19 business properties at flood risk in Dinas Powys; this is predicted to rise to 368 residential properties and 19 business properties by 2117 due to the effects of climate change. Most of the flood risk in Dinas Powys comes from the Cadoxton River, with approximately one-fifth of the properties at flood risk attributed to the East Brook.

Flooding in Dinas Powys is caused by peak flood flows exceeding the watercourses' capacity and spilling into the floodplain. Development has taken place in close proximity to the watercourses and there is little remaining floodplain in the village to naturally store and convey floodwater in flood events. This leads to the onset of flooding in a flood event with a 3.33% chance of happening in any year. To address flooding in Dinas Powys will require either a reduction in peak flows or an increase to the channel capacity.

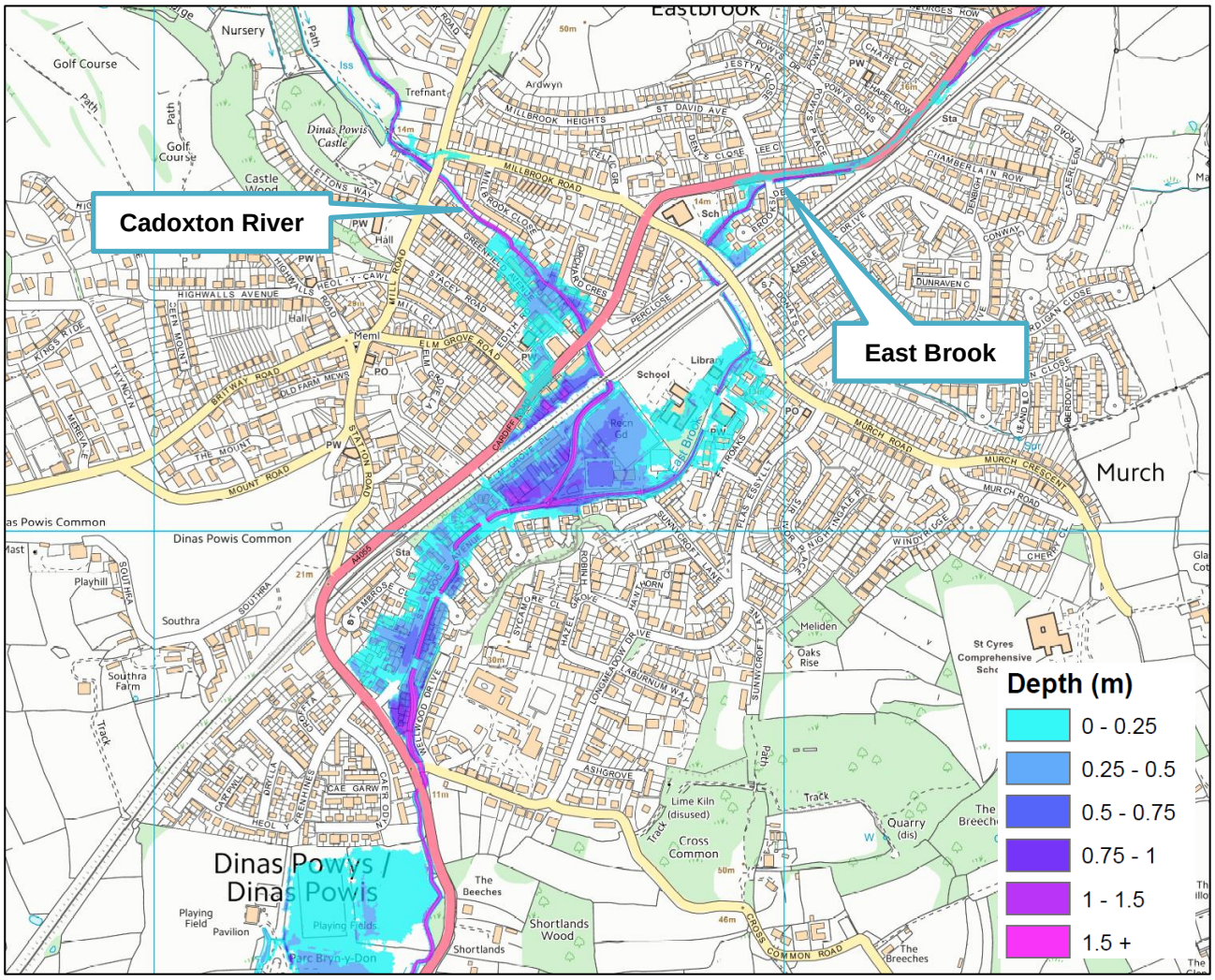

Figure 1-2: Map showing flood depths in Dinas Powys during the 1% present day flood event

1.4.2. Current Flood Risk Management Arrangements

We have no flood management assets in Dinas Powys at present. We take a risk-based approach to maintenance of the watercourse and will respond to clear channel obstructions if they increase the risk of flooding.

We operate a flood warning service for the Cadoxton River in Dinas Powys and Palmerstown.

Six properties at St Cadoc's Avenue were previously provided with individual property level protection measures. The maintenance and operation of these temporary measures is the responsibility of the property owners.

1.4.3. Previous Studies

The extensive flood history of the Cadoxton River catchment has led to several previous studies that aimed to understand the issues and explore possible engineering solutions.

Relevant studies include:

- Dinas Powys Flood Alleviation Scheme Engineering Feasibility Study. Atkins for Environment Agency Wales, 2000.
- Cadoxton Flood Risk Study. JBA Consulting for NRW, 2015.
- River Cadoxton Strategic Flood Risk Assessment: Phase 2 Strategic Options Appraisal. JBA Consulting for NRW, 2015.

1.5. Investment Objectives

Investment objectives identify the desired outcome from spending money on the project, i.e. 'where we want to be' or 'what do we want to achieve'. The desired investment objectives to be achieved by this project are:

- To reduce the risk to properties and life from fluvial flooding from the Cadoxton River to low (less than a 1% chance).
- To reduce the risk to properties and life from fluvial flooding from the East Brook to low (less than a 1% chance).
- Contribute to the Sustainable Management of Natural Resources by maintaining and enhancing biodiversity and ecosystem resilience, through working with natural processes and identifying wider environmental opportunities.
- Contribute to NRW's Well-being objectives and consider the needs and views of the local community through effective engagement.

These should be delivered by 2022.

For a flood risk management option to be taken forward for Short List consideration it should have the potential to achieve at least one of the investment objectives.

1.6. Summary of potential opportunities and benefits from investment

Investment could benefit up to 197 homes and 19 business in Dinas Powys that will be less likely to flood from the Cadoxton River. Table 1-1 shows properties at risk during the 1% AEP event in years 2017 and 2117. Key infrastructure, including road links such as Cardiff Road, and public buildings such as Dinas Powys Primary School, Murch School and Dinas Powys Library will also benefit from improved flood risk management (see cover photographs).

The project will explore what wider environmental and social benefits it can provide to Dinas Powys, seeking partnership opportunities and involving the community throughout. We will consider natural flood management options and the biodiversity and water quality benefits they offer, as well as ways to improve the quality, quantity and connectivity of local ecosystems. We hope to be able to contribute to the Cadoxton River achieving or surpassing its classification status under the Water Framework Directive. There may be opportunities to improve access to amenity, recreation or heritage in Dinas Powys, helping people connect with their natural and historic surroundings to live healthier, more fulfilled lives.

Table 1-1: Property counts within the study area at flood risk during a 1% event in year 2017 and 2117

	Dinas Powys	Eastbrook	Sully Moors	TOTAL
Baseline Year 2017				
All properties	170	33	14	**217**
Residential	167	30	0	**197**
Non-residential	3	2	14	**19**
Future Year 2117				
All properties	268	101	50	**419**
Residential	258	97	13	**368**
Non-residential	10	3	37	**50**

1.7. Summary of potential risks, constraints and dependencies from investment

1.7.1. Main risks

The main risks associated with the overarching strategy for this investment are discussed below. Specific project risks associated with options will be detailed in the Economic Case.

Table 1-2: Investment risks

No	Key Investment Risk	Mitigation Measure(s)
1	**Missed opportunities** The main purpose of the OBC is to identify the best solution to a problem.	Identify and consider all viable options, and their associated opportunities and risks. Work with key stakeholders to explore and evaluate all opportunities.
2	**Assessment of whole life costs / benefits of options.** Changes resulting in options being unviable.	Undertake regular costs/benefits review of options and whole life future maintenance and repair costs, utilising professional advice. Consider how any change could impact costs and benefits. Mitigate key construction risks early with detailed site investigation and ground investigations to confirm study findings. Review wider area benefits and the benefits of new Dinas Powys flood management measures' such as Cross Common Bridge and Cadoxton Outfall Improvements, to avoid double counting when assessing the benefit of potential options.
3	**Landowner & stakeholder Objections**: The successful delivery of flood management schemes requires broad support from a wide range of affected and interested parties. Landowners and stakeholders may object to proposals and seek to intervene.	Consult affected landowners during appraisal stage. The project will follow a comprehensive live Stakeholder Engagement Plan, to identify, understand and engage with key stakeholders. Consult stakeholders on OBC to gain views and inform way forward.
4	**Public support:** Public support for a flood scheme cannot be taken for granted, and positive support can significantly aid successful project delivery.	Stakeholder Engagement Plan shall manage public engagement and the project communication strategy. Seek to engage with all demographic of community, utilising political representatives (eg community councils, councillors, AMs, MPs). Consult community on OBC to gain views and inform way forward.
5	**Environmental or community impacts:** Impacts of options unacceptable to NRW and threaten viability or support.	Impacts must be managed in accordance with the mitigation hierarchy, seeking to avoid first and foremost, Opportunities for wider environmental and well-being improvement identified and realised where feasible. Overall investment purpose and benefits must be considered against the impacts in the short and long term.

1.7.2. Environmental Constraints

An Environmental Constraints and Opportunities Record (ECOR) has been prepared (see Appendix A), which documents the baseline environment conditions for receptors (ie living organisms other than humans, their supporting habitat, or natural resources which could be affected) within the Cadoxton River catchment.

The following environmental studies have been undertaken to inform the OBC, with key findings recorded within the ECOR and used to inform the options appraisal:

- Preliminary Ecological Appraisal
- Outline Woodland Survey Report and Arboricultural Impact Assessment
- Casehill and Newland Wood Botanical Walkover Survey
- Heritage Desk-based Assessment and Archaeological Walkover Survey

- Landscape Scoping Summary
- Cadoxton River Fluvial Audit
- Water Framework Directive Preliminary Assessment Report and Assessment Report
- Dormouse Survey Report
- East Brook Ecological Walkover
- Dinas Powys Ecological Walkover
- NFM JFLOW Modelling and Analysis

During November 2017, we consulted on an early draft of the ECOR with Vale of Glamorgan Council, Glamorgan Gwent Archaeological Trust, Cadw, the Woodland Trust, Glamorgan Bat Group and the RSPB. Following this the ECOR was revised, and we will consult again on our revised ECOR following the public sharing of this draft OBC.

1.7.2.1. Upper Cadoxton Valley (including Dinas Powys itself)

The upper catchment is mostly rural and comprises of open grassland and woodland. The village of Dinas Powys is located to the south east whilst Michaelston-le-Pit is to the north.

Dinas Powys is a typical village community with a broad mixture of housing stock, alongside small businesses and infrastructure such as schools, a library and train stations. The Cadoxton River flows through the village from north to south and is heavily constrained by adjoining development, with many property gardens abutting the river bank. There are several road and foot bridges across the river, as well as a railway bridge.

The area to the north of Dinas Powys and to the south east of Michaelston-le-Pit, is mostly rural comprising of open grassland and woodland. A network of Public Right of Ways (PRoWs), permissive footpaths and a permissive bridleway extend across the area, providing an important public amenity, used frequently by both local residents and visitors to the area. The PRoW heading north from Dinas Powys forms part of the Salmon Leap Walk, one of the well-publicised Ten Vale Walks that connects Dinas Powys with Cwrt-yr-ala Historic Park and Garden. A proportion of the area, known as the “Cwm George and Casehill Woods”, is owned and managed by the Woodland Trust and is again a popular location with visitors.

As portrayed within Figure 1-3, there are several parcels of Ancient Woodland (as recorded on the Ancient Woodland Inventory for Wales) present upstream of Dinas Powys. Ancient woodland (land that has been continually wooded since at least AD1600) is one of the UK’s richest habitats, supporting at least 256 species. Ancient woods form a unique link to the primeval wildwood habitat that covered lowland Britain following the last ice age. In ancient woodlands the interactions between plants, animals, soils, climate and people are unique and have developed over hundreds of years. Ancient woodland is irreplaceable, covering less than 3% of the UK. In addition to ancient woodlands there are many trees throughout the valley having been awarded Tree Preservation Orders, with several veteran or notable trees also present as recorded on the Woodland Trusts Ancient Tree Inventory.

There are Sites of Importance for Nature Conservation (SINC) present within the upper catchment. SINCs are local non-statutory designations with high nature conservation value. Coed Clwyd-Gwyn SINC and Case Hill Wood SINC are situated alongside the Cadoxton River. Both Coed Clwyd-Gwyn and Case Hill Wood SINCs are described as Lowland mixed deciduous woodland United Kingdom (UK) BAP (UK Biodiversity Acton Plan) Priority Habitat.

The river corridor through Dinas Powys is vegetated along its length, with sparse narrow woods along both banks and areas of amenity grassland. Given the available habitat there’s potential for protected and notable species to be present, including: Bats, Otters, Reptiles, Amphibians, Nesting Birds (kingfisher is of particular interest as they usually nest within high riverbanks. Whilst there’s again potential for these species north of Dinas Powys where the catchment becomes more rural, there’s also potential for protected and notable species such as Badgers and Dormice. The Cadoxton River supports macroinvertebrates and important fish species such as Atlantic Salmon, Stickleback, Eel, and Bullhead. Opportunities exist to preserve and enhance the ecological value of marginal aquatic habitat, bank and riparian zones.

The Cadoxton River is a surface waterbody classified under the Water Framework Directive (WFD). The Cadoxton River supports macroinvertebrates and important fish species such as Atlantic Salmon, Stickleback, Eel, and Bullhead. Cadoxton – headwaters to tidal limit (GB110058026420) has an overall WFD water body status of Moderate. Reasons for failing Good status include copper from an unknown source (affecting ecological status), and agriculture and rural land management (diffuse source of phosphates causing increased macrophyte and phytobenthic growth). Groundwater WFD waterbodies within the Cadoxton River catchment include Thaw & Cadoxton

Carboniferous Limestone (GB41002G201600) and the Thaw & Cadoxton Jurassic Lias (GB41002G201400). Both have a quantitative status of Good, and a chemical status of Good, giving them an overall status of Good. There are opportunities to improve the WFD status of the Cadoxton River, through changing land use practices and re-naturalising its sinuosity and improve connectivity with its natural floodplain.

Four Scheduled Monuments (SMs) are located within the Upper Cadoxton Valley:

- Dinas Powys Earthworks and Settlement (previously Cwm George or Cwrt-yr-Ala Camp SM) is a small promontory fort crowning the highest northern spur of the hill above the area and is Iron Age in origin;
- Tyn y Coed Earthwork SM consists of two parallel banks and ditches running northwest/southeast across the ridge, and is scheduled as a medieval enclosure;
- Dinas Powys Castle is one of the earlier Norman castles built in the Vale of Glamorgan, of late 12th or early 13th century in origin.
- Romano-British Farmstead, Dinas Powys Common. The monument consists of the remains of a Romano-British settlement dating to the 2nd and 3rd centuries AD.

Dinas Powys Conservation Area covers parts of the older village and its defining characteristics include the historic core of a former rural settlement beside a Norman castle, the architectural and historic interest of some of the area's historic buildings and structures including six grade II listed buildings and a SM (Dinas Powys Castle). Michaelston-le-Pit Conservation Area covers the historic hamlet of Michaelston-le-Pit, with its linear form alongside St Michael's Parish Church and the informal village green.

There are several listed buildings located within the upper catchment as portrayed by Figure 1-3. Cwrt-yr-Ala Park and Garden, is a grade II registered historic park and garden, located a short distance upstream from Michaelson-le-Pit. It is a particularly notable landscaped park, containing a string of ponds which appear as one sinuous piece of water. It contains a formal twentieth-century garden with terraces and a canal.

Special Landscape Areas are local non-statutory designations used by local authorities to define areas of high landscape importance. The majority of the upper Cadoxton Catchment falls within Cwrt-Yr-Ala Basin Special Landscape Area (SLA).

The northern area is located within Agricultural Land Classification Grade 2 (very good quality). The southern area is located within Agricultural Land Classification Grade 3 (good to moderate quality). The area is partially located within a groundwater source protection zone associated with Biglis Wells.

1.7.2.2. East Brook Tributary

The area surrounding East Brook is mostly rural pasture and mainly comprises fields bounded by hedgerows, with the settlement of Dinas Powys to the south west and Llandough to the north. Several PRoW's are present.

There are no Ramsar sites, Special Areas of Conservation (SAC), Special Protection Areas (SPA), Sites of Special Scientific Interest (SSSI), National Nature Reserves (NNR) or Local Nature Reserves (LNR) within 2km of the area. However, there are several SINCs within 2km (detailed above within Upper Cadoxton Valley section) and records of protected species including Great Crested Newt and Bat. Habitats surrounding the East Brook channel include amenity grassland, dense scrub and semi-natural woodland. There is potential habitat for protected and notable species including birds (kingfisher of particular interest), reptiles, bats, otter, badger and amphibians.

The waterbodies within the East Brook Tributary area are ephemeral and not designated WFD waterbodies. They are located approximately 1.4km upstream of the closest WFD waterbody; the Cadoxton River.

There are no SM, Listed buildings, National Parks, Areas of Outstanding Natural Beauty (AONB), Conservation Areas, nor Historic Parks and Gardens within the area. A field system of unknown date and extent has been identified within this area. A Holy Well is also recorded but has not been located on the ground. The area is located within the Cwrt-yr-Ala Basin SLA. The area comprises field boundaries comprising linear woodland and hedgerows.

The area is located within Agricultural Land Classification Grade 3 (good to moderate quality).

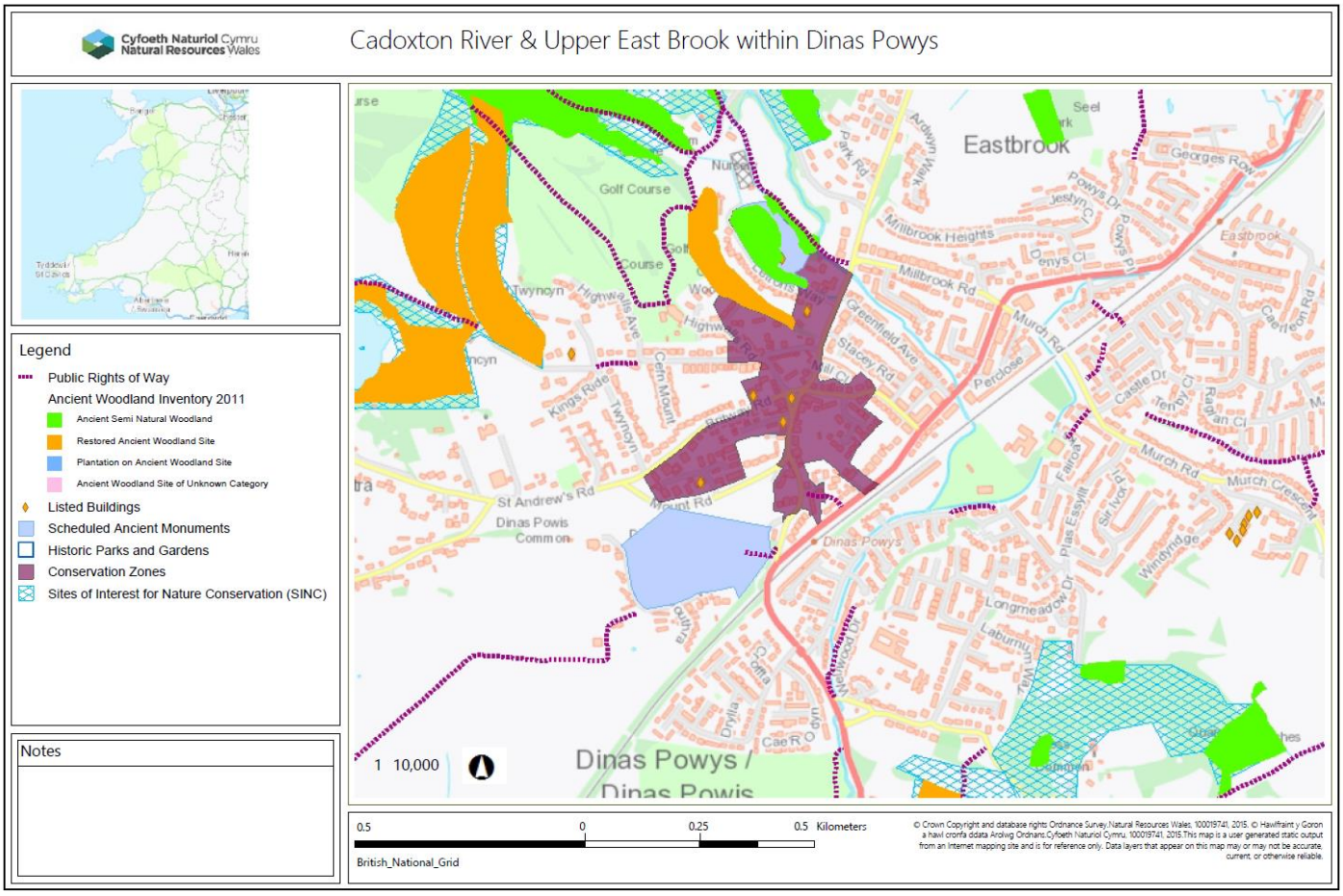

Figure 1-3: Upper Catchment and East Brook Environmental Constraints

1.7.3. Dependencies and external influences

The project will be delivered independently of any other plans or projects, as it does not require and is not influenced by any such plans or projects.

Successful delivery of the project will require a range of permissions, agreements and support that could include:

- Planning permission with associated Environmental Assessment, Flood Consequences Assessment, Consent under Tree Preservation, Conservation Area Consent
- Highways Act Order(s) - Public Right of Way Diversion Order / Extinguishment Order
- Flood Risk Activity Permit / Ordinary Watercourse Consent with associated Water Framework Directive Assessment
- Protected Species License
- Landowner agreements and Notice of Entries under the Water Resources Act
- Public engagement and broad community support.

1.8. Stakeholder engagement

A stakeholder mapping exercise has identified the following interested parties that may be involved in the project going forward.

Table 1-3: Stakeholder mapping

Likely higher interest	Likely lower interest
Local community (Dinas Powys and Michaelston-le-Pit)	Local businesses
Land and property owners	CADW
Local campaign group(s)	Utilities (electricity, BT, Network Rail)
Welsh Government Members of the Senedd	Public Service Board (VoG)
South Wales Central and VoG MS's (Jane Hutt MS, David Melding MS, Andrew R T Davies MS, Gareth Bennet MS, Neil McEvoy MS)	Third Sector Organisations (eg RSPB)
Vale of Glamorgan Council MP (Alun Cairns MP)	British Horse Society
Vale of Glamorgan Council Councillors	Ramblers Association
Dinas Powys and Michaelston-le-Pit Parish Councils and Councillors	
Vale of Glamorgan Council (Planning, Heritage, Landscape, Conservation, Highways, Public Right of Way)	
The Woodland Trust / Coed Cadw	
NRW Regulatory Functions	
Glamorgan Gwent Archaeological Trust	

2. The Economic Case

2.1. Introduction

In line with the Five Case Model, the economic case has been prepared to assess value for money for the proposed flood risk management scheme options. The economic assessment has been undertaken in accordance with the Flood and Coastal Risk Management Appraisal Guidance (FCERM-AG; Environment Agency), Multi-Colour Manual (MCM; Flood Hazard Research Centre, 2013) and HM Treasury's Green Book (2011). The assessment presents costs and benefits as present-day values to enable the like-for-like comparison of options, by adjusting future whole-life costs and benefits over the next 100 years back to a present-day equivalent.

Costs have been developed from indicative designs and consider all aspects required to deliver a project and operate the scheme. Benefits are based on flood damages avoided by the implementation of a scheme. The estimate of damages is calculated in the theoretical Walkaway scenario (where all current flood risk management arrangements are stopped), and incorporates three main components:

- Flood damage costs to property in the Cadoxton catchment;
- Vehicle damages in flood;
- Emergency services costs.

Avoidance of these costs through a flood risk management scheme measure is counted as a benefit attributable to that measure.

An economic damages assessment has been carried out for the Cadoxton catchment as a whole, to estimate the current damages within the catchment and to estimate any remaining damages for each of the flood risk management measures once in place. The catchment has been split into three specific areas to help us understand how the flood risk and benefits are spread across the area. These areas or reporting units are Dinas Powys, Eastbrook and Sully Moors, and are shown in Figure 2-1.

The properties in the Barry Industrial Area in the Sully Moors unit will have a low fluvial flood risk once the separate Cadoxton Outfall capital scheme that is ongoing is completed. Hence managing flood risk to properties in this area is not the aim of this OBC, which focuses on the Dinas Powys and Eastbrook units.

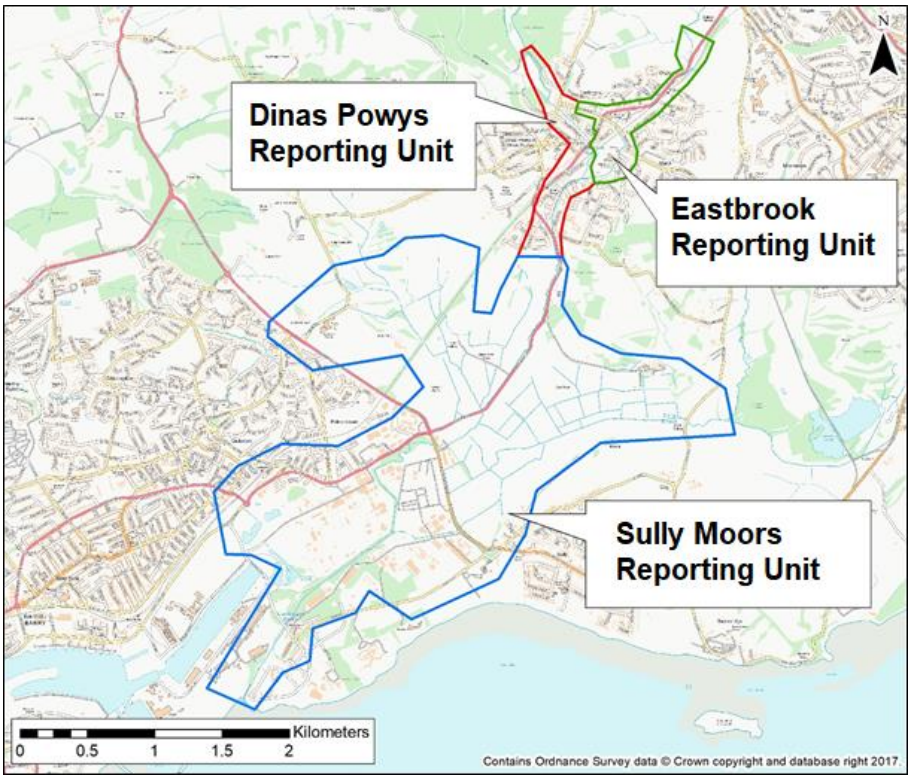

Figure 2-1: Economic Reporting Units

2.2. Critical success factors

The critical success factors have been developed by considering the essential aspects to the successful delivery of the scheme. The critical success factors are:

Table 2-1: Critical Success Factors

Item	Critical Success Factors	Measurement Criteria
A	Strategic fit & Business needs	Manages fluvial flood risk to a low level (1% chance) for homes affected in the community of Dinas Powys, to support Welsh Government outcomes. Sustainably manages and uses natural resources. Manage existing habitat and biodiversity and deliver wider benefits to the local ecosystems that promotes resilience.
B	Potential value for money	Is economically viable, so the benefits from the scheme are greater than the costs to deliver it, to achieve a benefit-cost ratio of greater than 1.
C	Supplier Capacity and Capability	Deliverable by available suppliers. Future maintenance and management are agreed and clearly understood.
D	Potential affordability	Can be funded by Welsh Government Grant in Aid, supplemented by other potential contributions (eg business contribution or community infrastructure levy).
E	Potential achievability	Technically viable to deliver. Can secure relevant consents and permissions. Fits with the study area's constraints, with manageable effects elsewhere. Stakeholder and community involvement to co-deliver.

2.3. Approach to options appraisal

The options appraisal process has been split into two phases:

1. Long list

A high-level review across a large range of measures.

At this stage the project team discounts any unviable measures and carries forward reasonably practicable measures. The performance of each measure is screened against the Investment Objectives and Critical Success Factors. For a measure to be taken forward for Short List consideration it should achieve at least one of the Investment Objectives and be likely to meet all CSFs. A high-level assessment of the likely cost compared to the likely benefits is completed at this stage to provide an indication of economic viability.

2. Short list

A detailed review of a select group of measures or combination of measures.

At this stage the project team assesses each measure against economic, technical, social and environmental criteria and records this in an appraisal summary table. The outcome is to select the most viable measure or combination of measures. As more information becomes available the assessment of each measure is reviewed against the Investment Objectives and Critical Success Factors to check its viability. If a measure no longer has the potential to achieve at least one of the Investment Objectives and unlikely to meet all CSFs, it is discounted from further consideration.

This business case appraises four options:

- **Walkaway Option (Previously Do Nothing)** – this baseline scenario represents the present-day conditions of the Cadoxton catchment with no intervention measures and cessation of asset and watercourse maintenance. It has, however, been assumed that the tidal outfall will not fail long term, and improvement works have been completed.
- **Business As Usual Option (previously Do Minimum)** – this scenario represents the present-day conditions of the Cadoxton catchment with the current watercourse maintenance continuing to current standards.
- **Do-Something** – in this scenario a range of flood risk management measures will be proposed to reduce the flood risk within the Cadoxton catchment, however these measures

may not meet all Investment Objectives, but must have the potential to meet all Critical Success Factors.

- **Do-Maximum** – in this scenario the intervention measure or combination of measures will meet or, have the potential to meet, all Investment Objectives and Critical Success Factors.

We aspire to deliver a Do-Maximum option on all Flood Risk Management projects, however we appreciate that this is not always possible and that doing something may be an acceptable compromise.

2.4. Identify Long List

Our approach to identifying the long-list measures has been an iterative process of identifying, assessing and reviewing potentially feasible measure throughout the life time of the project. Frequent reviewing and updating of the long list has ensured we have looked at all practicable options and combinations of options to manage the flood risk in Dinas Powys.

The initial long list of measures was derived during the 2015 River Cadoxton Strategic Flood Risk Assessment – Phase 2 study. During the appraisal since the production of the 2015 study, additional data was collected, and feedback received from stakeholders, which was used to produce the OBC and enhance the list of measures considered.

Many of the measures are only capable of reducing flood risk to one of the Cadoxton River or Eastbrook areas, and thus all measures are not directly comparable to one another. Measures were assessed on their own merit as standalone in the 'Do-Something' scenario and their potential to contribute to a catchment wide cumulative approach to managing flood risk in the 'Do-Maximum' scenario.

Measures that manage flood risk to the Sully Moors area, such as improvements to the existing outfall structure, are not presented in this OBC as they have been appraised in a standalone OBC and progressed separately. This ensures the benefits from flood damages avoided of the outfall works are attributed correctly and not double counted or subsumed into a wider catchment project.

During the long listing process Vale of Glamorgan Council confirmed that it would remove the old Cross Common Bridge. Hence the option was no longer available to this project and subsequent short list modelling has assumed that this work has been completed to avoid potential double counting of benefits.

Table 2-2 provides a summary of each long-list measure, its performance against the critical success factors, and the outcome (i.e. rejected at this stage or progressed to shortlist).

A proportionate approach was undertaken to the long listing during the appraisal, with some measures rejected using professional judgement. Some of the hydraulic modelling and economic data used in the long listing is high level, being proportionate for the stage and option viability, so is not directly comparable with the more detailed work subsequently undertaken for the shortlisting.

Table 2-2: Long List Screening

Measure	Technical	Constructability	Environmental Impact/Benefit	Maintenance	Economics	Critical Success Factors	Decision
1. Natural Flood Management in Cadoxton catchment. Various NFM measures to reduce and slow peak flows.	Hydraulic performance not proven for long list. 44 homes may benefit up to 3.33% event. No homes benefits at 1% event. Measures will be overwhelmed at 3.33% event.	Long term landowner agreements required. Wide variety of techniques may be needed, but all simple engineering. Locations and access may be challenging.	Sustainable, works with natural processes. Could enhance upstream habitats and Water Framework Directive (WFD) through water quality improvements.	Potentially extensive, long-term, varied and difficult, subject to measures.	Benefits = £1.17M (max as likely overstated, and only to 3.33% SoP) Cost = £839k Benefit to Cost Ratio (BCR) = 1.4 (likely overstated due to benefits)	Accords with C and D. Further investigation needed to A, B and E.	**Shortlisted.**
2. Channel storage in oversized channels upstream of Eastbrook Engineered structures such as small dams store water and reduce and slow peak flows.	31 homes and 4 businesses benefit at 1% event.	Long term landowner agreements required. Established engineering techniques.	Sustainable, works with natural processes. Could enhance upstream habitats and WFD through water quality improvements.	Reasonable ongoing long-term maintenance need. Channel access may be issue.	Benefits = £1.50M (max) Cost = £852k BCR = 1.77	Accords with A, B, C and D. Further investigation needed to E.	**Shortlisted.** Note East Brook work alone would compromise protecting remaining 166 homes due to shared benefits.

Measure	Technical	Constructability	Environmental Impact/Benefit	Maintenance	Economics	Critical Success Factors	Decision
3. Upstream flood storage on Cadoxton River Flood storage area to reduce peak flows through Dinas Powys.	167 homes and 6 businesses benefit at 1% event	Embankment would be Reservoir Act structure. Established engineering techniques.	Loss of and impact to Ancient Woodland & Sites of Importance for Nature Conservation. Potential other flora and fauna impacts. Potential impact to Cwrt-yr-Ala Basin Special Landscape Area (SLA). Popular amenity area owned by Woodland Trust. May impact WFD status. Potential impact to Scheduled Monuments setting. Opportunities for wetland creation.	Reservoir Act (Cat A) inspection and maintenance regime. Mechanical and electrical apparatus maintenance.	Benefits = £5.70M Cost = £4.59M BCR = 1.24	Accords with B, C and D. Further investigation needed to A and E.	**Shortlisted.**
4. Flood defences along Cadoxton River in Dinas Powys. Full containment by 1.985km of walls to convey flood flows through village.	197 homes and 19 businesses benefit at 1% event	Walls typically 1m high, along river bank for much of reach. Construction difficult and high risk. Established engineering techniques.	Extensive walling of river corridor through village May impact WFD status through loss of river corridor habitat (trees and vegetation). Opportunity for channel improvements, achieving WFD benefits.	Low maintenance.	Benefits = £3.54M Cost = £8.87M BCR = 0.40	Accords with C, D and E. Further investigation needed to A and B.	**Shortlisted.** Although BCR < 1 there may be opportunity for efficiencies in this option or the opportunity to combine with other options. Hence it is taken forward to shortlist.

Measure	Technical	Constructability	Environmental Impact/Benefit	Maintenance	Economics	Critical Success Factors	Decision
5. Short flood wall to St Cadoc's Avenue. 120m long flood wall to most at risk properties on St Cadoc's Avenue	Protects only 6 homes to 3.33% event, previously provided with individua186l property protection measures.	Walls 1.5m high along river bank. Construction difficult and high risk. Established engineering techniques.	Local walling of river corridor. May minorly impact WFD status through local loss of river corridor habitat (trees and vegetation).	Low maintenance.	Benefits = £663k Cost = £750k BCR = 0.88	Accords with C, D and E. Further investigation needed to A. Fails B.	**Rejected.** Does not provide sufficient standard of protection and insufficient BCR.
6. Improve conveyance at A4055 Cardiff Road bridge. Enlarge bridge size to reduce throttle and lower upstream river levels.	Would only benefit some homes locally upstream at flood risk by lowering flood depths, but not reducing flood risk.	Closure of main transport route through Vale with Cardiff (estimate 6 months). Bridge replacement relatively straightforward engineering. Directional drilling more complex. Numerous critical services present.	Limited environmental and WFD impact/benefit.	Maintenance of new bridge would revert to VoG as Highway Authority.	Benefits = £217k Cost = £2.5M BCR = 0.09	Accords with A, C and D. Further investigation needed to E. Fails B.	**Rejected.** Does not provide sufficient standard of protection and insufficient BCR.
7. Heavy channel maintenance of Cadoxton River and East Brook. Regular removal of significant obstructions and vegetation to improve conveyance.	Protects only 9 homes to 1% event. River level generally reduced by ~0.04m through Dinas Powys, giving little flood risk reduction.	No construction, straight forward clearance with standard machinery.	May impact on WFD status of the waterbody. Loss of river corridor habitat (trees and vegetation). Prolonged environmental impact given recurring works.	Regular and intensive maintenance required.	Benefits = £1.34M Cost = £1.4M BCR = 0.96	Further investigation needed to A and E. Fails B, C and D.	**Rejected.** Does not provide sufficient standard of protection and insufficient BCR.

Measure	Technical	Constructability	Environmental Impact/Benefit	Maintenance	Economics	Critical Success Factors	Decision
8. Flood relief culvert to East Brook An additional new culvert to provide extra capacity for flood flows.	Reduces flood risk to properties locally only. Complex hydraulic design as inverted siphon required. Difficult to align culvert perpendicular to railway.	Culvert in school grounds, constraining construction. Difficult to construct beneath live railway. Challenging engineering techniques with risks.	Existing concrete section of channel could be re-naturalised, with WFD improvement. Opportunity to incorporate habitat improvements with educational benefit to adjoining school.	Difficult to inspect and maintain inverted siphon. Confined space maintenance if small culvert.	Benefits = £318k Cost > £370k BCR < 0.86	Accords with D. Further investigation needed to A and C. Fails B and E	**Rejected.** Does not provide sufficient standard of protection, insufficient BCR and not technically viable to deliver.
9. Property flood resilience. Provide individual property protection (eg flood doors etc).	Could be provided to all 197 homes. Measure best for frequent flood risk with shallow water depth: not the case for much of Dinas Powys. Does not reduce risk to life and of disruption Measures may not be viable on some properties.	No large scale construction impacts / disruption.	No environmental impacts or benefits.	Maintenance responsibility with property owner. Assets typically have 20 year design life, so replace four times over appraisal period. High recurring cost.	Benefits <£3.54M Cost = £4M (excluding properties at future risk) BCR <0.89	Further investigation needed to A, C, D and E. Fails B.	**Rejected.** Insufficient BCR.

Measure	Technical	Constructability	Environmental Impact/Benefit	Maintenance	Economics	Critical Success Factors	Decision
10. Combination Measure: Upstream flood storage and flood defences along Cadoxton River. A smaller flood storage area coupled with walls through Dinas Powys.	197 homes and 19 businesses benefit to 1% event. Flood storage area reduces peak flood flow through village, but walls still required to contain, albeit shorter and lower.	Embankment would be Reservoir structure. Walls along river bank for much of reach. Construction difficult and high risk. Established engineering techniques.	Smaller flood storage area reduces impacts, but loss of and impact to Ancient Woodland & Sites of Importance for Nature Conservation would still occur. Potential other flora and fauna impacts. Popular amenity area owned by Woodland Trust. Potential impact to Cwrt-yr-Ala Basin Special Landscape Area (SLA). May impact WFD status for combined reach. Potential impact to Scheduled Monuments setting. Opportunities for wetland creation. Extensive walling of river corridor through village Loss of river corridor habitat (trees and vegetation).	Maintenance of both measures needed. Reservoir Act (Cat A) inspection and maintenance regime. Mechanical and electrical apparatus maintenance.	Benefits = £3.54M Cost = £11.8M BCR = 0.30	Accords with C and D. Further investigation needed to A and E. Fails B.	**Rejected.** Insufficient BCR.

Measure	Technical	Constructability	Environmental Impact/Benefit	Maintenance	Economics	Critical Success Factors	Decision
11. Combination Measure: Natural Flood Management in Cadoxton catchment and flood defences along Cadoxton River. Various NFM measures coupled with walls through Dinas Powys.	May benefit up to 197 homes and 19 businesses to 1% event, assuming NFM could achieve similar benefit of smaller flood storage (optimistic), otherwise walls not reduced by same extent.	Long term landowner agreements required. Wide variety of techniques may be needed, but all simple engineering. Locations and access may be challenging. Walls along river bank for much of reach. Construction difficult and high risk. Established engineering techniques.	Could enhance upstream habitats and WFD through habitat and water quality improvements. Extensive walling of river corridor through village Loss of river corridor habitat (trees and vegetation) through Dinas Powys.	Maintenance of both measures needed. Reasonable ongoing maintenance need. Channel access may be issue.	Benefits = £3.54M Cost = £7.48M BCR = 0.48	Accords with C and D. Further investigation needed to A and E. Fails B.	**Rejected.** Insufficient BCR.

Measure	Technical	Constructability	Environmental Impact/Benefit	Maintenance	Economics	Critical Success Factors	Decision
12. Combination Measure: Natural Flood Management in Cadoxton catchment and upstream flood storage Various NFM measures coupled with flood storage.	May benefit up to 167 homes and 6 businesses to 1% event. Flood storage area would not be reduced by use of NFM.	Long term landowner agreements required. Wide variety of techniques may be needed, but all simple engineering. Locations and access may be challenging. Embankment would be Reservoir structure.	Loss of and impact to Ancient Woodland & Sites of Importance for Nature Conservation. Potential other flora and fauna impacts. Popular amenity area owned by Woodland Trust. Potential impact to Cwrt-yr-Ala Basin Special Landscape Area (SLA). Potential impact to Scheduled Monuments setting. May impact WFD status, but opportunity for improvement also (water quality). Opportunities for wetland creation.	Maintenance of both measures needed. Reasonable ongoing maintenance need. Channel access may be issue. Reservoir Act (Cat A) inspection and maintenance regime. Mechanical and electrical apparatus maintenance.	Benefits = £5.70M Cost = £5.43M BCR = 1.08	Accords with C and D. Further investigation needed to A, B and E.	**Rejected.** Sensitive BCR.

Measure	Technical	Constructability	Environmental Impact/Benefit	Maintenance	Economics	Critical Success Factors	Decision
13. Combination Measure: Natural Flood Management in Cadoxton catchment and Channel storage in oversized channels upstream of Eastbrook.	Hydraulic performance not proven for long list. Benefits 31 homes and 4 businesses in Eastbrook up to 1% event. 44 homes may benefit up to 3.33% event.	Long term landowner agreements required. Wide variety of techniques may be needed, but all simple engineering. Locations and access may be challenging.	Sustainable, works with natural processes. Could enhance upstream habitats and Water Framework Directive (WFD) through water quality improvements.	Potentially extensive, varied and difficult, subject to measures. Channel access may be an issue.	Benefits = £1.87M Cost = £1.69M BCR = 1.1	Accords with A, C and D. Further investigation needed to E. Likely fails B.	**Rejected.** Sensitive BCR Does not reduce flood risk community-wide to low level, and would compromise future protection.
14. Combination Measure: Upstream flood storage on Cadoxton River and Channel storage in oversized channels upstream of East Brook	193 homes and 8 businesses benefit at 1% event	Embankment would be Reservoir structure. Established engineering techniques. Long term landowner agreements required. Established engineering techniques.	Loss of and impact to Ancient Woodland & Sites of Importance for Nature Conservation. Potential other flora and fauna impacts. Potential impact to Cwrt-yr-Ala Basin Special Landscape Area (SLA). Popular amenity area owned by Woodland Trust. May impact WFD status. Potential impact to Scheduled Monuments setting. Opportunities for wetland creation.	Reservoir Act (Cat A) inspection and maintenance regime. Mechanical and electrical apparatus maintenance. Channel access may be an issue.	Benefits = £6.15M Cost = £5.44M BCR = 1.13	Accords with B, C and D. Further investigation needed to A and E.	**Shortlisted.** Sensitive BCR Reduces flood risk community-wide to low level.

2.4.1. Rejected Long List Measures

- 5 - Short floodwall to St Cadoc's Avenue – Construction of a new 120m long flood wall at the end of St Cadoc's Avenue.

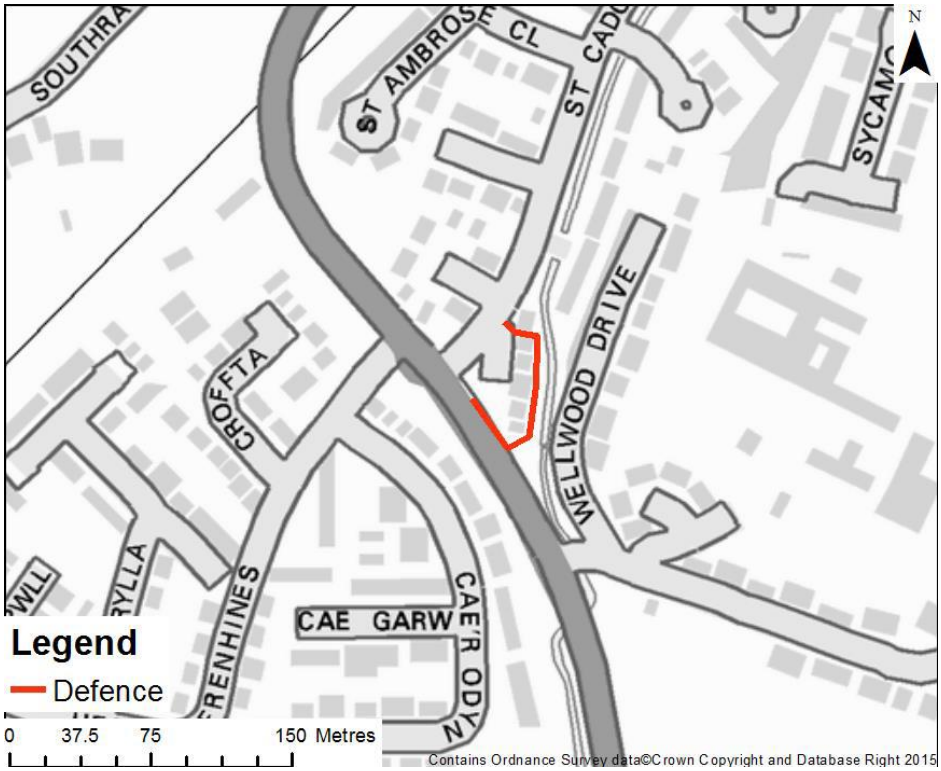

Figure 2-2: Measure 5 location

This measure is to construct a new flood wall at the downstream end of St Cadoc's Avenue to locally protect six houses at high flood risk. The wall would be approximately 120m in length to a level of 10.7mAOD to 10.8mAOD, so 1.5m high. Installing piles to construct the wall would be challenging in a narrow working corridor of property gardens, causing significant disruption and requiring substantial reinstatement. Constructing the upstream wall return to high ground in a narrow gap between two properties will also be difficult.

Hydraulic modelling shows that the proposed defence increases flood risk to other properties nearby when providing a standard of protection to a 3.33% event. Hence greater standards of protection have not been tested as further detriment would be created. The defence would overtop above a 3.33% event, such as during a 1% event, flooding the properties which would remain at medium risk.

The measure does not meet the critical success factors as an individual solution, as most other properties in Dinas Powys remain at risk. The standard of protection achieved for the six benefiting properties is insufficient also. The measure was rejected as a standalone measure, however would be reconsidered if another measure showed residual flood risk in this area and this measure could provide benefit in combination.

- 6. Improve conveyance at A4055 Cardiff Road bridge - Enlarge bridge size to reduce throttle and lower upstream river levels.

The Cardiff Road Bridge, which spans the Cadoxton River in Dinas Powys, is one of a number of hydraulic structures that contribute to flood risk in Dinas Powys. The bridge causes a throttle which elevates water levels upstream and increase flood risk along St Cadoc's Avenue. For all events above and including the present day 3.33% AEP event (2117 20% AEP event) the bridge becomes surcharged, after which pressure flow initiates driving more flow through the structure, until the point at which the bridge overtops. For the present day 1% AEP event there is a change in water level across the Cardiff Road bridge structure of approximately 0.8m. In this event all flows are conveyed through the bridge (ie. no overtopping). Despite the change of water level across Cardiff Road bridge, out of bank flooding is caused by other restrictive structures upstream, flooding initiates upstream of the St Cadoc's Avenue road bridge, on the right bank of the East Brook.

To better understand the contribution of the bridge structure to flood risk a hypothetical scenario has been tested whereby the cross-sectional area of the bridge opening has been increased, from 7.7 to 14.6m2. This increase in capacity has been achieved in the hydraulic model by increasing the height of the bridge. Increasing the bridge capacity has a limited beneficial impact, it reduces upstream

water levels in the immediate vicinity of the bridge, however, it has little or no impact at the other restrictive structures upstream. Flood risk is only significantly reduced for events above 0.1% AEP as the bridge can already convey flows up to and including that event.

The increase in capacity of the bridge could be achieved by either replacing the bridge with a new larger structure or constructing an additional bypass culvert. Both of these would be difficult to construct in a constrained area and the road, a major transport link between Barry and Cardiff, would have to be closed for an estimated six months, causing significant disruption and potential compensation payments by NRW. Enlarging the bridge would not address flood risk to the whole community or to an acceptable level alone, and other measures would be required such as walls along the upstream reach. Additional walls may also be necessary downstream to manage possible detriment. With only £217k of benefits available this option cannot be economically delivered.

- 7 - Heavy channel maintenance of Cadoxton River and East Brook – regular removal of significant obstructions and vegetation to improve conveyance.

We would undertake regular maintenance to the main rivers within the Cadoxton catchment to manage vegetation, debris and obstructions. This includes work such as vegetation clearance, tree felling, significant de-silting of the river bed and manual removal of debris and obstructions. This would result in a clearer river channel to allow increased flow due to a decreased channel roughness. Work is estimated to cost £47,000 annually on average, so over 100 years this would total £1.4 million at present day prices. However, the regular and recurring nature of the works would give rise to prolonged environmental impacts locally within the river channel.

This measure only achieves marginal benefits with reduced flood depths of between 0.02m and 0.04m in Dinas Powys during a 1% event. It does not remove many properties from flood risk, it just lowers the depth of flooding to properties during an event.

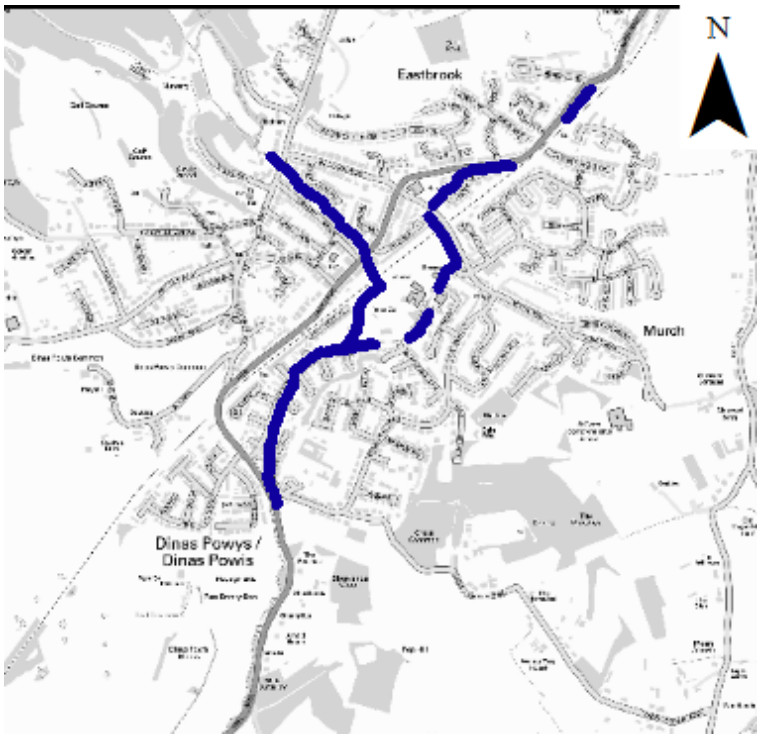

Figure 2-3: Measure 6 location

The measure does not meet the critical success factors as an individual solution, as very few properties in Dinas Powys have a reduced flood risk. The standard of protection achieved across Dinas Powys is insufficient. The benefit cost ratio of unity requires a high annual maintenance spend that would have to be funded by revenue and not capital funds.

- 8 - Flood relief culvert to East Brook - An additional new culvert to provide extra capacity for flood flows

This measure involves a flood relief culvert from immediately upstream of the railway culvert to Cadoxton River to provide additional channel capacity. A 1m diameter culvert was tested, which compared to the railway culvert alone increases capacity by 46%. This modestly reduces flood risk at the culvert inlet and immediately downstream on the East Brook.

Figure 2-4 shows the concept design of the flood relief culvert. The new culvert beneath the railway would have to be perpendicular to the track and have a minimum 4.9m cover from rail level to the culvert crown to comply with Network Rail requirements. Due to site constraints a perpendicular culvert is difficult to achieve, whilst 4.9m cover is not possible due to the downstream channel level of the Cadoxton River. An inverted siphon arrangement would be too complex and costly to install beneath a live railway. We have therefore concluded that this option is unlikely to be practical from an engineering perspective and with a benefit-cost ratio of less than unity, it is uneconomically viable.

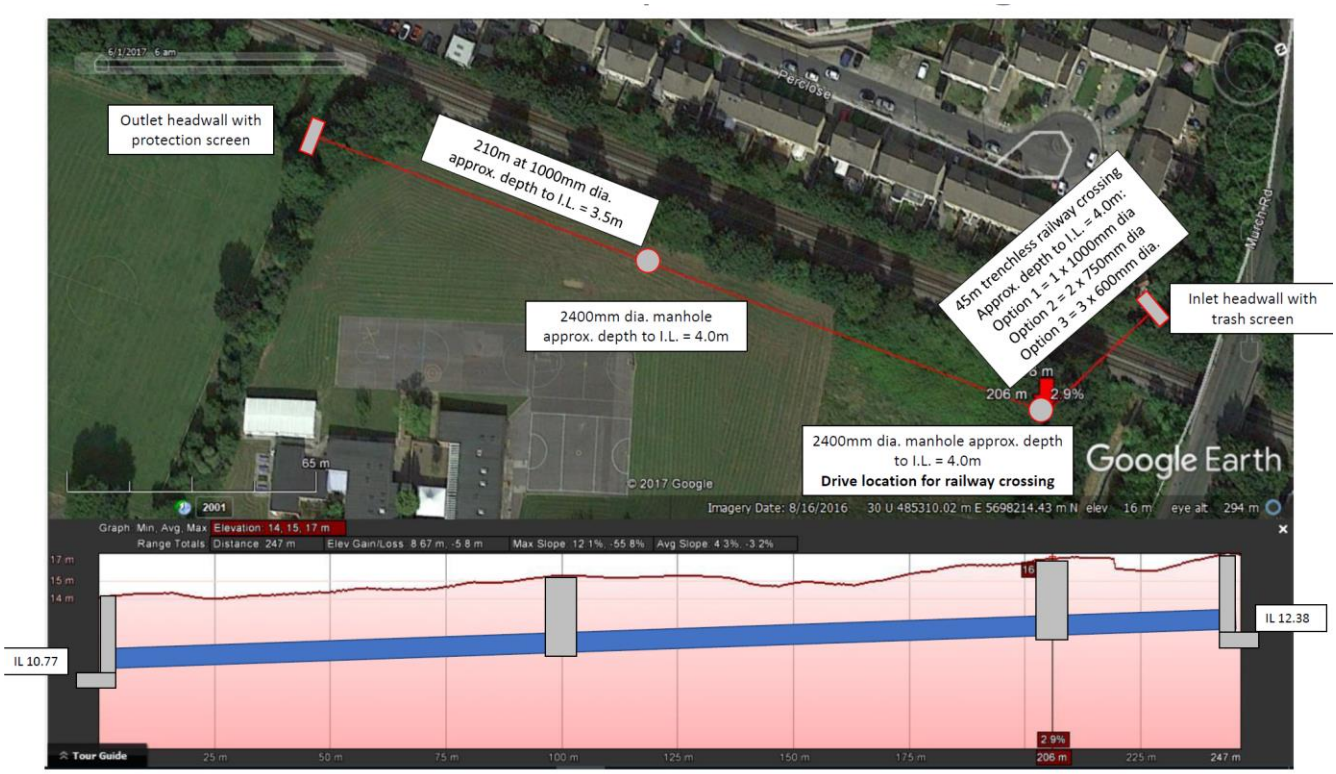

Figure 2-4: Concept design for flood relief culvert on the East Brook

- 9 - Property Flood Resilience - Provide individual property protection

Figure 2-5: Example of Property Level Flood Resilience

This would see protection measures, such as flood doors, flood gates or barriers and air-vent covers, installed to the 197 individual properties at medium flood risk in Dinas Powys. Six properties in Dinas Powys were provided with property flood resilience in 2014 at a cost of £9,870 per property. It would therefore cost approximately £2M to protect all homes at medium risk in Dinas Powys. Property protection measures typically have a 20 year design life, so would need replacing every 20 years at a cost of £2M each time, plus the cost for additional properties predicted to be at future flood risk due to climate change. The whole life present value cost over 100 years would be at least £4M, plus additional properties at future flood risk. We could not guarantee that funding would be available to replace measures in 20 years' time.

Individual property protection is not considered to be appropriate for the large number (95) of properties at high flood risk. Flood depths and velocities pose a risk to life and this measure would not address this issue, as flood water would still flow through the streets of the village. Damage would also still occur to unprotected infrastructure and assets, and there would be significant disruption during a flood event.

Not all properties may want such measures or maintain and operate them suitably, which can expose adjoining properties to damage, so there is a risk that flooding to some properties may still occur. Analysis of previous schemes identified that where products were needed and deployed 84% of properties benefitted from improved protection, meaning 16% were unsuccessfully protected.

The measure does not meet the critical success factors to economically reduce flood risk across the community to a low level as an individual solution and as such was rejected from further consideration.

- 10 - Combination Measure – Upstream flood storage and flood defences along Cadoxton River

Combining upstream flood storage with flood defences through the village has the potential to reduce the length and height of walls whilst reducing the size of the flood storage area upstream. Lowering the flood storage area embankment crest level by 1m compared to measure 3 would substantially reduce the storage volume, from 180,000m^3 to 96,000m^3. A smaller flood storage area could operate in two ways:

- Flow limited – restrict outlet flow to maximum permissible to prevent flooding in Dinas Powys (approximately 6.5m^3/s). Due to a smaller storage volume the embankment would overtop to the spillway ahead of the design flood event, resulting in higher flows in the village.
- Storage limited – restrict storage volume to the design flood event, which would not overtop the spillway. Due to a smaller storage volume an outlet flow greater than the maximum permissible to prevent flooding in Dinas Powys is required (approximately 10.3m^3/s), resulting in higher flows in the village.

The higher flows through the village would cause flooding, so defence structures are needed to complete the standard of protection. Hydraulic modelling shows that the length and height of the flood walls would be reduced for the flow limited scenario, but not for the storage limited scenario. 850m of walls are still needed, at an average height of 0.75m, which would be difficult to build in a constrained urban area.

A smaller flood storage area and less walls would have reduced impacts in their respective locations, however the accumulative impacts would be greater than either solution individually. An area of ancient woodland would still need to be removed to construct the embankment, and an area impacted by impounding water. Additionally, habitat and trees would be lost along the river corridor in the village to construct the defence walls.

A flood storage area with half the storage capacity is not proportionately cheaper, but will cost only slightly less to construct and maintain as the full-sized measure, a saving of 10-20% anticipated over the larger FSA.

Similarly, the greatest savings in constructing walls is achieved by reducing the length, whilst reducing the wall height has a much smaller impact. The requirement for significant lengths of walls in complex locations more than outweighs the decrease in costs to construct the smaller flood storage area, as demonstrated by a benefit-cost ratio of 0.30. Maintenance of the combined measures will be significantly more than that of the standalone measure also. The combined measure of a smaller flood storage area with flood walls was therefore not taken forward.

- 11 - Combination Measure – Natural Flood Management on Cadoxton River and flood defences along Cadoxton River.

Natural flood management measures are most effective at regular, smaller, flood events, typically up to approximately a 5% event. Unfortunately, in Dinas Powys the onset of flooding is the 3.33% event, when most of the benefit of natural flood management has been achieved, before measures drown out. For example, rainfall attenuation features are full, leaky dams fully impounded, de-compacted soil saturated, or trees unable to absorb more water. If the onset of flooding was lower in Dinas Powys then natural flood management may be able to achieve more in reducing flood risk. Hence combining with flood walls would not reduce their length and height, so constructing significant lengths of walls in complex locations produces a benefit-cost ratio below unity (0.48).

For full appraisal of natural flood management on the Cadoxton River please see short list measure 1.

- 12 - Combination Measure – Natural Flood Management on Cadoxton River and upstream flood storage.

Hydraulically natural flood management works in a similar manner to flood storage, slowing the flow and catchment response to rainfall. Water is not lost from the system however so the volume draining to the flood storage area remains materially unchanged, although it will arrive typically less than one hour later. The delay of the flood peak due to flood storage will be longer than the natural flood management, typically hours, and therefore little or no reduction in the flood storage capacity can be achieved.

As above, natural flood management measures are ineffective during less frequent, larger, events so there would be no reduction to the flood storage area. However, natural flood management offers other benefits in relation to water quality and biodiversity, and has the potential to reduce the frequency of inundation of the flood storage area. Combining natural flood management with flood storage would not reduce the impacts of the flood storage measure, producing a benefit-cost ratio at unity.

For full appraisal of natural flood management on the Cadoxton River please see short list measure 1.

Investigations showed that the flood risk management benefits of NFM are likely to be substantially reduced. This is because NFM measures identified slow the rate of runoff by minutes but change very little the total volume of water ultimately conveyed downstream. A flood storage area will store flood water for a longer time (ie hours) so the NFM attenuation will not influence the flood storage area's attenuation and outlet hydrograph. Hence there will be little or no flood risk management benefit to providing NFM upstream of a flood storage area and the combined option was discounted.

- 13. Combination Measure: Natural Flood Management on Cadoxton River and Channel storage in oversized channels upstream of Eastbrook

Whilst temporarily storing flood water in the naturally oversized channels of the East Brook is economically viable, combining it with natural flood management measures reduces the economic viability as a combined option due to the overlapping properties protected and shared benefits.

It is not a community wide solution and does not reduce flood risk to a low level, as 166 homes are still at a 1% chance flood risk.

For full details regarding measures 5, 7 and 9, including the modelling approach and initial economic assessment, refer to the 'River Cadoxton Strategic Flood Risk Assessment – Phase 2, Strategic Options Appraisal Final Report December 2015' report. For full details regarding measures 10 and 11 refer to the 'Cadoxton River Project Appraisal Review – Further appraisal (2018)' report. For full details regarding measure 12 refer to the 'NFM JFLOW modelling and analysis (2017)' report.

2.5. Identify the Short List

2.5.1. Overview

Based on the outcomes of the long-listing process, the four short-listed options have been further investigated, optimised and assessed in more detail. Additionally, recognising that many of the options are not mutually exclusive, a fifth short list option was progressed to look at a combination of options.

2.6. Assessment of Short List

2.6.1. Engineering performance of Short List

- **Walkaway Option (previously Do Nothing)**

This baseline scenario represents the present-day conditions of the Cadoxton catchment with no intervention measures taking place and no capital or future investment costs for this option. It has been assumed that Cross Common Bridge deck has been removed, as Vale of Glamorgan Council has committed to this. The scenario provides a basis for assessing the benefits of the Do Something and Do Maximum options.

The baseline hydraulic modelling shows that out of bank flooding from the Cadoxton River begins during the 3.33% event. Figure 2-6 shows the extent of current day flooding for this event at the following locations:

- Right and left bank of the Cadoxton River upstream of Cardiff Road bridge;

- The right bank of the Cadoxton River, between Cardiff Road bridge and the railway line;
- Right bank of the Cadoxton River directly downstream of the railway line; and
- Right bank of the Cadoxton River upstream of St Cadoc's Avenue.

94 residential and 11 non-residential properties are predicted to flood in Dinas Powys during this 3.33% event. For the 1% event this rises to 197 residential and 19 non-residential properties. Alongside property damage, there will be vehicle damage, disruption and a risk to life from unexpected deep and fast flowing water in urban streets.

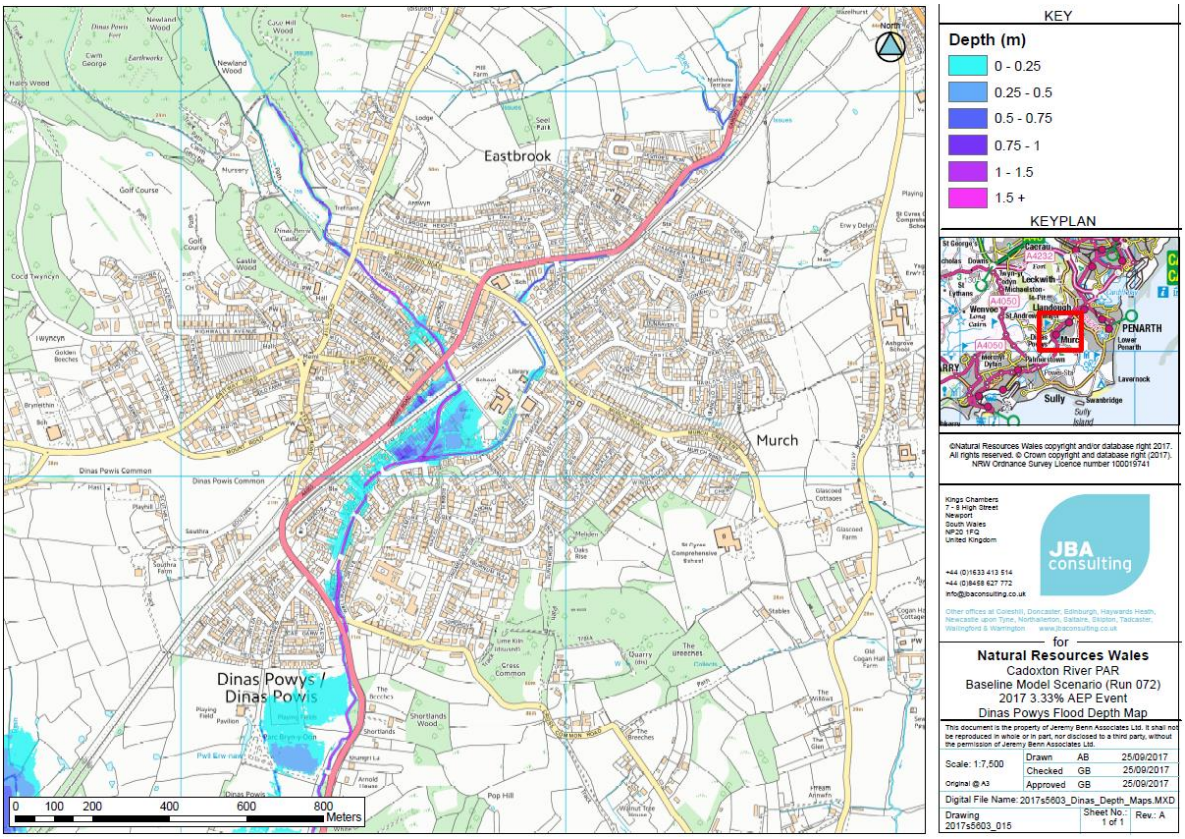

Figure 2-6: Baseline present day 3.33% event

With the predicted effects of climate change up to 2117, out of bank flooding from the Cadoxton River in Dinas Powys begins during the 20% event. Figure 2-7 shows the extent of flooding associated with the 2117 20% event at the following locations:

- Right and left bank of the Cadoxton River upstream of Cardiff Road bridge;
- The right bank of the Cadoxton River, between Cardiff Road bridge and the railway line; and
- Right bank of the Cadoxton River directly downstream of the railway line.

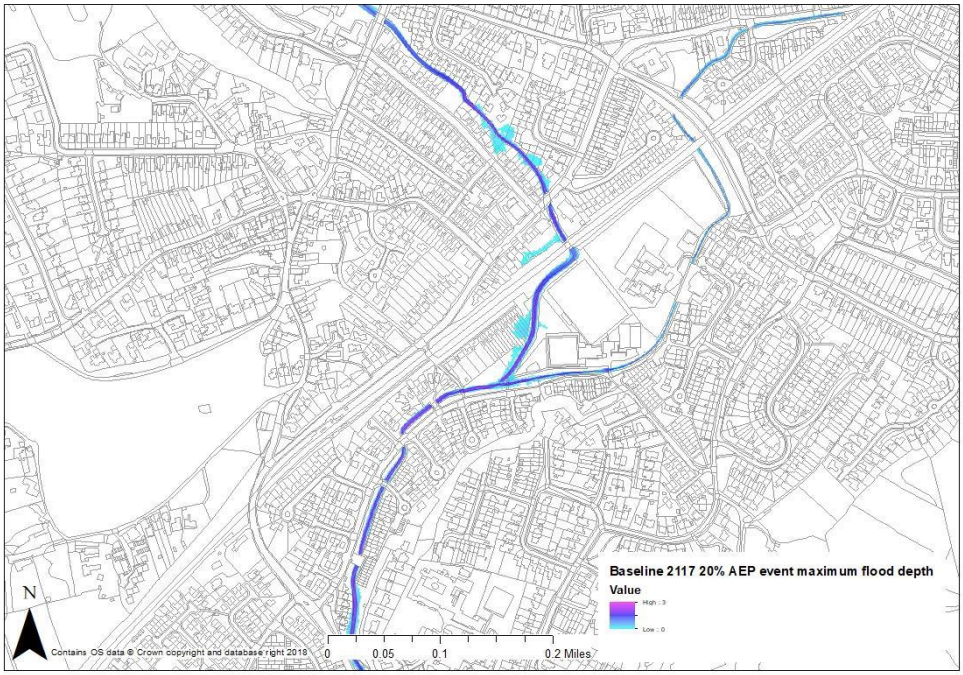

Figure 2-7: Baseline 2117 20% event

14 residential properties are predicted to flood in Dinas Powys during this 20% event (2117). This rises to 203 residential properties in the 3.33% event and 368 residential and 50 non-residential properties in the 1% event (2117). A summary of the number of properties at flood risk for each exceedance event for baseline 2017 and 2117 is shown in Table 2-3.

Table 2-3: Number of properties at flood risk for each exceedance event for baseline 2017 and 2117

Baseline – Properties at flood risk							
	Type	**20% AEP**	**3.33% AEP**	**1.33% AEP**	**1% AEP**	**0.5% AEP**	**0.1% AEP**
Dinas Powys, Eastbrook and Sully Moors areas							
2017	**Res**	0	94	169	197	290	498
	Non-res	0	11	14	19	45	61
2117	**Res**	14	203	319	368	438	683
	Non-res	9	18	46	50	53	81

- **Business as Usual option (previously Do Minimum)**

This scenario represents the present-day conditions of the Cadoxton catchment with the current watercourse and flood management asset maintenance continuing to current standards. This includes clearing blockages that pose a threat of elevating flood risk when they occur and providing a flood warning service.

If this option were to progress due to there not being a viable do something option, we may consider improving flow measurement on the Cadoxton River to obtain more data and improve confidence in hydrology and hydraulic modelling predictions. However, there are operational constraints to achieving this.

- **Do-Something Options**

Each shortlisted option has been assessed and scored in the appraisal summary table (AST) (Appendix B) against technical, environmental, social and strategic criteria. This has informed the viability of each option and whether any can be discounted prior to the economic appraisal.

Measure 1: Natural Flood Management – Cadoxton River and Upper Catchment

A Natural Flood Management (NFM) or Working with Natural Processes (WWNP) approach to managing flood risk means taking action to reduce fluvial flooding by protecting, restoring and emulating the natural functions of catchments, rivers and floodplains. An NFM approach looks to slow and temporarily store flood water by increasing the river's connectivity to the floodplain and improving soil infiltration. This approach can complement and increase the resilience of other flood

risk management measures, including to projected climate change effects, whilst giving other benefits for the environment and society.

The whole Cadoxton catchment has been considered for NFM opportunities. Different NFM scenarios have been modelled to achieve changes to flood flows for analysis. Options tested were runoff attenuation features and soil improvement approaches. The runoff attenuation features and soil improvements are analogous of a range of NFM methods that achieve the same effect on flows.

A number of techniques have been used to identify opportunities. Potential runoff attenuation features (RAFs) were identified using JBA's in-house Runoff Attenuation Feature Finder (JRAFF) spatial analysis tool. This is a desk-based technique using local geographical data to identify individual unconnected depressional areas (land sunken or depressed below the surrounding area) greater than 100m2 that already potentially store floodwater that can be utilised and enhanced. These areas are defined as potential Runoff Attenuation Features (RAFs), also known as opportunity pond stores. JRAFF was applied to the rural catchment. RAFs were identified on tributaries, such as small dams using leaky barriers, and in the floodplain, such as small ponds and scrapes. Upstream of Pen-Y-Turnpike Road, 98 RAFs with potential to influence the Cadoxton River were identified and assessed, along with increasing storage within the 'Salmon Leaps' ponds. An optimistic scenario was considered, whereby the level of every RAF was lowered by 1m and the ground was assumed to be dry throughout the catchment. The software does not identify connected flow routes that do not have existing containment, such as weirs or embankments that can be modified to increase benefit. To account for the limitations of the technique additional investigation techniques are used to identify and develop natural flood risk management options. In addition to JRAFF, the catchment has also been 'ground proofed' by targeted on foot surveys undertaken by NFM experts to identify additional opportunities the software cannot identify, such as upstream flood storage opportunities

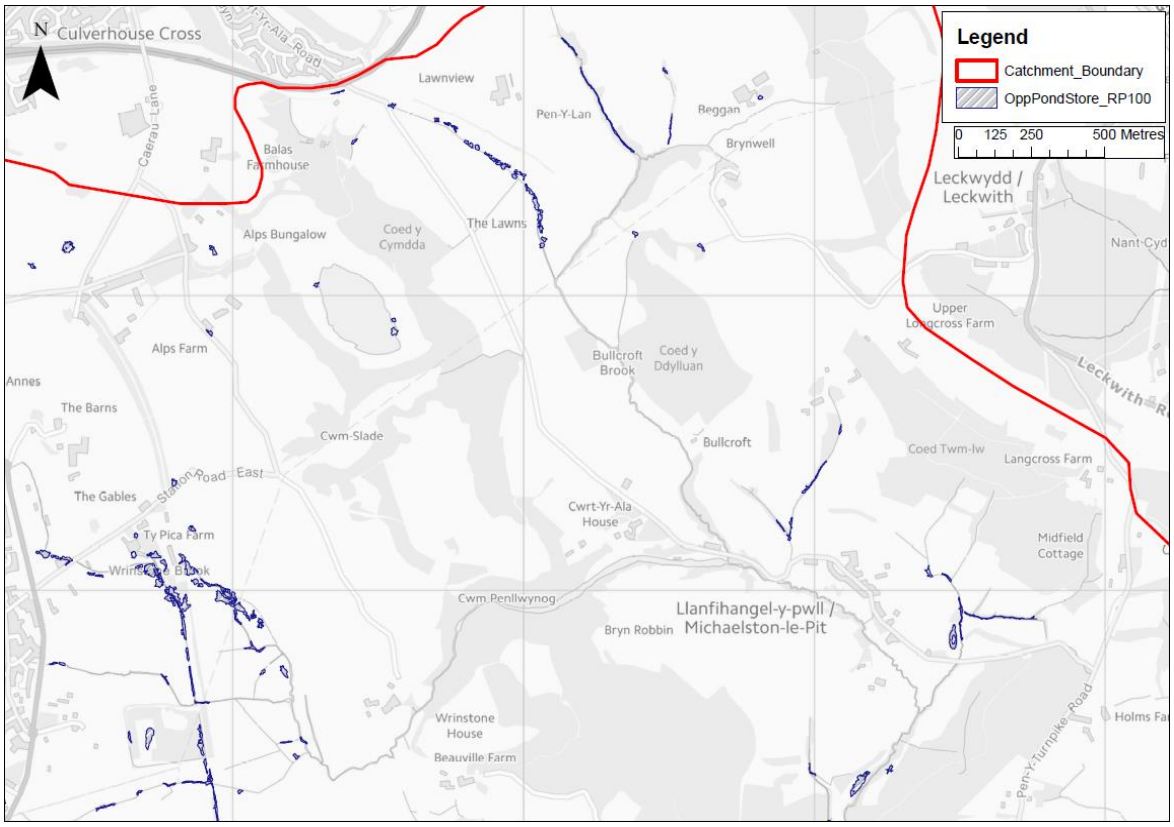

Figure 2-8: Potential Rainfall Attenuation Features in upper Cadoxton catchment

A soil improvement scenario was also considered. The scenario assumed that there has been a degradation of soil structure across all grass fields in the rural catchment (e.g. due to soil compaction caused by livestock trampling and/or heavy machinery trafficking in wet conditions) and a significant improvement of the soil structure can be achieved, resulting in improved soil infiltration and lower surface water runoff. In reality there will be a wide range of in-field soil conditions (from good to bad) across the catchment.

The assessment concluded that NFM measures on the Cadoxton River would not significantly reduce flood flows and associated risk in Dinas Powys. It is acknowledged that NFM can offer some flood benefit during more regular flood events and has many wider benefits, however the flood risk management benefits are not substantial enough to provide the standard of protection required

across the community by the critical success factors. No properties at flood risk would be protected to a low level by the measures. The predicted maximum reduction in peak flow for the RAFs was 22% of the 3.33% flow and 18% of the 1% flow. The predicted maximum reduction in peak flow for the soil improvements was 27% of the 3.33% flow and 22% of the 1% flow. The investigated and modelled NFM proposal is very optimistic, it will not be possible to deliver all of the modelled RAFs and soil improvement opportunities or achieve the full effects predicted, due to local constraints such as landowner agreements, baseline soil conditions and baseline soil saturation at the onset of an event. Hence the stated benefits from avoiding flood damages (£1.17M) are a maximum value possible and are overstated – it will not be possible to achieve this value in practice.

A successful NFM scheme of combined RAFs and soil improvement measures throughout the Cadoxton catchment could reduce peak flow by 10% to 15% at frequent flood events. Crucially NFM measures will become drowned at approximately a 4% to 3.33% event, which is the onset of flooding in Dinas Powys, as RAFs will be filled and soils saturated prior to the peak of a larger event, greater than 3.33% chance. A successful NFM measure in this instance will provide very little improvement in flood risk management and will not reduce flood risk to properties in Dinas Powys, the optimistic scenario fails to keep pace with a predicted increase of 30% from climate change effects. This measure, as a standalone solution, was therefore discounted from the shortlist.

Measure 2: Channel storage in oversized channels upstream of Eastbrook

NFM measures such as RAFs and soil improvements were modelled in the Eastbrook catchment. The predicted maximum reduction in peak flow on the East Brook for the RAFs was 16% of the 1% flow. This has virtually no impact (ie 1% reduction) on the peak flow in the Cadoxton River due to the magnitudes of the watercourses. The predicted maximum reduction in peak flow on the East Brook for soil improvements was 10% of the 1% flow. As per Measure 1, these options were discounted as they did not significantly reduce flood risk.

However, a favourable option was identified to store flood water by building small dams in the naturally over-sized channels of the East Brook and Mill Farm Brook tributaries immediately upstream of Cardiff Road in Dinas Powys.

East Brook channel storage would consist of 7 small dams on the Mill Farm Brook and 10 small dams on the East Brook. The typically dry and naturally oversized channels are approximately 10m to 15m wide and 2m to 2.5m deep, so they offer considerable potential to temporarily store flood water.

Each small dam would allow baseflow to pass unimpeded, so that water is only impounded during a flood. At times of flood the dams would cause water to back up in the channel, creating storage to reduce the peak flow being passed downstream. The dams would not be so high as to force water out of the channel on to adjacent land, so could be two thirds the depth of the channel to allow overtopping. Flow reductions of both 50% and 75% to the East Brook have been tested within the catchment flood model, as the lower and upper bounds of what is considered achievable.

Several conceptual designs for small dams have been prepared for this East Brook channel storage measure, and further investigations would be required to complete the design. A possible version is shown illustratively in Figure 2-9.

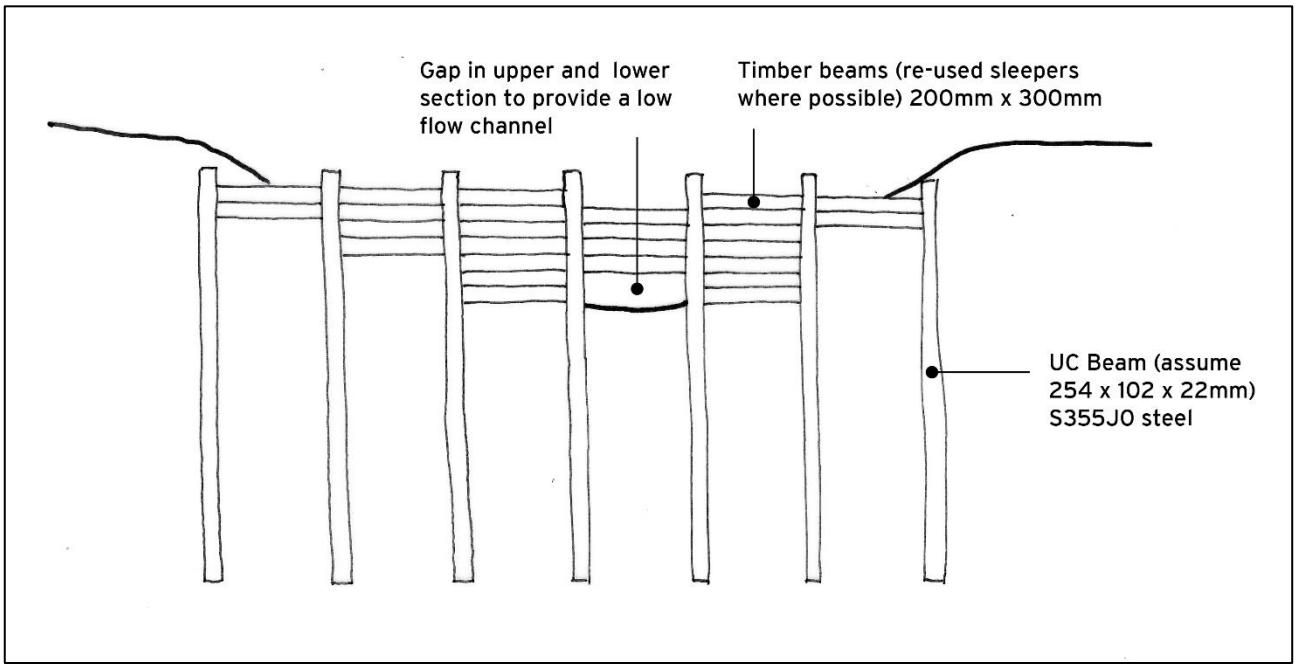

Figure 2-9: Illustrative concept design of a small dam / barrier formed of piles and timber beams

We recommend that the East Brook channel storage measure is considered further in the economic appraisal to manage flood risk on the East Brook.

Measure 3: Upstream flood storage on Cadoxton River

This measure involves the construction of a flood storage area on the Cadoxton River upstream of Dinas Powys to store peak flood flows that would otherwise affect the village downstream. Following site walkovers, inspection of the catchment topography and review of land data upstream of Dinas Powys, a potential flood storage area and embankment location was identified in the vicinity of Cwm George, Newland and Casehill Woods. It is noted that this area is environmentally sensitive, with ancient woodland and Sites of Importance for Nature Conservation present, coupled with the significant landscape, heritage and amenity value of the area.

An initial indicative embankment location was used to explore the measure's viability to manage flood risk. An embankment location was initially modelled close to the village to capture as much of the catchment as possible. A maximum out flow from the storage area and total storage volume was required to assess the hydraulic potential of the measure. This would then inform optimisation of the measure in terms of size and location as we investigated its viability in greater detail against the project critical success factors.

Flooding begins when the Cadoxton River flows at approximately 6.5m^3/s in Dinas Powys, so this flow was selected as the target discharge outflow of the flood storage area to avoid flooding downstream. Initial modelling with a 'fixed orifice' control structure found that a total storage volume of 180,000m^3 would protect Dinas Powys properties from flooding up to the present day 1% event. Figure 2-10 shows the potential flood storage area with an embankment crest of 21mAOD (3.5m from ground level) that could provide the required storage within the valley, without adversely impacting flood risk to property or infrastructure upstream or downstream. At this location an area of approximately 983m^2 of ancient woodland would be lost to construct the embankment, and a further area of approximately 4,365m^2 of ancient woodland would be impacted through periodic inundation of the flood storage area, unless additional mitigation measures can be included to avoid or reduce impacts to the ancient woodland.

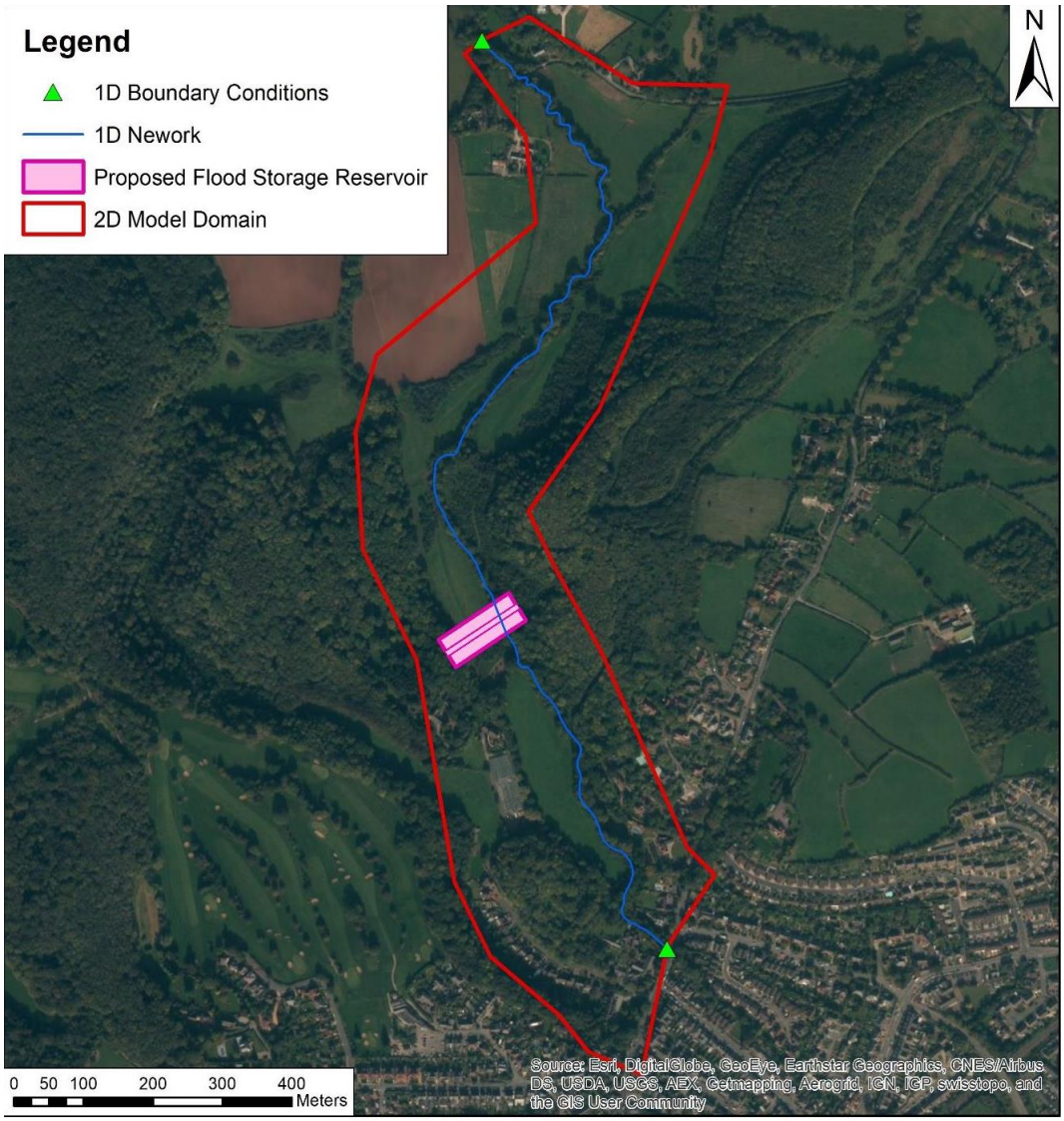

Figure 2-10: Potential flood storage area location

Additional investigations, usually undertaken at detailed design, were completed during the appraisal to consider constraints and explore opportunities to reduce potential negative impacts, as they are pertinent to the measure's viability. The hydraulic performance and design of the storage area was scrutinised in order to maximise the benefits downstream and minimise the impacts upstream and of the embankment. Alternative embankment locations, crest levels and outflows were considered that reduced the frequency and depth of inundation.

The embankment crest level could be lowered to reduce the loss of and inundation of ancient woodland. Due to the narrow valley and steep sides the flood storage volume is rapidly reduced if the embankment height is lowered, reducing the standard of protection to Dinas Powys. Modelling shows that a 1m lowering of the embankment crest level, from 3.5m high to 2.5m high, at 20mAOD would almost halve the available storage volume to 96,000m^3, resulting in a standard of protection of 1.33% in Dinas Powys. This has the potential to reduce the direct loss of ancient woodland arising from the embankment footprint by approximately a third. The relationship between the embankment crest level and flood storage volume is shown in Figure 2-11.

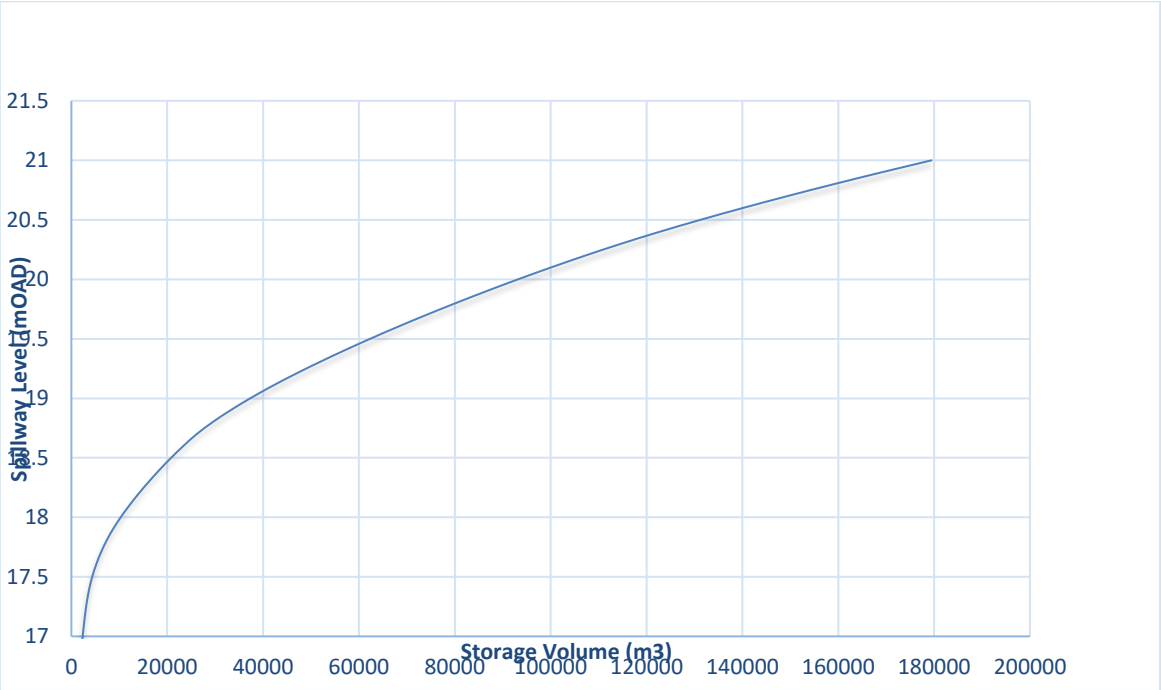

Figure 2-11: Embankment crest level relationship to flood storage volume curve

To avoid direct loss of ancient woodland by constructing the embankment, a location to the south of Newland Woods has been considered for the embankment. This location will still create a flood storage area that will impact ancient woodland when flood water is impounded. Two variations were investigated, the first maintained the embankment crest level at 21mAOD, increasing available storage volume to 240,000m^3. This protects properties in Dinas Powys from the Cadoxton River to the present day 0.5% event and manages the future effects of climate change better.

The second variation provides 180,000m^3 of storage volume to protect properties against flooding up to the present day 1% event. The embankment crest level is required to be 0.5m lower at 20.5mAOD.

This embankment location would impact the sole access to and land of Tyn-y-Coed although it may be possible to provide an alternative access. Lettons House would also be significantly impacted by construction and the embankment location.

To avoid the direct loss of ancient woodland and impacting ancient woodland by inundation, a location to the north of Newland Woods has been considered for the embankment. Two variations were investigated, the first provides 180,000m^3 of flood storage volume to protect properties from flooding up to the present day 1% event. This requires the embankment crest level to be raised to 22.79mAOD. Modelling results show this causes upstream flood detriment to St Michaels Close, Felin Dawel and to the sole access to Lower House and Lower House Barns.

The second variation restricted the embankment crest level to 21mAOD to avoid significant upstream flood detriment. Consequently, the flood storage volume was significantly reduced to 56,000m^3. This provides a standard of protection of 3.33% chance to properties in Dinas Powys.

A critical component of the embankment is the hydraulic structure that controls the discharge of flood water from the storage area. Additional analysis has been undertaken to understand if the control structure could be optimised to reduce the size of the flood storage area and the frequency and duration of inundation that potentially impacts ancient woodland and disrupts amenity use.

A standard fixed orifice structure would be expected to start filling the flood storage area from a 50% event, flooding ancient woodland at the bottom of the valley side for a short duration. Two alternative arrangements have been considered, a mechanically adjustable control structure such as an automated gate, and a vortex or baffled orifice structure such as a Hydro-Brake.

The adjustable control structure could reduce the peak water level within the storage area to prevent filling for this event. The vortex structure cannot significantly reduce the peak water level at the 50% event. The use of an adjustable control structure does not prevent filling at larger events and the optimised performance compared to the fixed orifice quickly deteriorates until both are broadly performing the same for the 1.33% event. In the 1% event the peak water level is reduced by 170mm. The vortex is less effective, reducing the peak water level in the 1% event by 90mm.

Hence an adjustable or vortex control structure is unlikely to provide a significant reduction in the flood storage area or embankment crest level. However, the adjustable control structure does have the potential to modestly improve the storage performance compared to a fixed orifice structure, so

should be considered at detailed design. An adjustable gate operated by automated hydraulic instruments would deliver optimal performance, only filling the storage area with flood water when required and then only at the rate required. Such idealised performance is in practice difficult to achieve so it is unlikely that any structure would be as efficient as modelled, but an optimised performance could still be achieved.

The assessment of the flood storage area size and embankment location is recorded in the appraisal summary table (AST) found in Appendix B. A small reduction in the height of the embankment leads to a notable decrease in storage volume and hence standard of protection provided to Dinas Powys and associated economic benefits. However, this leads to a comparatively small reduction in costs. A lower embankment height offers a small reduction in the overall footprint but would not avoid the environmental impacts. A higher embankment and larger flood storage area would have greater environmental impacts and cause flood detriment upstream.

The AST shows that the more viable embankment locations are the central and southerly ones that are hydraulically controlled to limit the peak discharge to 6.5m^3/s in the 1% event. The hydraulic control is best achieved with a mechanically adjustable structure, such as a penstock on the culvert through the embankment.

The storage area will fill with approximately 180,000m^3 of flood water during a 1% event, whilst discharging 6.5m^3/s to ensure no flooding to Dinas Powys properties downstream. During events larger than the 1% event the embankment spillway will operate to safely pass the Probable Maximum Flood (PMF) and 1 in 10,000 chance flood.

Figure 2-12 shows an artist's impression of what the potential flood storage area embankment could provisionally look like and Figure 2-13 shows an indicative design illustration.

Figure 2-12: Impression (looking south downstream) of potential flood storage embankment measure

Figure 2-13: Illustration of potential flood storage embankment measure (subject to further consideration and design)

Measure 4 – Flood defences along Cadoxton River in Dinas Powys.

This measure assessed three arrangements for containing flood waters in Dinas Powys with raised defences and increasing conveyance to a 1% event (present day) standard of protection (SoP). The three arrangements investigated were:

- full containment along the river reach,
- increased conveyance and containment along the river reach,
- upstream flood storage (96,000m3) and containment along the river reach.

Table 2-4 details which improvement measures were used for each arrangement.

Table 2-4: Improvement measure arrangements

Measure	Details	Impact	Consider in arrangement
Channel widening	Cadoxton River channel widening between St Teilo Close and St Pauls Close.	Limited impact as measure on its own.	Yes, forms part of arrangement 2
Structure widening	Cardiff Road bridge, between Millbrook Road and Greenfield Avenue, widened width of the channel.	Reduction in peak water levels upstream but flooding still occurs during 1% event.	No (limited flood risk benefit and expensive)
Structure raising	All bridge and culvert structures on the Cadoxton River from St Teilo Close to St Pauls Close raised above the 1% event peak water level.	Reduction in peak water levels but flooding still occurs during the 1% event.	Yes, forms part of arrangement 2
Flood walls/bunds	Flood walls built throughout Dinas Powys to ensure all flows contained in-channel for the 1% event.	Floodwalls can contain all water in-channel for the 1% event.	Yes, forms part of arrangement 1, 2 and 3

Arrangement 1 consists of flood walls and bunds only, with no conveyance improvements.

Arrangement 2 consists of the following:

- Flood walls/bunds upstream and downstream of the railway bridge on the Cadoxton River;
- Widen and raise the soffit of the following bridges/culverts:
- St Lythan Close;
- St Cadoc's Avenue; and
- St Paul's Close.
- Two stage channel on the Cadoxton River from St Teilo Close to St Paul's Close.

Hydraulic modelling shows that out of bank flooding for all present-day events up to the 1% chance is prevented. For events of greater magnitude, the proposed flood defences overtop or are outflanked, resulting in property flooding.

Arrangement 3 consists of the following:

- Smaller (96,000m^3) upstream flood storage area
- Flood walls/bunds upstream and downstream of the railway bridge on the Cadoxton River;
- Widen and raise soffit of the following bridges/culverts:
- St Lythan Close;
- St Cadoc's Avenue; and
- Two stage channel on the Cadoxton River from St Teilo Close to St Paul's Close.

Hydraulic modelling of the flow limited reservoir configuration shows that the lengths and heights of the proposed flood defences is significantly reduced in comparison to arrangements 1 and 2. For present day events, there is no flooding of properties in Dinas Powys up to and including the 1% event. However, for events of greater magnitude the proposed flood defences overtop or are outflanked, resulting in property flooding.

Hydraulic modelling of the storage limited reservoir configuration shows that upstream of the railway line the lengths and heights of the proposed flood defences is significantly reduced in comparison to arrangements 1 and 2.

Downstream of the railway line water levels are increased and both the lengths and the heights of the proposed flood defences are increased in comparison to arrangements 1 and 2.

Arrangement 3 provides the greatest benefits from flood damages avoided due to the upstream storage area. However, this arrangement combines the impacts of both measures, as shown in the AST score. Arrangements 1 and 2 give identical benefits and score similarly. All three arrangements are likely to cost more than the benefits they provide, however the measure, based on the least cost arrangement with a sensitivity for the best AST score, is recommended for inclusion in the economic appraisal.

- **Do-Maximum**

In this scenario the intervention measure or combination of measures will meet or, have the potential to meet, all Investment Objectives and Critical Success Factors.

Measure 5: Combined option

The final do-something shortlisted measure is a combination of two short-listed measures based upon our understanding of the flood risk and measures from the appraisal. The measure utilises the Cadoxton River flood storage area and East Brook channel storage with 50% flow reduction to achieve flow reductions in both rivers and reduced flood risk to properties in Dinas Powys. Each measure is as described above.

2.6.2. Sustainability and well-being performance of Short List

This section provides a summary of how each measure contributes towards environment, sustainability and Well-Being. The Environmental Constraints and Opportunities Record (ECOR) (Appendix A) documents the environmental baseline of the study area; and identifies the potential environmental impacts and opportunities of each short-listed measure. Information from the ECOR and the supporting environmental surveys/assessment, have been used to assess and score the short-listed options in the appraisal summary table (AST) (Appendix B)

Table 2-5 provides an indication of the extent to which the 5 measures contribute to the Sustainability and Well-being strategic context as set out within Section 2.3. The following ranking has been used to demonstrate the potential each measure has in contributing to set goals, objectives and priorities.

Significantly Positive	**+ +**
Positive	**+**
Neutral	**/**
Negative	**-**
Significantly Negative	**- -**

Table 2-5: Sustainability and Well-being Strategic Context

Sustainability and Well-being Strategic Context	Strategic Goal / Objective / Priority	Extent to which Measure contributes:				
		Measure 1	Measure 2	Measure 3	Measure 4	Measure 5
"NRW Well-being Statement – Managing today's natural resources for tomorrow's generation 2017-18": Well-being Objectives:	Champion the Welsh environment and the sustainable management of Wales' natural resources.	+ +	/	-	-	-
	Ensure land and water in Wales is managed sustainably and in an integrated way.	+ +	/	- -	-	- -
	Improve the resilience and quality of our ecosystems.	+ +	-	-	-	-
	Reduce the risk to people and communities from environmental hazards like flooding and pollution.	+	+	+ +	+ +	+ +
	Help people live healthier and more fulfilled lives.	/	/	/	/	/
Vale of Glamorgan Public Service Board (PSB) – Well-being Plan: Objective	To enable people to get involved, participate in their local communities and shape local services.	/	/	/		/
	To protect, enhance and value the environment.	+ +	-	-	/	-
Environment (Wales) Act 2016: Section 6 duty.	"Maintain and enhance biodiversity….and in doing so promote the resilience of ecosystems, in particular the diversity, connectivity, scale, condition and adaptability of ecosystems".	+ +	-	- -	-	- -
Natural Resources Policy – Welsh Government (2017). National priorities:	Delivering nature-based solutions	+ +	/	/	- - -	/
	Increasing renewable energy and resources efficiency	/	/	/	/	/
	Taking a place-based approach.	+ +	+	+	+	+

Indicative ranking as set out within

Table 2-5 has been determined based on potential environmental impacts (i.e. negative and positive impacts) associated with each short-listed measure. A summary of potential environmental impacts for each short-listed measure is provided below:

Measure 1: Natural Flood Management – Cadoxton River and Upper Catchment

Potential Negative Environmental Impacts

Whilst there's potential for environmental impact to occur during the introduction of Runoff Attenuation Features, impacts are likely to be localised and temporary. Given the nature of Natural Flood Management measures, environmental opportunities are more likely to be realised than negative environmental impacts.

Potential Positive Environmental Impacts

- Use natural processes to manage flood risk.
- Opportunities for habitat creation and ecological improvements within the upper Cadoxton River catchment.
- Through encouraging habitat creation, NFM is likely to enhance the amenity value of the upper catchment.
- NFM is likely to give rise to water quality benefits delivering Water Framework Directive mitigation/improvement measures.
- Health and wellbeing benefit to people from reduction in flood risk. Although it will not provide a community wide solution to reducing flood risk within Dinas Powys, 44 homes may benefit up to a 3.33% chance event.

Measure 2: Channel storage in oversized channels upstream of Eastbrook

Potential Negative Environmental Impacts

- Constructing the small dams would lead to localised loss of trees and streamside habitat.
- Protected and notable species: Species present, or potentially present in light of suitable habitat, include: Bats, Otters, Reptiles, Amphibians, Nesting Birds (including Kingfisher). Depending how this option is implemented, there's potential for the above referenced protected and notable species to be impacted.

Potential Positive Environmental Impacts

- Improve ecology and geomorphology of the waterbody.
- Work with adjoining landowners to review and alter land management practices to achieve water quality benefits.
- Enhance, and promote long term conservation, of the adjoining species rich grassland.
- Health and wellbeing benefit to people from reduction in flood risk. Although it will not provide a community wide solution to managing flood risk within Dinas Powys, 31 homes and 4 businesses may benefit up to a 1% chance event.

Measure 3: Upstream flood storage on Cadoxton River

Potential Negative Environmental Impacts

- Public Amenity: Both Public right of way (PROW) and permissive access will be inundated with flood water, rendering it unusable until the water recedes (estimated to be 24hr following the flood event). There will be a need for the PRoW to pass over the flood embankment which will cross its existing location. The PROW forms part of the popular Salmon Leap Walk, which is one of the counties 10 Vale Trails. It's likely there will be a need to permanently re-route approximately 60m of the PRoW to accommodate (i.e. up and over) the embankment. The flood storage inundation would also impact upon a Woodland Trust Permissive Bridleway (approximately 150m stretch) and permissive footpaths. The Permissive Bridleway is one of only two bridleways located within the south east of the county.
- Ancient Woodland is irreplaceable, given the complex interrelationships between plants, animals, soils, climate and people having developed within them over centuries. The indicative location for the flood storage embankment, would lead to direct loss of ancient woodland. It's also likely flood water inundation of the Flood Storage Area will impact the ancient woodland. In any given year there's between 50% and 100% chance of ancient woodland being inundated. Whilst it's not believed inundation will have an adverse impact upon trees, there is likely to be an impact upon the composition of the woodland ground flora and soils. The ancient woodland forms part of Coed Clwyd-Gwyn and Case Hill Wood Site of Importance for Nature Conservation (SINC). SINCs are local non-statutory designations with high nature conservation value. Any loss of ancient woodland would go against aspirations as set out within "Woodlands for Wales" (2018), the Welsh Government's strategy for woodland and trees within Wales. Furthermore,

Planning Policy Wales (2018) states: “Ancient woodland and semi-natural woodlands and individual ancient, veteran and heritage trees are irreplaceable natural resources, and have significant landscape, biodiversity and cultural value. Such trees and woodlands should be afforded protection from development which would result in their loss or deterioration unless there are significant and clearly defined public benefits; this protection should prevent potentially damaging operations and their unnecessary loss. In the case of a site recorded on the Ancient Woodland Inventory, authorities should consider the advice of NRW. Planning authorities should also have regard to the Ancient Tree Inventory.”

- Environment (Wales) Act - Section 7 priority habitats: "Lowland mixed deciduous woodland": In addition to the potential impact upon ancient woodland, there is likely to be a direct loss and inundation of other broadleaved woodland (i.e. non ancient woodland) which forms part of Coed Clwyd-Gwyn and Case Hill Wood Sites of Importance for Nature Conservation (SINC). Areas subject to more regular inundation may result in woodland transition from lowland mixed deciduous woodland to wet woodland, which is also a section 7 priority habitat. As the change would involve a transition from one priority habitat to another, the hydrological impact is not deemed to be negative. There is however potential that the inundation may lead to nutrient loading and introduction of invasive species that would have a negative effect upon the woodland. There are 3 Veteran Trees (a tree which shows ancient characteristics) and 1 Notable Tree (a tree which is significant locally) within the indicative flood storage inundation area, all of which are oaks. Considering frequency and duration of flood inundation it’s unlikely these trees will be adversely impacted. Hedgerows: Up to 6 hedgerows are located within the indicative Q1000 flood storage area inundation extent. The hedgerows present are well managed Hawthorn hedges with a low diversity of other woody species. Considering frequency and duration of inundation the hedgerows are unlikely to be negatively impacted, the scheme has a means to have a positive impact through enhancing existing hedgerows and incorporating new hedgerow planting. Rivers: There will be the small-scale loss of river bank (approximately 60m) where the dam is constructed, this is likely to include loss of riparian woodland and scrub habitat.
- Protected and notable species: Species present, or potentially present in light of suitable habitat, include: Bats, Badgers, Otters, Dormouse, Reptiles, Invertebrates, Nesting Birds (Kingfisher in particular). Depending on the approach to implementation of the scheme, there’s potential for the above referenced protected and notable species to be impacted. A Dormouse survey undertaken in 2017 concluded that Dormice were not likely to be present, however as certainty can’t be fully determined at this stage a precautionary approach is proposed where further surveys and assessment of potential impacts need to be considered should this option proceed. Likewise, in relation to all above referenced protected and notable species, should this option progress, further assessment (e.g. targeted surveys) will be necessary to ensure potential impacts are considered further and mitigation applied.
- Landscape and Visual Amenity: The flood storage embankment will alter the visual appearance of the valley and therefore have an impact upon the Cwrt-Yr-Ala Basin Special Landscape Area (SLA), it may be possible for the scale of impact to be reduced through sensitive design and introducing screening measures to restrict views from key visual receptors. Floodwater inundation is unlikely to have a significant impact upon the SLA due to it being infrequent and temporary in nature. There are up to 23 Tree Preservation Orders situated within the footprint of the indicative flood storage area, although further assessment is necessary it's believed unlikely that floodwater will have a significant impact upon these TPO's given the infrequent and temporary nature of inundation. Key visual receptors include residential properties and Public / Permissive Rights of Ways.
- Historic Environment: Although there are no historic designations within the flood storage area and embankment footprint, the setting of three adjoining Scheduled Monuments (Cwm George Camp SM; Tyn y Coed Earthworks SM; Dinas Powys Castle SM) could be impacted by the flood storage area. Whilst currently it’s envisaged that significant impact is unlikely given the topography and wooded nature of the valley, further assessment of impact upon SM setting is required (as advised by Cadw) in addition to the schemes potential to change historic landscape character of the area. The indicative embankment location will cross and impact upon two non-designated historic features (Dinas Powys Mill Race; Historic Boundary of Newland Wood).
- Water body (Water Framework Directive). Hydromorphology: Overall, at this indicative design stage, whilst there's potential (e.g. impact on river continuity and sediment transport processes within the watercourse), "it's not foreseen the Flood Storage Area is likely to adversely impact the WFD status of the waterbody, based on Hydromorphological Elements" (WFD Assessment - Dec 2017). Nevertheless, changes in flow and sediment transport will need to be considered further if

this option progresses to detailed design stage. River Biology: Depending on nature of the embankment/culvert design there's potential for adverse effects to fish (e.g. fish passage; potential for increased sediment upstream and the effect this would have on fish eggs within gravels), invertebrates (e.g. potential for changes in sedimentation and flow/hydrodynamics to impact on invertebrates upstream and downstream of the culvert), macrophytes and phytobenthos (Inundation of nutrient rich farmland could mobilise nutrients in agricultural soil into the waterbody which may cause eutrophication). Again, if this option progresses to detailed design further impact assessment will be undertaken to assess potential risks to these biological elements and subsequently whether the proposed scheme could affect water body status or inhibit the water body from achieving its status objectives. More information necessary regarding embankment design before a definitive consensus can be reached. Chemical & Physio Chemical: It has been concluded that the construction and operational activities associated with the proposed flood storage area are unlikely to affect the status of chemical elements of the Cadoxton River water body. Physiochemical elements are also unlikely to be significantly affected, though the risk of increased nutrient (phosphate and ammonia) input to the water body from increased inundation of nutrient-rich farmland, and the effects this may have, further development of the WFD compliance assessment will be necessary should this option progress to detail design stage.

- **Potential Positive Environmental Impacts** Health and wellbeing benefit to people from reduction in flood risk. Although not a community wide solution for flood risk management within Dinas Powys.
    - Improve public access within the upper catchment, maximising opportunities for the local community and visitors to access this green space. The Woodland Trust's "Cwm George and Casehill Wood Management Plan 2014-2019" states that:

      - site suffers from inappropriate behaviour,

      - areas of bridleway can become heavily poached in winter and the meadows are particularly prone to intensive use which can lead to degradation of routes in wet weather,

      - wooden installations are subject to rot and infrastructure is also vandalised.

      Measures could be introduced that will contribute to addressing the above challenges.
    - Introduce measures to protect and enhance historic environment interests within the area e.g. improved interpretation at the Scheduled Monuments; archaeological recording of historic mill race.
    - Deliver woodland improvement measures e.g. Enhance woodland age structure and species composition through the creation of gaps and thinning. Tree planting to improve connectivity between woodland parcels. Scattered native black poplar planting along the river corridor and across the floodplain to provide continuity of habitat between existing areas of ancient woodland and encourage the redistribution of a rare native tree species.
    - Aid delivery of long-term objective for the Planted Ancient Woodland Site (PAWS) as recorded within The Woodland Trust's "Cwm George and Casehill Wood Management Plan 2014-2019" i.e. Gradual removal of remaining conifer components and restoring to broadleaved woodland. Thinning of Beech where dense shade is posing a threat to ground flora.
    - Restore sinuosity to historically straightened Cadoxton River and provide improved connectivity of the river with the floodplain. Preserve and enhance the ecological value of marginal aquatic habitat, bank and riparian zones.
    - Incorporate habitat creation and/or improvement measures, that would support and/or encourage protected and notable species. Such measures could include:

      - Wet Woodland Creation (Environment (Wales) Act 2016 - section 7 priority habitat)

      - Introduce network of ponds and wetland scrapes to encourage amphibian colonisation such as great crested newt.

      - Improve condition of existing hedgerows and introduce new hedgerows, targeting plant species that support dormice.

Measure 4 – Flood defences along Cadoxton River in Dinas Powys.

Potential Negative Environmental Impacts

- Public Amenity: An extensive network of flood walls through Dinas Powys will impact access along the Cadoxton River, reducing people's amenity enjoyment of the river with less connectivity. However, locally widening channel section presents an opportunity to improve connectivity for a short length. Whilst the flood wall will need to accommodate PRoW at Wellwood Drive.
- Environment (Wales) Act - Section 7 priority habitats: Construction of river bank walls, bridge improvements and channel widening through the village will lead to loss of riverine habitat, likely to include Section 7 priority habitats "Lowland mixed deciduous woodland", "wet Woodland" and "River".
- Protected and notable species: Given the habitats available, there is potential for the following species to be present and impacted: Bats, otters, reptiles, amphibians, nesting birds (kingfisher). Further surveys (including extended phase 1 habitat survey) needed if option progresses to determine likely impact.
- Landscape: Whilst the works are not situated within a sensitive landscape area walls would create a visual barrier between residential, public areas and the river due to their height and proximity to the banks. This canalising of the watercourse will have a negative impact upon the landscape. The proposed walls' most northern point adjoins Dinas Powys Conservation Area, but is unlikely to have significant negative impact considering proximity and scale of the proposed wall.
- Carbon footprint: Extensive walls require high quantities of steel and concrete, producing high carbon footprint.
- Water body (Water Framework Directive): Hydromorphology: The Cadoxton River through Dinas Powys has been significantly engineered. Further assessment and design are necessary before the extent of hydromophological impact can be determined. If the wall is set back from the riverside it will reduce the impact. **Biological**: Works will remove riparian habitat (trees/vegetation), which would negatively impact the waterbody. **Chemical & Physio Chemical**: Defences are unlikely to affect the status, providing good pollution prevention measures are adhered to during construction.

Potential Positive Environmental Impacts

- Deliver water body improvements, e.g. changing existing canalised channels into 2-stage channel for biological improvement' introducing riffles; converting modified hard engineering banks to more natural features.
- Introduce facilities to improve existing amenity areas/land e.g. seating, disabled access, signage.
- Incorporate the planting of trees and shrubs to enhance streetscape, whilst also providing sustainable drainage; water quality; and biodiversity benefits.
- Health and wellbeing benefit to people from reduction in flood risk, although not a community wide solution for flood risk management within Dinas Powys.

Measure 5: Combined option - Cadoxton River flood storage area and East Brook channel storage

Potential Negative Environmental Impacts

- Environmental impacts would be as per those referenced against Option 2 and 3 above.

Potential Positive Environmental Impacts

- Environmental impacts would be as per those referenced against Option 2 and 3 above

As previously mentioned, environmental assessment is an iterative process that starts at the inception of a project and continues through options appraisal, detailed design, construction and operation. The appended Environmental Constraints and Opportunities Record (ECOR) documents the environmental appraisal of the short-list of options/measures, that has informed the overall appraisal of delivering a flood risk management scheme at Dinas Powys.

If/when a preferred option/measure is identified the next step of the environmental assessment process would be to identify the scope of Environmental Impact Assessment (EIA) needing to be integrated into the schemes detail design stage. The EIA would provide a systematic and transparent way of managing environmental risks/impacts through applying the mitigation hierarchy (in order of preference: (i) avoid; (ii) minimise (or reduce) and (iii) restore/compensate). Consultation on the proposed scope of EIA would be undertaken prior to commencement of the detail design stage. Depending on the option being progressed, in accordance with the

Town and Country Planning (Environmental Impact Assessment) (Wales) Regulations 2017, there could be a requirement to produce an Environmental Statement for the scheme.

With regards to Measure 3 - Upstream flood storage on Cadoxton River, the Vale of Glamorgan County Borough Council have provided a screening opinion (31sr of May 2018) in accordance with the Town and Country Planning (Environmental Impact Assessment) (Wales) Regulations 2017. They concluded the measure has potential for significant environmental effects, and so a statutory EIA would be required, and an Environmental Statement be produced and submitted in support of a planning application.

Through application of the mitigation hierarchy (in order of preference: (i) avoid; (ii) minimise (or reduce) and (iii) restore/compensate), it's sometimes possible to manage certain environmental risk arising from projects. Whilst mitigation measures can only be fully defined via the environmental assessment process as a scheme design progresses, following are examples of potential mitigation measures that could possibly be applied should measure 13 be identified as the preferred measure for flood risk management in Dinas Powys.

- To avoid or reduce flood water inundation impacting the public right of way (PRoW); mitigation may involve marginally re-routing the PRoW, or alternatively raising it so that it's positioned above the more frequent inundation level.
- As Ancient Woodland is irreplaceable, its loss or deterioration is only permitted if there's significant and clearly defined public benefits (Planning Policy Wales (Edition 10, December 2018), where loss occurs significant measures are required to compensate for any loss. The transport project High Speed 2 (HS2) has put forward a compensation package of planting 30 (ha) of new broadleaved woodland for every 1 (ha) loss of ancient woodland. This provides an indication on the level of compensation that may be necessary should loss of ancient woodland occur.
- Compensate for the loss of broadleaved woodland. The compensation for non-ancient broadleaved woodland loss may involve replanting three trees for every one loss.
- Should it be determined that flood water inundation will have an adverse impact up ancient woodland, in order to reduce the impact, it may be necessary to raise ground levels along the periphery of the ancient woodland, reducing frequency of inundation.
- Mitigation for the impact of the embankment upon landscape and amenity value will need to be incorporated within the design, with the aim of avoiding or reducing impacts. Mitigation may involve: screening structures through use of tree planting; applying natural topography that's in keeping with the existing landscape; introduce engineering solutions that will allow the scale of the structure to be reduced; avoid using hard engineering where feasible.
- Whilst impacts upon the Cadoxton River need to be assessed further. Mitigation will likely be needed to ensure fish and eel passage through the proposed culvert (e.g. introduction of eel brushes). Likewise, suitable measures will need to be in place to ensure sediment transport and water quality are not adversely affected.

2.6.3. Economic performance of Short List

2.6.3.1. Benefits

The assessment of benefits has been undertaken in accordance with FCERM-AG, the Multi Colour Manual and Green Book economic analysis methods, using a 100 year appraisal period with present value discounting based on flood damages avoided by implementation of a measure.

The key area of interest for this project is the village of Dinas Powys, where residential properties are at risk of flooding.

There is also a number of properties in the downstream Sully Moors area at risk of both fluvial and tidal flooding. We have ensured that the flood damages for these properties are not double counted within this appraisal by removing the £11k of present value damages due to tidal flooding from the fluvial baseline scenario present value damages. Hence any potential benefit achieved against this damage will be omitted from the flood risk management measure.

There is also a number of properties in the downstream Sully Moors area at risk of both fluvial and tidal flooding. We have ensured that the flood damages for these properties are not double counted within this appraisal by removing the £11k of present value damages due to tidal flooding from the fluvial baseline scenario present value damages. Hence any potential benefit achieved against this damage will be omitted from the flood risk management measure.

The model results in the form of depth grids were used to calculate the damages for each measure, in conjunction with the National Receptor Dataset (NRD). To undertake this analysis with efficiency and with reduced risk of errors, the analysis was supported by JBA's proprietary software 'FRISM'. Flood modelling allowed for the assessment of flood damages across four epochs (2017, 2037, 2067, 2117) over the next 100 years. In addition to property damages, vehicle damages and emergency

services costs have been included as indirect tangible damages, in accordance with the MCM. No allowance at this stage has been made for intangible damages in this economic assessment.

Different measures achieve varying degrees of benefits, depending on the area the measure aims to protect. For example, Measure 2: Channel storage upstream of Eastbrook predominantly reduces flood risk to properties along the East Brook, Measure 3: Upstream storage - Cadoxton River predominantly focuses on reducing flood risk to properties along the Cadoxton River in Dinas Powys, whilst Measure 4: Flood defences along Cadoxton River in Dinas Powys and Measure 5: Combination both focus on reducing flood risk to properties in Dinas Powys and Eastbrook.

The following table summarises the present value damages for the walkaway option plus the benefits for the do-something option, along with a breakdown of the properties protected by each measure for a 1% event in 2017 and in 2117 allowing for climate change. To aid clarity only one configuration of each measure is presented below. Measure 2: Channel storage upstream of Eastbrook uses the 50% reduction in flow as this is most likely achievable and achieves lower benefits than the 75% flow reduction. Measure 3: Upstream storage - Cadoxton River uses a 180,000m^3 storage volume at a central location as it represents the measure that can protect properties up to the present day 1% event. Measure 4: Flood defences along Cadoxton River uses arrangement 2 of flood defences with channel widening and raising of bridges and culverts as this represents both arrangements 1 and 2. Arrangement 3 provides limited advantage over a smaller 96,000m^3 storage area alone.

Table 2-6: Summary of present value damages, benefits and property counts

Measure	Present Value damages (£k)	Present Value benefits (£k)	Properties protected [2017 1% event]		Properties protected [2117 1% event]	
			Residential	Non-residential	Residential	Non-residential
Walkaway	8,280	N/A	N/A	N/A	N/A	N/A
Measure 2: Channel storage upstream of Eastbrook	6,776	1,504	31	4	100	2
Measure 3: Upstream Storage	2,578	5,702	167	6	164	11
Measure 4: Flood Walls*	4,741	3,539	197	19	130	0
Measure 5: Combination	2,133	6,147	193	8	262	12

2.6.3.1. Costs and Present Values

A whole life present value cost estimate has been produced to deliver each measure, which includes design, construction, maintenance and a 50%ile risk allowance using 29% optimism bias. This indicates the economic viability of the above short-listed measures.

The present value discounted benefits and costs over the 100-year appraisal period for the above short-listed do-something measures are presented in the table below

Table 2-7: Summary of present value costs, damages, benefits and BCR

Measure	Present Value costs (£k)	Present Value damages (£k)	Present Value benefits (£k)	Benefit-Cost Ratio
Walkaway	N/A	8,280	N/A	N/A
Measure 2: Channel storage upstream of Eastbrook	852	6,776	1,504	1.77
Measure 3: Upstream Storage	4,589	2,578	5,702	1.24
Measure 4: Flood Walls	8,870	4,741	3,539	0.37
Measure 5: Combination	5,441	2,133	6,147	1.13

2.6.3.2. Benefit-cost ratio

The ratio of present value benefits to costs (i.e. the benefit-cost ratio) is the calculation made to assess the economic viability of a measure. The higher the benefits that are achieved for the lower cost, the greater the benefit-cost ratio will be. For a scheme to be considered economically viable, the benefit-cost ratio must be greater than unity.

Based on the benefit-cost ratios presented in the table above all measures except for measure 4 are economically viable. Typically, the most economically viable measure would be the measure with the highest benefit-cost ratio, however measures 2 and 3 only manage flood risk to individual areas, (Eastbrook and Dinas Powys respectively). Consequently measure 5, which combines measures 2 and 3, is the most economically viable measure and achieves the greatest present value benefits across the catchment. This measure has a benefit-cost ratio of 1.13 and will deliver a holistic catchment-based reduction in flood risk. However, its impacts to the environment and amenity are presented in this business case to inform the selection of the preferred measure.

The benefits of measure 5 are less than the combined benefits of individual measures 2 and 3, as although the measures are complimentary to one another, where they protect the same property the benefits cannot be achieved twice, and the benefits cannot exceed the baseline damages for an area.

Although there is an overlap in benefits between the Channel storage upstream of Eastbrook and the Cadoxton River flood storage area, the East Brook work cannot be implemented alone to effectively manage flood risk to Dinas Powys as a community. The East Brook measure reduces flood risk across some of Dinas Powys, as it reduces water levels in the East Brook at its confluence with the Cadoxton River, and therefore downstream. This reduction in water levels results in shallower flood depths to properties in a 1% event and results in benefits. However, the properties are not removed from medium flood risk and are still predicted to flood in the 1% event, with the changes in flood depths being comparatively small. With the flood storage area in place alongside the Channel storage upstream of Eastbrook, flood depths are reduced by a greater amount in most areas, and the majority of properties which still experience flooding with the Channel storage upstream of Eastbrook in place are removed from medium flood risk to no longer flood in a 1% event. The flood storage area measure protects a much greater number of properties and is required alongside the Channel storage upstream of Eastbrook measure if property flooding in Dinas Powys is to be effectively and substantially reduced.

This is shown by the property count data in the economics report, summarised as follows:

- Catchment wide, 170 properties are protected in a 1% (2017) event by the Cadoxton River flood storage area measure (167 residential, 5 non-residential).
- Catchment wide, 28 properties are protected in a 1% (2017) event by the Channel storage upstream of Eastbrook measure (26 residential, 3 non-residential).

The Channel storage upstream of Eastbrook measure is however required to manage flood risk to properties in the Eastbrook area, which are not protected from flood risk by the flood storage area.

Optimisation of the flood storage area has been considered and a full economic assessment and appraisal of potential impacts of the variations has been undertaken. Additional work would be required to further optimise the most viable location and complete the detailed design.

2.6.4. Most Viable Measures

The most viable approach to maximise achievement of the critical success factors is a combination of flood risk management measures that have been developed through holistic consideration of the catchment dynamics. All of the measures work with natural processes to slow the flow.

Based on multiple criteria, the most viable flood risk management measure is the do-something combined measure 5. This measure comprises of:

Measure 2: Channel storage upstream of Eastbrook (50% flow reduction)

Measure 3: Upstream storage - Cadoxton River – 6.5m^3/s flow restriction, 180,000m^3 flood storage

This is due to the resulting significant reduction in flood risk in Dinas Powys and associated economic benefits. Other options were discounted as either being technically unviable or achieving a benefit-cost ratio below unity.

The Walkaway and Business As Usual measures are viable, but do not achieve the critical success factors or investment objectives.

The cost estimate of the combined measures is £5,441k, which would provide £6,147k benefits over the 100 year appraisal period. This gives a benefit-cost ratio of 1.13, providing an economic justification to support the implementation of the scheme.

Hence this combined measure is economically viable and reduces flood risk to a low level for the majority of the community. However, they do not currently have broad stakeholder and community support, and have a number of significant issues and associated risks. These are primarily associated with measure 2 (flood storage area) and particularly notable issues include:

- Loss of and impact to an important area of ancient woodland and broadleaf woodland.
- Stakeholder and public objection to the loss and impact of ancient woodland and Sites of Importance for Nature Conservation (SINC), with potential obstructive protests.
- Landowner objection to the works and resultant potential compulsory purchase of land.
- Potential impacts to protected species (bats, dormice, kingfisher, otters, badgers, reptiles, amphibians) and licencing requirements.
- Public objection to change at a popular local amenity.
- Potential impacts or amendments to existing Public Right of Ways, walking routes and open space.
- Potential WFD impacts caused by possible changes in the geomorphology of the river.
- Given the above factors, it is possible that the planning application process and statutory EIA will not be straightforward.

The above issues and associated risks will affect the viability and delivery of the measures. A range of varying impacts can be forecast, but the likelihood of occurrence and resulting actual impact is difficult to predicted at this early stage, especially given the nature of the issues. It may be possible to manage the issues and associated risks within the cost estimate to deliver a successful scheme with a positive benefit-cost ratio. However, there is significant exposure to high probability and high impact risks that could incur large costs and result in a benefit-cost ratio falling below unity.

2.6.5. Sensitivity Testing

A number of sensitivity assessments have been undertaken to determine whether the assumptions and parameters used in the economic analysis are sufficient to influence the benefit-cost ratios. This assessment helps to determine the robustness of the most viable measures. Sensitivity tests have been undertaken for the following aspects which have inherent uncertainty, and which are thought to have the greatest influence:

- Variations to cost estimates and risk realisation;
- Flood model parameters;
- Property threshold levels;
- Capping of property damages.

The most sensitive aspect of the combined measure's economic viability is currently the third party cost estimates and potential increases due to risk realisation, due to the nature and scale of risks present. These include the cost to manage and mitigate the impacts to the ancient woodland, land purchase and compensation costs, with a risk of having to compulsory purchase land, the planning process and potential appeals, with the risk of not obtaining permission, and dealing with public objections and obstructions and the adverse PR. The future selection of a preferred option will need to consider these risks, their likelihood of occurring, potential mitigation and their residual impacts, and how this may affect the economic justification by increasing costs.

Model parameters, such as structure configurations and flow scaling factors, are based on technical judgement and hence could be adjusted subject to experience and opinion. We have tested the model sensitivity to changes in some of these, and they could reduce benefits. However, the model outputs are calibrated to reflect flood risk expected from experience of events, so we are confident in the flood risk prediction.

Increasing the property level threshold from 150mm to 300mm results in a decrease in damages for the walkaway option, which will consequently reduce the benefits for each of the do-something options and the benefit-cost ratios. Based upon preliminary modelling this could reduce benefits by up to 50%, making measures potentially economically unviable with benefit-cost ratios below unity.

The removal of capping damages for each property at its estimated market value resulted in an increase in the damages for the walkaway option and all do-something options. Preliminary modelling increased the benefits by up to 40% for each measure.

It should also be noted that potential impacts of the combined measures have not been quantified.

2.7. OBC Consultation and Stakeholder Engagement

Due to the high profile and contentious nature of the project, and as the most viable measures have the potential to impact areas of public interest in amenity and environment, we shared a draft OBC with stakeholders and the public. Opinion and feedback regarding the flood risk and measures was invited. This consultation exercise, which included writing to residents, engaging MS's, Community Councils and campaign groups, and use of social media, resulted in almost 400 responses being received. Notable responses were received from:

- Elected representatives, including MS's and Alun Cairns MP.
- Dinas Powys Community Council
- Michaelston-le-Pit and Leckwith Community Council
- The Woodland Trust / Coed Cadw
- Save Dinas Powys Woods and Protect Homes From Flooding Campaign Group

Of the responses over 95% object to upstream storage on the Cadoxton River. Less than 2% fully support the most viable combination measure of upstream storage on the Cadoxton River and channel storage upstream of Eastbrook. There is limited support for alternative options such as flood walls through the village.

Many responses noted that they believe there to be a flood risk in Dinas Powys and a flood risk management project should be pursued. This was especially evident from residents in the St Cadoc's Avenue area who are at high flood risk. Some responses dismissed the flood risk or believe it is over estimated or unfounded.

The majority of responses support 'Save Dinas Powys Woods and Protect Homes From Flooding' campaign group's position (many used a template letter produced by the group), which is to improve monitoring of flows on the Cadoxton River, implement NFM on all tributaries upstream of Dinas Powys, create channel storage upstream of Eastbrook, improve conveyance at Cardiff Road bridge, build a short flood wall for the most at risk properties on St Cadoc's Avenue and undertake more frequent and enhanced river channel maintenance, to collectively reduce flood risk. They have called this collection of measures NFM+. The campaign group states that if the combination of NFM+ proves inadequate to manage flood risk over the next 10 years, the other OBC options should be revisited.

From review of the consultation responses and social media comments, there appears to be a common misconception of the benefits that NFM+ could achieve in Dinas Powys, with many people believing that NFM+ can 'solve flood risk for all properties in Dinas Powys'. We have been clear in our communications of the limited benefits each discounted option can achieve to try to ensure people understand the issues, and sections '2.4.1. Rejected Long List Measures' and '2.6.1. Engineering performance of Short List' of this OBC explain that taking this piecemeal approach to managing flood risk is ineffective. Improving conveyance at the A4055 Cardiff Road bridge only slightly reduces upstream water levels in the immediate vicinity of the bridge and has little or no impact at the other restrictive structures upstream. A short flood wall to St Cadoc's Avenue provides benefit to just 6 houses, which already have individual property protection measures installed. Heavy channel maintenance of the Cadoxton River and East Brook only achieves marginal benefits with reduced flood depths of between 0.02m and 0.04m during a 1% event. NFM measures on the Cadoxton River would not reduce flood risk to low for all of the community.

Encouragingly, responses have shown a willingness amongst the community to work with NRW and other partners to further explore and develop natural flood management options in the Cadoxton catchment. Potential partners may include the Woodland Trust, Welsh Government, the Vale of Glamorgan Council, the Dinas Powys Community Council, the Michaelston-le-Pit and Leckwith Community Council, landowners and others such as the campaign group.

Consultation on the draft OBC has generated a high volume of public interest and responses, which has enabled the feelings of the community to be further heard and understood. This has allowed full consideration of all measures against the project's appraisal criteria (reference the Appraisal Summary Table). It is clear that the majority of responses believe that the perceived negative impacts of delivering the upstream flood storage measure do not outweigh the benefits it could provide.

Without broad stakeholder and community involvement and support to co-deliver a measure, it no longer has the potential to meet all Critical Success Factors (notably Item E Potential achievability). Hence it would be challenging to deliver and its viability is questionable.

2.8. Conclusion and Recommended Way Forward

2.8.1. Conclusion

Based on the appraisal of options conducted in this Outline Business Case we conclude that there is not currently a viable scheme to deliver a community-wide solution to manage the flood risk in Dinas Powys to low. Further funding should not be invested in the next stage of this project, to undertake detailed design, obtain approvals and complete a Full Business Case for any option, including the most viable option of combined measure 5.

The marginal benefit-cost ratio of measure 5 alongside the risks and consultation responses received would make progressing measure 5 very challenging. Although the next stage would offer the opportunity to confirm the details of the upstream storage option through the detailed design and Environmental Impact Assessment processes to quantify the actual impacts and further explore possible mitigation, as well as undertake further consultation and complete the democratic planning process, it is felt that the level of risk and public objection is too great to continue.

No other viable measures exist that could meet the Critical Success Factors and at least one of the Investment Objectives of this project, particularly providing value for money and reducing flood risk across Dinas Powys to low.

Hence NRW should continue with its current approach (the Business as Usual option) to manage flood risk in Dinas Powys, including maintaining and clearing the river channel of obstructions that pose a flood risk.

2.8.2. Other options

Delivering the campaign group's promoted NFM+ does not have the potential to meet all of the Critical Success Factors of this project, specifically to reduce the risk to properties and life from flooding to low, nor is it likely to provide value for money. The estimated cost of the combined measures that form NFM+ is £6,341k, the benefit of these measures is £4,890k (ignoring potential double counting of overlapping benefit, so actual benefit is likely to be lower) providing an optimistic

benefit-cost ratio of 0.77. The proposed NFM+ is economically unviable and would only provide benefit to circa 44 properties in the present day 1% storm event. NFM+ is therefore not recommended as a way forward by this project.

The benefit-cost ratios of conveyance improvements to Cardiff Road bridge (0.09), a short flood wall to St Cadoc's Avenue (0.88) and heavy channel maintenance of Cadoxton River and East Brook (0.96) are below unity, offer limited benefit and have negative impacts through their delivery. Hence they have previously been discounted in this appraisal and should not be considered further as a way forward.

Heavy channel maintenance of Cadoxton River and East Brook is unsustainable, as it would result in the loss of river corridor habitat (pools, riffles, trees and vegetation), with a prolonged environmental impact through recurring works. Properties in the location of the short flood wall to St Cadoc's Avenue currently benefit from IPP, so a flood wall would offer limited protected above this. Works to the Cardiff Road bridge would be extensive and cause traffic and disruption to residents and businesses for many months.

The remaining measures in NFM+, namely Natural Flood Management measures in the Cadoxton catchment and channel storage in oversized channels upstream of Eastbrook, have the potential to offer a flood risk management scheme with a positive benefit-cost ratio, possibly in the region of 1.5, Technical assessments in this appraisal have shown that these measures would not reduce the risk to all properties in Dinas Powys from flooding to low, as they are typically suited to mitigate the impacts of smaller, more frequent floods that affect small communities, rather than larger floods, as evidenced by the following research:

https://researchbriefings.files.parliament.uk/documents/POST-PN-0623/POST-PN-0623.pdf

https://www.oxfordmartin.ox.ac.uk/downloads/academic/Oxford_Martin_Restatement4_Natural_Flood_Management.pdf

Hence these measures are not recommended as a way forward by this project, as they could not meet all of the Critical Success Factors. They do however have the potential to be economically viable, provide some mitigation to lower level flood risk and offer wider environmental and wellbeing benefits.

2.8.3. Recommended way forward

NRW should continue with its current approach (the business as usual option) to manage flood risk in Dinas Powys.

This project will be closed.

FRM Business Board should consider if a new project, with new Critical Success Factors and Investment Objectives, is initiated to investigate Natural Flood Management measures in the Cadoxton catchment and channel storage in oversized channels upstream of Eastbrook.

The Minister for Environment, Energy and Rural Affairs has recently announced a Welsh Government Flood Branch funding opportunity for NFM schemes to all Risk Management Authorities in Wales with the aim of increasing understanding and delivery of NFM. This potential funding may be an opportunity for NRW to engage further with the Dinas Powys and Michaelston-le-Pit communities and potential partners to explore NFM opportunities in the Cadoxton catchment.

Appendix A – Environmental Constraints and Opportunities Record

Appendix B – Appraisal Summary Table