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The returns on investment of river improvement projects: A Cost-Benefit analysis of WRT's interventions in Cornwall and Devon

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EXECUTIVE SUMMARY

This report presents the results of a research aiming to estimate the impacts of the Westcountry's Rivers Trust (WRT) river improvement projects in Cornwall and Devon. NEF consulting estimated the impacts of five distinct projects financed by the River Restoration Fund in:

1) The Par, St Austell and Caerhays basins, St Austell bay area (SCRIP)
2) The Exe and Axe catchments (AERIP)
3) The Dart and the Teign basins (DTRIP)
4) The Avon catchment, encompassing as well as the Erme and the Yealm rivers (SHRIMP)
5) The Taw basin (TRIP)

This research used extended Cost-Benefit Analysis (CBA) in order to estimate the socio-economic and environmental returns generated by respective projects. For this purpose, this research estimated:

- The potential environmental (ecological) impacts of respective projects
- The potential societal benefits supported by those ecological impacts
- The value of those benefits, expressed in monetary terms
- The Benefit-Cost ratios, i.e. the comparison between the investments put in the projects and the wider benefits generated.

By improving water quality and ecological conditions in respective catchments, we find that all projects generate substantial social benefits and support a variety of Ecosystem Services.

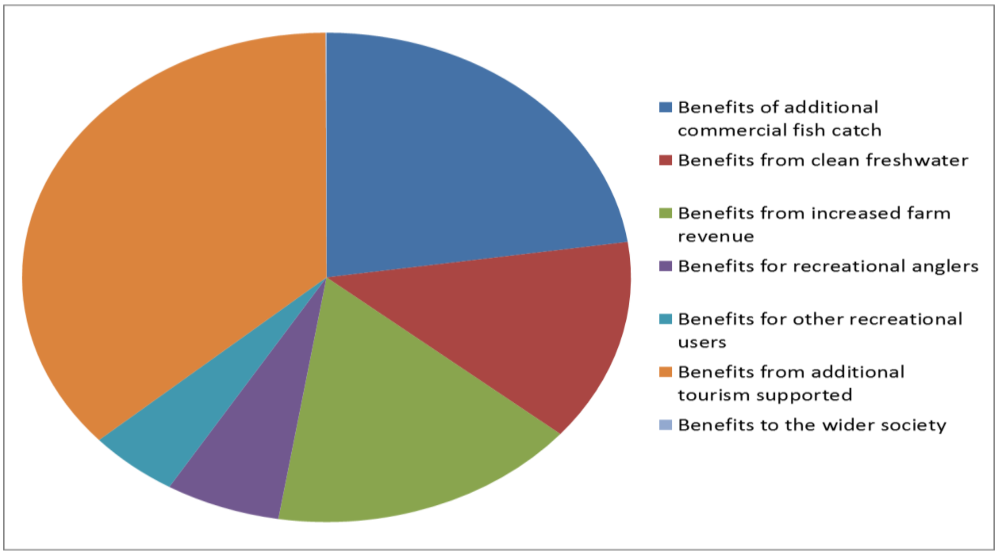
For each £1 invested in the WRT's river improvement projects, between £1.9 and £4.5 are generated, depending on the project location. The Net Present Value (representing the total benefits, net of costs) is positive for all projects. This means that investing in river improvement projects is economically efficient and effective.

Table A: Overview of results, assuming a 10 year benefit period and a 3.5% discount rate.

	Net Present Value	Benefit:Cost Ratio
Dart & Teign RIP	£1,088,572	4.53
Axe & Exe RIP	£979,908	3.93
South Hams RIP	£948,471	3.37
South Cornwall RIP	£211,324	1.91
Taw RIP	£2,652,016	3.39
TOTAL	£5,880,291	3.46

The impacts generated by the project come in the form of both strict market (economic) benefits, such as increased fish catch and increase visitor spend (tourism), as well as less tangible ones, such as additional well-being for recreational visitors (including recreational anglers) and the wider society. The benefits from improving water quality are also significant.

Figure A: Distribution of benefits supported by the projects



These results need to be placed within their wider context. Rivers and freshwater ecosystems support substantial economic activity, which can be undermined when they are degraded. As this research illustrates at a micro scale, river improvement projects can yield significant benefits even if considering “hard” economic benefits only - namely tourism and commercial fishing revenues and jobs.

Thus, beyond the requirements for adhering to the Water Framework Directive (WFD), protecting and restoring rivers is of critical importance for the South West economy. Indeed, tourism (of which nature-based tourism is prominent) represents 22% and 11% of total FTE jobs in Cornwall and Devon respectively. Angling recreation alone supports £51 million of yearly Gross Value Added and 2300 FTE jobs in the South-West. A study of the Environment Agency determined that if Salmon fishing were to stop in the South-West, the household income loss would be of £1.7 million per year. Finally the South West’s saltwater fisheries, which represent 50% of England’s fisheries, are also partly dependent on freshwater quality, and thus on river ecosystems. In short, rather than asking whether we can afford to invest in river improvement projects, is it perhaps more sensible to ask whether we can afford not to.

Nonewithstanding the importance of the results, these need to be caveated. There are large uncertainties involved in projecting possible environmental impacts, and their associated socio-economic benefits, into the future. This research has required the use of a number of assumptions whose limits are clearly outlined throughout the report. We conclude by recommending improvements in environmental data collection and socio-economic monitoring of interventions. This would involve collecting baseline and post-intervention data in order to improve WRT’s understanding of the wider socio-economic impacts of its interventions, and of the benefits accruing to wider stakeholders as a consequence of WRT’s interventions.

INTRODUCTION

This report presents the results of a research aiming to understand and quantify the benefits generated by WRT's rivers restoration interventions in Cornwall and Devon. The research consisted in evaluating four distinct projects financed by the River Restoration Fund, and undertaken in 1) the Par, St Austell and Caerhays basins (St Austell bay area), 2) the Exe and Axe catchments, 3) the Dart and the Teign basins 4) the Avon catchment (encompassing as well as the Erme and the Yealm rivers) and finally 5) the Taw basin.

The approach used for this evaluation is an environmental Cost-Benefit Analysis (CBA), used in order to test whether these projects are efficient and effective. From an economic welfare standpoint, a key criterion for efficiency is that the benefits should be positive, net of costs. Comparing the costs and benefits of river restoration projects requires applying environmental and social valuation techniques for placing a monetary tag on goods which do not have a direct market price, such as ecosystem services or the well-being supported by ecosystem services.

A previous research conducted by Tom Le Quesne on behalf of WRT focused on strict "tangible" economic returns, finding that for each £1 invested about £4.4 were generated[1]. The present research builds on this approach by extending the analysis to encompass further non-market benefits. These non-market benefits come in the form of improvements in Ecosystem Services supported by WRT's projects in respective catchment areas.

In essence, the key questions this report aims to address are the following: What is the wider societal value supported and generated by river restoration projects in the Cornwall and Devon? Are river restoration projects efficient and effective from a socio-economic standpoint?

The report is structured as follows:

- **Section 1** outlines the frameworks used by this research for undertaking a Cost-Benefit Analysis. It presents the key frameworks of Ecosystem Services, Total Economic Value and valuation approaches for placing a monetary value on Ecosystem Services. Finally, it presents the overall steps undertaken in this research.

- **Section 2** outlines the change that should be expected by WRT projects in respective catchment areas. It links activities to outcomes and impacts expected both in environmental and socio-economic terms. This is the conceptual hypothesis subsequently tested in quantitative terms

- **Section 3** details the environmental changes expected, in biophysical (chemical and biological) terms. This is the necessary first step for understanding which Ecosystem Services may be affected in respective catchments, and in which way.

- **Section 4** focuses on monetary valuation of benefits, i.e. ecosystem services and the different values they support, and contrasts them with the costs of interventions to derive their return on investment.

- Finally, **Section 5** discusses results and concludes.

1. THE BENEFITS OF IMPROVING FRESHWATER ECOSYSTEMS

The present analysis combines two streams of literature for understanding the wider benefits of river restoration projects: 1) the framework of Ecosystem Services and 2) environmental valuation, used for placing a monetary price on Ecosystem Services. This section introduces the overall framework of this research by introducing key concepts and methods used throughout the report.

This conceptual overview is not exhaustive. Rather, it distils existing information drawn from previous case studies as well as presenting the overall analytical frameworks used to appraise similar interventions. A more detailed list of relevant previous case studies is available in Appendix 1.

1.1. The ecosystem services provided by rivers and freshwater ecosystems

1.1.1. Ecosystem services framework and rivers

Although there is no universally accepted typology of Ecosystem Services, both the United Nations Millennium Ecosystem Assessment (UN-MEA) and the UK-National Ecosystem Assessment (UK-NEA) provide a useful starting point for mapping out the benefits of ecosystems for human socio-economic welfare[2]. These benefits have been clustered by the MEA and the UK-NEA as follows:

- Provisioning services – benefits derived from products obtained from ecosystems, e.g. food, water and fuel;
- Regulating services – benefits derived from ecosystem processes that regulate the natural environment, such as flood regulation or waste dispersion;
- Cultural services – non-material benefits obtained through recreation, aesthetic enjoyment, or tourism;
- Supporting services – necessary for the production of all other services listed above, for example nutrient cycling. Supporting services are considered to be intermediary services, providing benefits through supporting all the other services.

The UK-NEA has mapped the type of ecosystem services supported by river ecosystems in the UK, as compiled in Table 1 below. This classification allows us to elicit the type of impacts river degradation might have on the economic system and the UK society. These impacts can be in the form of a) direct market (economic) benefits or of so-called b) non-market benefits.

Market benefits can include, for instance, the *direct* economic activities supported by rivers (freshwater), such as fishing, industries, agriculture, recreational service sectors and (when applicable) navigation. They can also include *indirect* economic benefits such as flood protection and avoided property damages (including e.g. insurance costs). Non-market benefits, on the other hand, are by definition more difficult to capture as they are less tangible. By supporting recreational activities, for example, rivers might provide physical and mental health benefits thus supporting a better quality of life. Similarly, cultural services can have an impact on broader well-being.

By and large, a same ecosystem service can provide both market and non-market benefits. For example, the abundance of fish populations can entail both a) market benefits (to the fishing industry) and b) non-market benefits (in the form of cultural, educational or aesthetic services).

The deterioration of river ecosystems, groundwater and open-water quality, has put at risk many of the ecosystem services presented in Table 1. The key drivers of this deterioration have been assessed to be[3]: a) Agricultural development; b) Industrial development; c) management of water supply; d) longer term dynamics, such as climate change and land cover change.

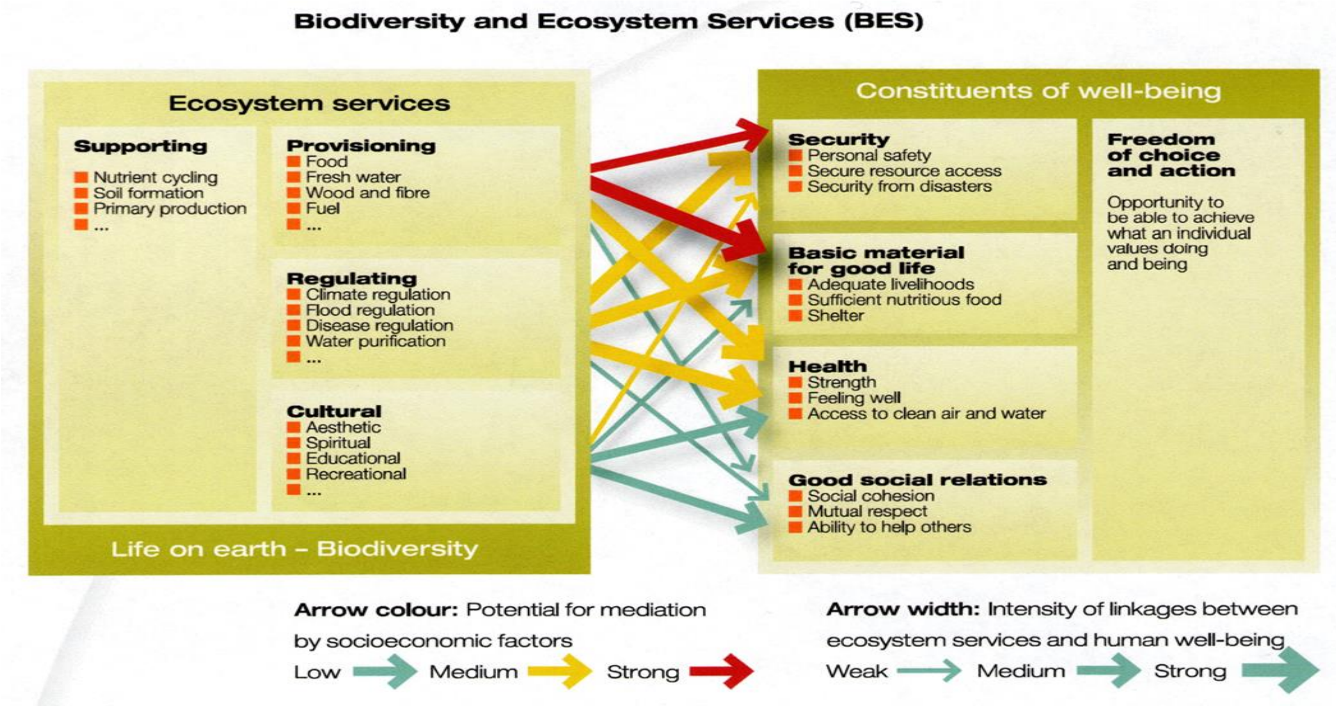
Table 1: A synthesis of ecosystem services provided by river ecosystems in the UK[4]

ECOSYSTEM SERVICES PROVIDED	DESCRIPTION AND CHARACTERISTICS
PROVISIONING SERVICES:	
Fish	Commercially significant fisheries (crayfish, salmon, trout) based on rivers, lakes and ponds in suitable conditions
Water for use	Open water habitats provide a water source for public supply, irrigated crops, power station cooling, industrial processing and fish farming, but high evaporation rates may suppress total water availability.
Navigation services	Navigable waterways need sufficient water depth and low velocity.
Health products	Mineral spas, medicinal plants (e.g. bog bean), medical leeches.
REGULATING SERVICES:	
Water flow and flood Regulation	River flow, groundwater recharge influenced by landscape location, water storage characteristics and connection with other water bodies. Flood reduction relies on available water storage; permanently saturated habitats with no storage may generate or augment floods
Water quality regulation	Freshwater systems can dilute, store and detoxify waste products and pollutants. Water quality affects suitability for use
Local climate regulation	Temperature and humidity may be different within the habitat and without; degree depends on size. Important moist microclimates can develop.
Human health regulation	Natural freshwater systems can increase well-being and quality of life if visually attractive and supportive of physical recreation. Mismanaged freshwaters can be sources of water borne diseases and disease vectors but also sources of bio-control agents
CULTURAL SERVICES:	
Science and education	Lake, floodplain and mire sediment sequences contain palaeo-environmental archives and human (pre)history, artefacts that may be lost if disturbed or desiccated. Freshwater ecosystems are important “outdoor laboratories”.
Tourism and recreation	Extensive recreational fisheries (game species and coarse fisheries depend on good habitat). Tourism depends on landscape appeal and iconic species, such as rare birds, flowers or amphibians. Good water quality and visual appearance required for natural swimming and boating.
Sense of place and history	Water is important in defining specific landscape character and features strongly in art and local culture. Freshwaters and especially wetlands are a recurrent feature at the heart of many historically important places, battlefields, territorial boundaries and many local folklore connections
SUPPORTING SERVICES:	
Biodiversity	All freshwater habitats with open water; species depend on conditions such as, temperature, oxygen level, depth and velocity of water and area with suitable conditions. Some habitats may provide temporary habitat for fish (e.g. for spawning), such as floodplains
Soil formation	Wetlands and floodplains are important habitats for soil generation though natural biophysical and chemical processes
Nutrient cycling	Recycling of soil and water natural and artificial nutrient occurs in wetlands, supporting enhanced water quality.

1.1.2. Ecosystem services and human well-being

The ecosystem services outlined in Table 1 reflect the so-called *direct* services. However, these services can also act as intermediaries for supporting broader human well-being services. The UN-MEA has provided a framework for illustrating the channels through which ecosystems can directly affect numerous constituents on human well-being (Figure 1).

Figure 1: Ecosystem Services and human well-being[5]



For example, Murato *et al* find that living within a perimeter of 1km of a freshwater ecosystem, (including rivers, wetlands and floodplains) increases UK Health Utility scores (Quality Adjusted Life Years) by 0.3%. This represents an annual health value of £20 to £68 per person[6]. They also find that undertaking physical activity in nature increases Health Utility scores by 0.2%, worth between £12 and £39 per person per year.

At a more micro level, Hazenberg & Bajwa-Patel, have mapped and measured the socio-economic impacts of restoring inland waterways in the UK[7]. They find that waterways restoration projects generate numerous well-being benefits, such as:

- Increased social capital
- Increased local income and employment rate
- Reduction of poverty levels and deprivation
- Improved housing conditions and coverage
- Improvements in health and education
- Greater sense of heritage

As these examples illustrate, Ecosystem Services can support human well-being in multiple ways. They often support spans of economic activity, directly or indirectly, as well as more intangible well-being components, such as social capital and heritage values. The methods and approaches used to map and measure these values are the object of the following sections

1.2. Analytical framework

1.2.1. Typology of benefits

The Total Economic Value (TEV) approach provides a useful framework for classifying, mapping and measuring the Ecosystem Services supported by river ecosystems and by river improvement projects. The TEV approach considers both market and non-market benefits, and distinguishes the different values which can be supported by an ecosystem (Table 2).

Table 2: Components of the Total Economic Value of an ecosystem or natural amenity

Value		Definition
Use values	*Direct use value*	Value derived from direct human use of ecosystem: it may be consumptive, for example value of drinking water, or non-consumptive, such as recreational
	Indirect use value	Value derived indirectly from the regulatory services provided by the ecosystem, e.g. hydraulic regulation, flood protection etc.
	Option value	Value attached to the option of using the ecosystem (of some functions of it) in the future – even if not being used currently
Non-use values	*Bequest value*	Value derived from knowledge that the ecosystem will be available to future generations – even if not benefitting from the ecosystem directly
	Existence value	Value derived from the knowledge that the ecosystem is there – even if not benefitting from the ecosystem directly

This approach has been used in the context of river improvement projects for assessing the benefits of implementing the Water Framework Directive in the UK (Table 3).

Table 3: An synthesis of potential impacts of river restoration projects

Project	Wider stakeholder categories	Type of use	Activities/stakeholders Impacted
Interventions for improving river ecosystem conditions and/or water quality	Users (use values)	In stream	Recreational: fishing, swimming, boating, kayaking…
			Commercial: fishing, boating
		Withdrawal	Municipal or utility companies: drinking water, waste disposal
			Agriculture irrigation, industrial and commercial use
		Near stream	Recreational: hiking, bird watching, picnicking…
			Aesthetic use and relaxation
	Non-users (non-use values)	Potential use	Option use in the near or far future
		No use	Bequest value: enjoyment from the knowledge future generations will use the river
			Intrinsic value: enjoyment from the knowledge the resource exists

Building on this typology, activities and stakeholders impacted can subsequently be linked to more specific benefits. Each activity can deliver a range of benefits. For example, recreational activities can support:

- A direct benefit to recreational users, for example in the form of well-being or physical and mental health;
- Economic benefits for the recreational service sector, for instance in a scenario whereby an environmental restoration project increases the number of recreational users or visitors;
- Wider socio-economic benefits for local communities, either in the form of additional income (local economic multiplier effects), or in the form of social resilience

1.2.2. Valuation methods

For valuing the benefits of river restoration, this research uses various non-market valuation techniques. These techniques have been developed to measure the Total Economic Value, or its individual components. By and large, they can be clustered in two categories: a) Revealed Preference Methods (RPM) and b) Stated Preference Methods (SPM).

- Revealed preference approaches assume that values people attach to an ecosystem can be revealed by their purchasing habits. For example, the value a recreational user places on a river ecosystem can be revealed by the amount of money (s)he spends for reaching the site. Similarly, the value placed on a water body can be revealed through the house price premium people and paying for living nearby the ecosystem.
- Stated preference approaches ask people to state how much they value an ecosystem service. This can include asking a recreational use how much (s)he would be willing to pay for improving a riparian habitat, or alternatively how much (s)he would be willing to accept for its degradation

Table 3: Valuation methods

Revealed Preference Methods	Description
Damage cost avoided	Cost which is avoided by preserving the condition of an ecosystem. For example, a wetland can provide flood attenuation services. If the wetland was lost, flood damages would rise. The cost of these flood damages are thus avoided as a consequence of the existence of a wetland.
Replacement cost	Cost that would be incurred to replace a natural ecosystem service with a man-made structure for providing the same service. For example, the cost of a water purification plant to replace natural water purification
Effects on production	These are the direct market impacts. An ecosystem can directly support economic activities. The effects on production reflect the % contribution of one specific ecosystem on human production on consumption, e.g. the contribution of a river delta on fish catch
Travel cost	The total cost paid by users of an ecosystem to access it. For example, the total money spent by a family to reach a wetland for recreation (or any other use).
Hedonic pricing	This approach measures the value of services provided by an ecosystem by the price people pay for the goods associated with this ecosystem. For example, people might be paying a premium for buying houses located nearby green spaces
State Preference Methods	
Contingent valuation	Contingent Valuation consists in asking people to state how much they value an ecosystem or an environmental site. This can include asking how much they are Willing-To-Pay for a service, or how much they would be Willing-To-Accept not to have access to a service. This is a hypothetical approach, since people do not/will not actually "spend" that money.
Choice experiment	Choice experiments are similar to contingent valuation, in that they ask people to hypothetically make choices and value alternative options. The main difference lays in that the scenarios and values people can attach are pre-fixed.

The respective approaches have advantages and disadvantages, and are used for valuing different types of benefits. Revealed preference methods are very useful for measuring use values; but they cannot be used for measuring the benefits to non-users. On the other hand, stated preference methods are based on strictly hypothetic judgment (on behalf of the respondents) and are thus more subject to numerous response biases; however, they are also more likely to encompass both tangible and less tangible benefits. They can thus represent a bigger fraction of the Total Economic Value stakeholders assign on a site.

Box 1: Example of valuation using Revealed Preference

An example of valuation using RPM is the research undertook Pretty *et al*, dealing with the costs of eutrophication of fresh waters in England and Wales[8]. Pretty *et al* value the economic costs of eutrophication (i.e. ecosystem degradation) notably by measuring:

- Replacement costs: drinking water treatment costs to remove algal toxins and nitrogen
- Hedonic pricing: loss of value properties located nearby freshwater bodies
- Direct (market) effects on production: loss of revenue for the tourism industry and commercial fisheries
- Damage costs: health costs to humans, livestock and pets.

Through this combination of approaches they find that eutrophication of fresh waters could cost the UK economy £54.8 million per year. Despite considering a range of benefits, this type of approach considers material costs of (or benefits of reducing) eutrophication only. This analysis does not factor in any form of non-use values, or wider well-being impacts. As such results only reflect a fraction of the Total Economic Value.

For example, the well-being value a person derives from spending time on a river can only be very partially represented by the amount of money he spends to reach that site. A revealed preference approach would thus only represent a small fraction of what the site is “worth” to that person. By using a Contingent Valuation approach, it will be more likely for that individual to express the full stream of value – tangible or not - he derives from spending time on the site. In short, there is no “silver bullet” methodology for capturing non-market values: the respective approaches can be deemed more appropriate depending on which benefits are to be valued, practical constraints and other considerations.

Finally, numerous analyses use “benefit transfer” (or “value transfer”), which consists in using figures from previous studies (on similar ecosystems and projects) to the site under study. This approach is selected when deriving primary estimates is not possible or desirable. Despite the limits of benefit transfer, Defra, has developed best practice guidance for transferring values from one site to another[9].

Box 2: Example of valuation using Stated Preference

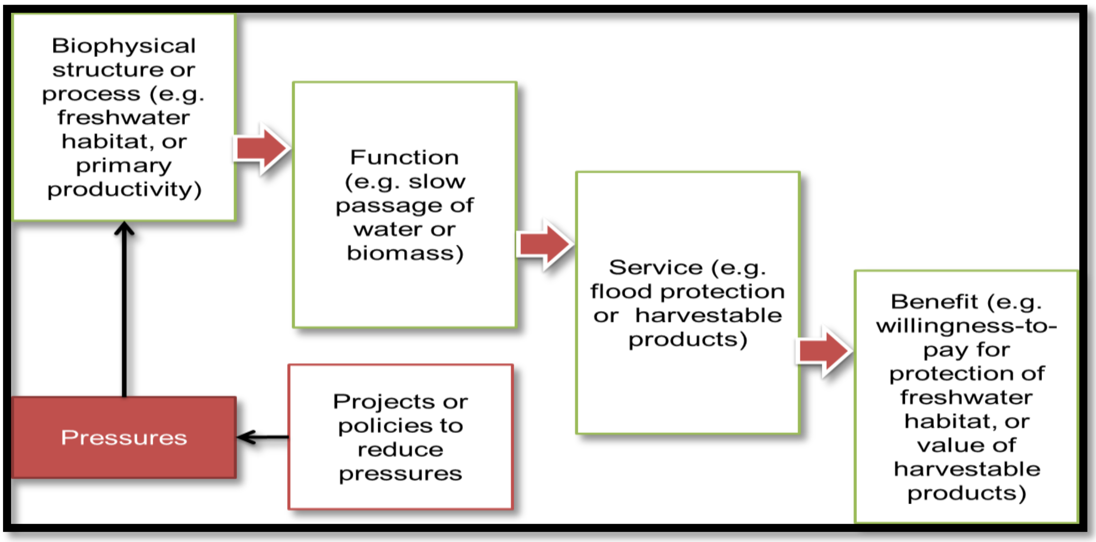
In the context of the implementation of the Water Framework Directive (WFP), Defra considers that direct market benefits associated with the incremental changes in water quality to be achieved are unlikely to be significant. A study undertook by NERA measured the non-market benefits of improving water quality of UK rivers to “good standards”[10]. NERA used a contingent valuation approach to estimate how much English and Welsh households are Willing-To-Pay for achieving a good quality status for rivers. The aim of this approach was to elicit the non-market benefits accruing to UK households as a consequence of the WFP’s implementation. This approach did not consider whether the household in question was directly using, or not, river bodies. As such, this methodology aimed to reflect on both use values and non-use values. The study found that UK households would be Willing-To-Pay an average of £55 per year - with a range between £45 (min) and £85 (max) per household per year. If upscaled to the totality of British and Welsh households, this is equivalent to benefits worth 1.14 billion per year which are to be compared to the annual costs of meeting the WFD targets.

1.3. Research structure and challenges

In order to measure the wider benefits generated by river restoration projects, this research has been structured in the following way:

- It starts by aiming to evidence how projects address key pressures on river ecosystems.
- It subsequently aims to measure how this translates into measurable biophysical structure changes, including among others chemical composition of water and biological diversity.
- It then considers how biophysical changes translate into changes into improved ecosystem services and socio-economic benefits (values) for affected stakeholders.

Figure 2: A graphic representation of key methodological steps[11]



This process is not without significant challenges. The challenges faced are similar to the ones faced by previous studies:

- Firstly, it is challenging to link specific activities with chemical and biological improvements. Indeed, this exercise requires the availability of comparable chemical and biological data before the intervention, and after the intervention. Even when this data is available it can be difficult to causally link specific project components (e.g. water course fencing) with measurable indicators (e.g. reduction of phosphates).

- Secondly, it is equally challenging to link chemical and biological data with ecosystem services. For example, it can be challenging to derive how much a change in Nitrogen content impacts on provisioning services, and subsequently on tourism, in a specific freshwater ecosystem. As such, secondary assumptions are often required to make the link between scientific data and respective ecosystem services. This is done through the use of previous studies having linked components of biodiversity with ecosystem function (e.g. impacts of alien species abundance on water flow)[12].

Because of these inherent complexities, this research does not aim to provide exact estimations on future developments. Rather, it provides a range of likely values and benefits supported by river restoration projects.

2. MAPPING THE IMPACTS OF WRT'S INTERVENTIONS

This section outlines the characteristics of respective River Improvement Projects (RIPs) considered in this analysis, and presents a conceptual theory of change framework for understanding the change expected as a consequence of RIPs. The conceptual theory of change presented in this section, and its links to the ecosystem services framework, constitutes the starting point for the quantitative analysis.

2.1. The context

Despite notable improvements in the chemical and biological quality of South West surface water bodies since the 1990s, only 33% of water bodies achieved a good ecological status and 51% a good biological status in 2012[13]. The drivers of poor ecological and biological quality have been assessed to be:

- Diffuse pollution from agriculture
- Diffuse pollution from mines (disused mines)
- Diffuse pollution from industries
- Physical modification and alteration of rivers, for meeting various human needs (urbanisation, flood protection, land drainage, etc.)
- Water industry sewage works
- Water abstraction

Beyond the necessity to adhere to the Water Framework Directive (WFD) objectives, protecting and restoring rivers is of critical importance to the South West's economy. For example, tourism in the South West is largely driven by its natural environment, and tourism represents 22% and 11% of total FTE jobs in Cornwall and Devon respectively. Similarly, approximately 50% of England's fisheries are located in the South West, and these are dependent to a large extent on freshwater and saltwater quality, and on biodiversity. Finally, angling supports £51m of Gross Value Added and 2300 FTE jobs in the South West[14]. As such, maintaining and improving the ecosystem services provided by river catchments is of critical importance not only for environmental reasons *per se* but equally for the South Western social economy.

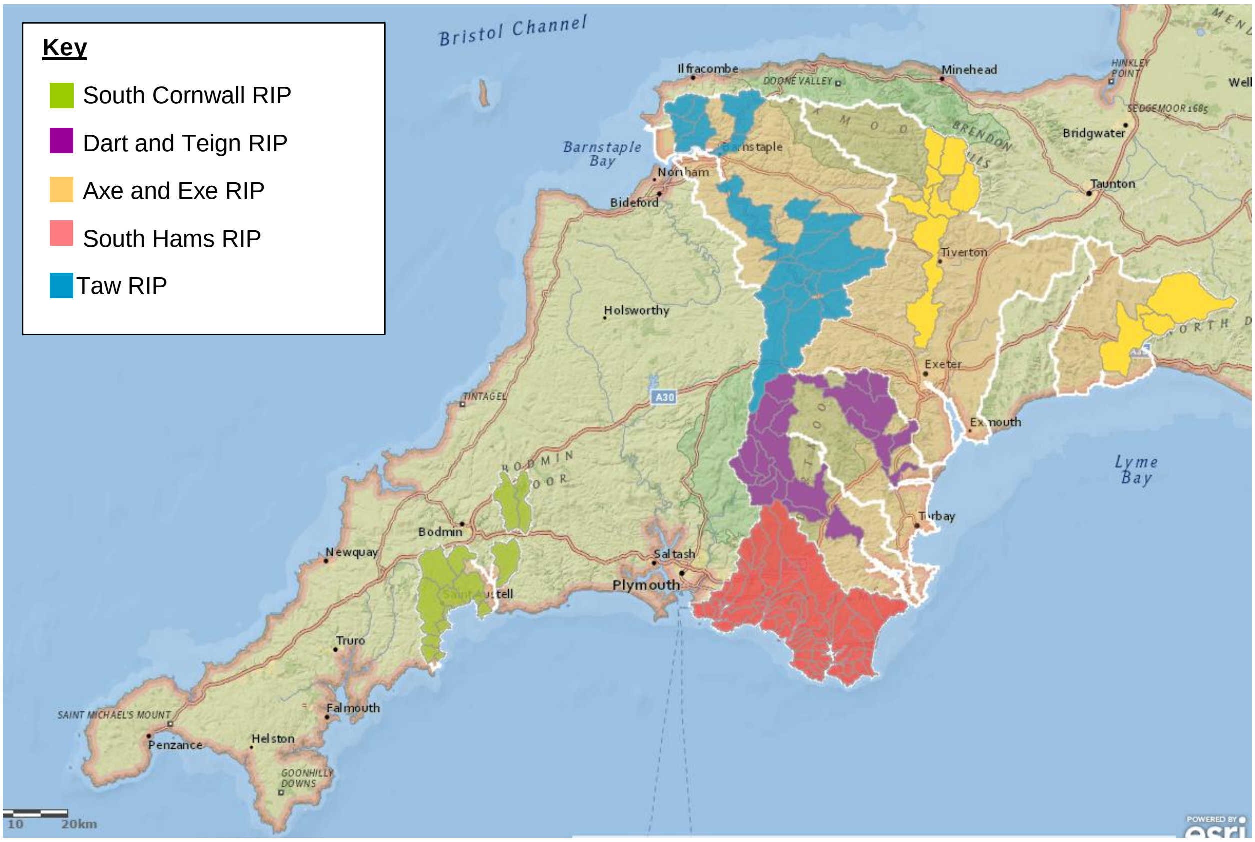
WRT's projects aim to respond both to the key drivers of water quality degradation and biodiversity loss as well as to the need of preserving ecosystem services and their impacts on human society and economy.

2.2. The projects

WRT funds five projects through the Catchment Restoration Fund:

- The South Cornwall River Improvement Project (**SCRIP**), which aims to restore the habitats of the Par, St Austells, Mevagissey, Warleggan, St Neot, Avon and Crinnis rivers as well as of the Polmear, Gorran, Portmellon, and Bokiddicks streams
- The Axe and Exe River Improvement Project (**AERIP**)
- The Dart and Teign River Improvement Project (**DTRIP**
- The South Hams River Improvement Project (**SHRImP**), which aims to restore parts of rivers Avon (Devon), the Erme and the Yealm
- The Taw River Improvement Project (**TRIP**)

Figure 3: Map of respective projects and catchment areas
White outlines give catchment areas; coloured sections are areas in which WRT works.



The objectives of respective projects consist of:

a) Improving water quality (reducing diffuse pollution),
b) Improving biological diversity
c) Improving wider riparian ecosystem conditions in respective catchment areas.

These objectives are evidently intertwined: for example, water quality improvements affect biological diversity and vice versa.

Each project carries out multiple activities to achieve these objectives. Broadly following the FORECASTER typology developed by REFORM, WRT's project activities in respective catchments can be divided into three types: (1) Improving longitudinal connectivity of rivers, (2) In-channel structure and substrate improvement, and (3) Riparian zone improvement. Project activities and resulting outcomes are described below:

1. Improving longitudinal connectivity of rivers
Structures in the river such as weirs and culverts act as artificial barriers, affecting water flow, sediment transport and habitat conditions both up- and downstream. In addition, barriers spanning the width of the river channel can immediately isolate contiguous river segments. This habitat alteration is problematic as the modification of natural flow alters the environmental triggers for fish migration and can ultimately severely reduce the amount of fish in the river[15]. Migrating fish rely on energy reserves built up in the marine environment. These reserves are limited: barriers that delay fish passage or require increased energy usage to cross limit the amount of energy fish have for mating and reproduction. Therefore even when

a structure does not constitute an absolute barrier, it can be detrimental to fish stocks – especially where multiple barriers exist on the same waterway.

In some cases, it may be appropriate to **remove the culvert/weir**. However these are often historical structures or have an important human function. In this case, it may be more appropriate to **install fish/eel passes** which enable fish migration. This will improve likelihoods of fish migration but may not improve physico-chemical capabilities such as sediment transport.

2. In-channel structure and substrate improvement

As described in section 2.1, multiple pressures have degraded instream habitats for fish and other biota. These are addressed by WRT projects. For example, water pollution from agricultural activities can lead to sedimentation of gravel at salmon spawning sites; an increase in fine sediment in spawning gravels causes decreased survival and emergence of salmonid eggs and young fish. Salmonid fish are very susceptible to sediment pollution because they build their nests at the stream bottom: eggs rely on a steady flow of clean water to deliver oxygen which may be disrupted if gaps between gravel are clogged by sediment. Similarly, juvenile salmon hide in interstitial gaps in streambed gravel, as does their food: if sediment clogs these spaces they lose their source of cover and food. **Spawning gravel can be augmented by cleaning** which encourages a healthy environment for salmonid spawning; it is also important to deal with the sources of sedimentation, through riparian zone improvement as described further on.

Another focus of in-river work aims at increasing structural physical diversity with the aim of promoting biological diversity[16]. For example, the **introduction of substrates such as large woody debris or boulders** can provide a key habitat for fishes and benthic macroinvertebrates whilst also stimulating habitat diversity (such as the creation of pools) by diversifying hydraulic conditions. Finally, artificial structures such as deflectors can be used to manage water flow diversity and erosion/deposition of sediment to manage in stream conditions.

3. Riparian zone improvement

Work in the riparian zone is concerned with mitigating the adverse impacts of land use (particularly farming) adjacent to streams and rivers. This is achieved through working closely with farmers. WRT carries out **soil tests** to identify the extent to which fertilisers and pesticides are likely to cause diffuse pollution in water runoff into the river. It then develops **farming management plans** in conjunction with farmers to minimize pollution; this may involve recommending changes to fertilizers used, or the creation of buffer strips at riverside to retain plant nutrients, fine sediments and toxic substances that may enter streams via surface run off. Where appropriate, **fencing is installed** where fields are grazed by livestock. This helps reducing both faecal contamination and stream bank damage, which impact on water quality (e.g. sedimentation).

Riparian vegetation also needs to be managed, whether on farms or public land. Trees provide both organic material (food) and shade (habitats) for instream biota. **Coppicing** encourages rapid regeneration, promotes tree health and helps to stabilize the river bank.

Table 4 summarizes the key activities undertaken in respective catchment areas, and the rationale for undertaking these (or outcomes expected).

Table 4: key activities and rationale

Activity	Rationale / outcome	SCRIP	TRIP	SHRIMP	DTRIP	AERIP
Eel and fish pass installation	Facilitate fish migration	X	X	X	X	X
Culvert/small weir removal	Removal of barriers to fish migration and improve longitudinal connectivity of river	X	X	X	X	
Culvert replacement /drowning outfall/low cost fish easements	Removal of barriers to fish migration and improve longitudinal connectivity of river	X	X	X	X	
Spawning gravel augmentation / gravel cleaning	Improve fish spawning environment and survival rates for juvenile salmonids	X	X	X	X	X
Managing in-river woody debris	Improve in-channel structure for fish and other biota; increase habitat diversity	X	X	X	X	X
In river features boulders and deflector	Improve in-channel structure for fish and other biota; increase habitat diversity	X	X	X	X	
Coppicing of bankside trees	Reduce bank erosion and improve riparian environment	X	X	X	X	X
Soil testing and farm advice plans	Improve water quality by changing agricultural practices and reducing phosphates (and other chemicals) run off	X	X	X	X	X
Farmyard practice management	Improve water quality by reducing phosphates run off and improving riparian habitats	X	X	X	X	X
Water course fencing on agricultural land	Improve water quality and reduce bank erosion by reducing river poaching by livestock and preventing run-off from farms	X	X	X	X	X
Interpretation/education boards	Educating local users and stakeholders	X		X	X	

These activities are not undertaken across the board in respective catchment areas. Rather, targeted interventions are selected on the basis of a) chemical and biological criteria (indicators for fish density and water quality), b) river connectivity, c) wider riparian ecosystem conditions and d) land-use. These criteria are used for identifying “hotspots” for action, and determine the location of individual activities in catchment areas. The process followed by WRT projects responds to the fact that not all sections of a river or catchment has the same quality: while some sections may achieve good quality (according to WFD criteria), others do not. Similarly, while some stretches of a river may achieve a good chemical status (low level of priority substances), the same stretches may fail to achieve good status in terms of biology or hydromorphology[17].

2.3. Mapping impacts and benefits

Although the feedback loops between the different activities and the environmental outcomes expected are numerous, complex, and ultimately non-linear, the links between activities, short-term and longer terms outcomes were mapped in a theory of change framework (Figure 6 below). The theory of change was used as a starting point for 1) mapping out benefits against the ecosystem services framework, 2) determining which of these benefits can be valued in the analysis of respective projects (and which not) and finally 3) for determining which key chemical and biological impacts should be tracked for valuing the extent to which significant impacts on ecosystem functions are to be expected from these interventions.

The benefits mapped in the theory of change are not exhaustive, and may exclude numerous indirect impacts of the projects. For example, improved land management and vegetation restoration in catchment areas may increase carbon sequestration or reduce greenhouse gas emissions. Similarly, an additional stakeholder may be the Environment Agency, in the sense that failure to comply with the WFD objectives may entail a penalty for British taxpayers. However, these societal benefits were deemed less material (less significant) in terms of their impact and relevance to this study.

Overall, most benefits identified are related to improved water quality, increased fish stocks and improved wider ecosystem conditions (e.g. landscape value). However there are other additional knock-on benefits, among which:

- Improvements in wider catchment area ecosystems and increase in fish population may provide revenue to commercial anglers, as well as recreational benefits. They may equally affect bird populations and density. In turn, this could translate into further benefits for recreational users (e.g. bird watching activities);
- Improvements in water quality may provide direct benefits to water companies who will have reduced water cleaning costs;
- Improvements in water quality and overall base flow and connectivity of rivers may also affect the ecology of respective estuaries (e.g. reduced dredging) and activities in estuaries: these include recreational activities, and mussel farming.
- Improvements in water quality and overall base flow and connectivity of rivers may finally affect the ecology of coastal ecosystems, and thus positively impact on both recreational (bathing) and commercial (saltwater fisheries, coastal tourism industry) activities.
- Improvements in on-farm management which (beyond affecting water quality) may improve soil condition and thus impact on the revenue of farmers;
- The general habitat quality of the ecosystem may have value to the local and wider community beyond that which is marketable: non-use and option values.

Finally, this framework is overarching; not all activities and benefits presented are applicable to all interventions and all rivers. For example, some rivers and streams located in South Cornwall (SCRIP project) are only marginally used for angling. Similarly, not all rivers and streams provide water for consumption.

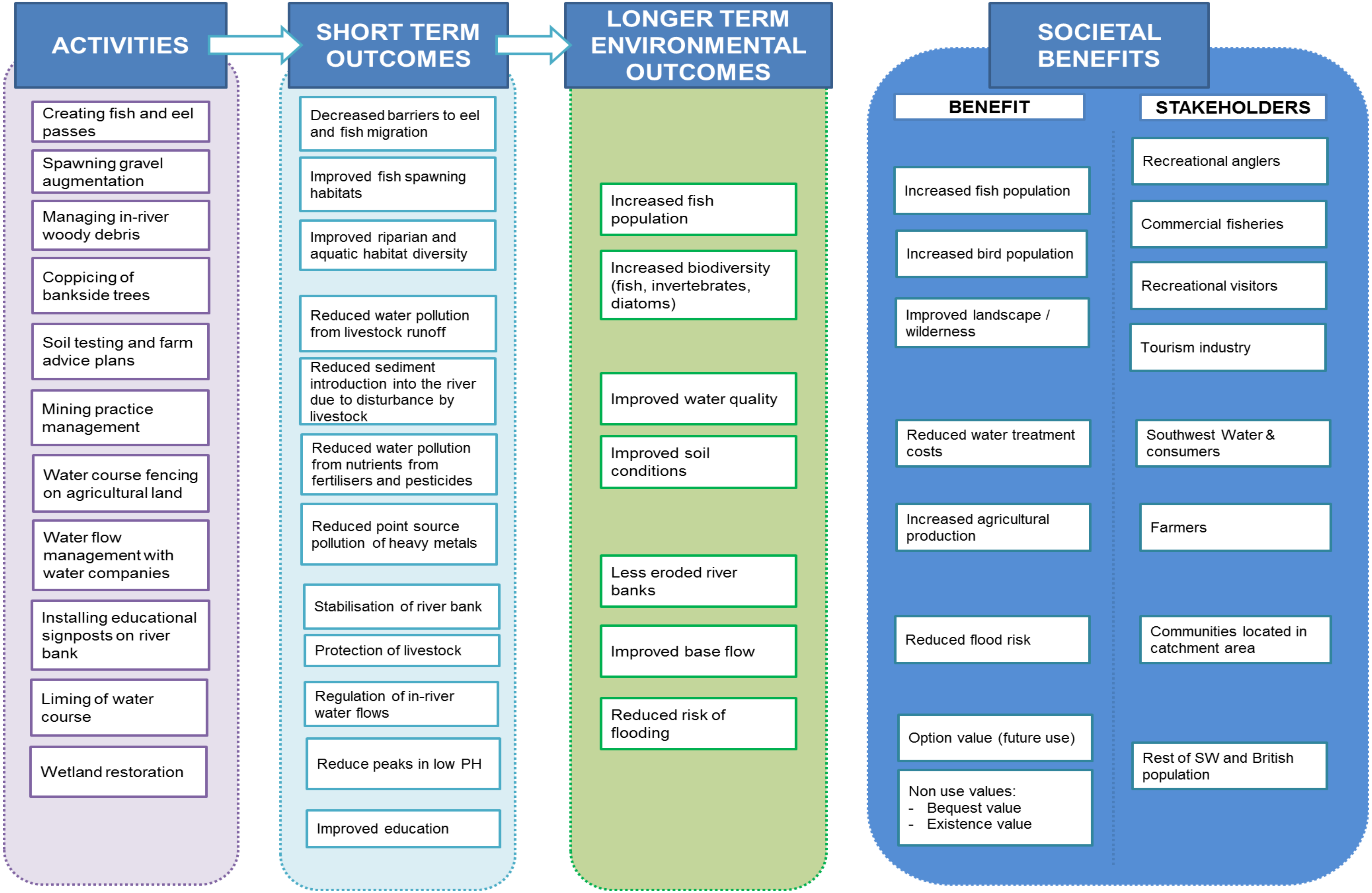

ACTIVITIES
Creating fish and eel passes
Spawning gravel augmentation
Managing in-river woody debris
Coppicing of bankside trees
Soil testing and farm advice plans
Mining practice management
Water course fencing on agricultural land
Water flow management with water companies
Installing educational signposts on river bank
Liming of water course
Wetland restoration
SHORT TERM OUTCOMES
Decreased barriers to eel and fish migration
Improved fish spawning habitats
Improved riparian and aquatic habitat diversity
Reduced water pollution from livestock runoff
Reduced sediment introduction into the river due to disturbance by livestock
Reduced water pollution from nutrients from fertilisers and pesticides
Reduced point source pollution of heavy metals
Stabilisation of river bank
Protection of livestock
Regulation of in-river water flows
Reduce peaks in low PH
Improved education
LONGER TERM ENVIRONMENTAL OUTCOMES
Increased fish population
Increased biodiversity (fish, invertebrates, diatoms)
Improved water quality
Improved soil conditions
Less eroded river banks
Improved base flow
Reduced risk of flooding
SOCIETAL BENEFITS
BENEFIT
STAKEHOLDERS
Increased fish population
Recreational anglers
Increased bird population
Commercial fisheries
Improved landscape / wilderness
Recreational visitors
Tourism industry
Reduced water treatment costs
Southwest Water & consumers
Increased agricultural production
Farmers
Reduced flood risk
Communities located in catchment area
Option value (future use)
Non use values:
- Bequest value
- Existence value
Rest of SW and British population

Table 5 maps the identified benefits against the Ecosystem Services framework, while distinguishing use values (i.e. benefits accruing to stakeholders as a consequence of using rivers and riparian ecosystems) from non-use values (benefits accruing to those who do not use the ecosystems in question). Benefits to be included in the analysis were selected on the basis of 1) available environmental data and 2) available socio-economic data.

Table 5: Benefits mapped against ecosystem services
*(*** indicates values which could be measured in the context of this study)*

	Provisioning services	Regulating services	Cultural services	Supporting (habitat) services
Direct use values	Value of fish stocks *** Value of clean freshwater *** Value of timber Value of increased farm revenue*** Value of tourism supported ***	*N/A* *All use values provided by regulation services are indirect*	Value of angling (recreational) *** Value of other recreational activities*** Value of education	*N/A* *All use values provided by supporting services are indirect*
Indirect use values	*N/A* *All values provided by provisioning services are direct*	Value of flood protection Soil formation (agricultural land) Local climate regulation	*N/A* *All values provided by cultural services are direct*	Value of habitat for fish (for spawning, nurseries for juveniles etc.) Value of habitat for birds and other species
Non-use values	• Value of the knowledge resources will be available for future generations (bequest)*** • Value of preserving the resource for future use*** • Value of the knowledge of the existence of fish species, bird species, and river ecosystems***			

The existing environmental data did not allow us to include biodiversity, climate regulation or habitat values in the quantitative analysis. This is because the causal links between the activities undertaken and these benefits are complex and multifaceted, and thus could not be quantified without the use of heroic assumptions.

Similarly, the links between in-channel / connectivity river interventions and reduced flood risk were not deemed quantifiable in this context. This is due to a lack of sufficient empirical data for the specific rivers considered in this analysis, which prevented us to assess how the projects could affect flood-prone areas in respective catchments.

In short, the ecosystem services which could be considered in this analysis were provisioning and cultural ones. Both can overlap: for example, an increase in fish numbers can translate into a higher recreational value (well-being) for anglers (a cultural service), while boosting the value of local and regional tourism income (a provisioning service) as a consequence of an increased number of Anglers.

Similarly, multiple values may be involved for a same ecosystem service. Social groups which may never visit or benefits directly from using respective rivers may nonetheless value the existence of these ecosystems intrinsically (existence value); they may value the preservation and improvement of the ecosystems in view of future use (option value); they may be finally willing to preserve them for future generations (bequest value). In short, non-users may also derive well-being benefits from river improvements.

Box 3: Example of evidence on the importance of non-use value

Spurgeon et al (2001) conducted a willingness-to-pay study for 1) the maintenance and improvement of the river Wye's fish population and 2) for the reconstitution of Salmon population in the river. Two separate surveys were used, one with Anglers (users), and one with the general public (non-users). Survey results suggested that Anglers were willing to pay from £2.50 to £4.77 (£2001) per trip, on top of their regular expenditures. The general public survey found that each household was willing to pay an average of £3.36 per year for maintaining and improving the fish population of the River Wye.

Existing surveys and previous studies conducted in the South-West region allowed us to include these non-use values in the analysis for considering the benefits supported for the wider population of the South-West.

2.4. Testing the hypothesis

This section formulated the conceptual hypothesis to be tested in a quantitative way. The next section deal with quantifying the changes brought about by river improvement projects. More specifically, section 3 tackles changes in ecological dimensions by looking at the likely impact in terms of water quality and increased fish population (for which data was available). Subsequently, section 4 translates changes in ecological conditions into socio-economic benefits before contrasting those benefits with costs.

3. QUANTIFYING THE ECOLOGICAL IMPACTS

This section examines potential and realised ecological improvements on the river ecosystems as a result of the River Improvement Projects. Measuring ecological impacts is necessary for measuring socio-economic impacts. Indeed, it would be impossible to estimate socio-economic benefits without an estimation of which ecological improvements may occur, and how much these improvements represent in quantitative terms.

Secondary literature was used to provide an estimation of impacts where direct data was not available. Chemical and biological indicator data for the project catchment areas provides a baseline of initial conditions. The net impacts of the projects are calculated, taking into account the counterfactual, meaning what would have happened in the absence of the projects, given current trends. Through this approach we also determined the effect of improvements in chemical and biological quality on the Water Framework Directive's ecological status classification.

3.1. Review of ecological impacts of river restoration measures

A primary estimation of the environmental impact of river improvement measures would require a) baseline data collection on a range of biological and chemical indicators and b) post-project data collection on these indicators. The latter would need taking into account the time lags between specific interventions and environmental improvements. To this date, WRT's data collection systems are not tailored to assessing the impacts of interventions per se. Electrofishing surveys, diatom measurement and water quality measurement are undertaken for planning purposes (e.g. selecting areas of action in respective river catchments) rather than evaluation ones. As such, this study has relied on a combination of a) primary baseline data and b) secondary post-intervention data.

In short, the ecological impacts of river restoration measures were determined through secondary literature and information on similar projects undertaken in the past. There are multiple syntheses on the effects of river restoration, for example Roni et al 2014[18], Feld et al, 2011[19] and the REstoring Rivers FOR effective catchment Management database[20]. Case studies from Europe and around the world were examined to forecast the range of potential improvements to biota and water chemistry of individual measures.

As aforementioned, WRT's activities can be divided into three types, based on where they occur and the processes targeted for improvement:

1. **Improving longitudinal connectivity of river**, such as removing weirs and other barriers to fish and other freshwater organism passage, or creating passages on existing structures to aid migration.

2. **In-channel structure and substrate improvement** to enhance instream mesohabitats for fish and other biota. For example placement of large woody structures and cleaning of fish spawning gravel. In general, such measures aim to increase structural physical diversity and thus promote biological diversity.

3. **Riparian zone improvement**, primarily aimed at mitigating the adverse impacts of agricultural land use adjacent to rivers. Riparian zone improvement can include the adjustment of riparian zone land to reduce undesired nutrient and sediment input into

the river, restore riparian vegetation and processes and improve bank stability and instream conditions. This includes coppicing of bankside vegetation, fencing of bankside agricultural land or the creation of buffer zones, and changing agricultural land use to reduce diffuse pollution.

Appendix 2 details a variety of studies giving quantitative estimates of the effects of various measures in previous studies, and the following table briefly summarizes these results to give a range of likely impacts.

Table 6: range of impacts of measures on biota and chemistry of river

Measure	Range of impacts
Improving longitudinal connectivity of river	Fish: Up to 200% increase in number of fish. Conservative estimates suggest a 50% increase. Where there were previously no fish, increases range from 0.009/m2 – 0.35/m2.
In-channel structure and substrate improvement **- in river woody debri management** **- gravel augmentation**	Fish: Increase in fish abundance ranged from 0% - 216% but was highly dependent on additional hydromorphological factors and sediment flow characteristics. The majority of studies found increase of around 30% - 60%. Other biota: mixed results for effects on macroinvertebrates, with most studies finding no change in species abundance, and in some cases changes in species richness ranging from 0 – 10%.
Riparian zone improvement **- riverside coppicing** **- riparian fencing** **- farming management practices**	Fish and other biota: Minimal effects have been found on fish and other biota as a direct result of riparian zone improvement. This may partly be because in most studies experimental design or duration is not adequate to capture these effects (Roni et al, 2012). We will not aim to capture this relationship in our study. Sediment and dissolved oxygen: Various riparian zone measures reduce sedimentation by 9 – 20%. Matlock et al (2003) found in a study that sediment oxygen demand was responsible for 50% oxygen depletion in streams studied. Therefore a 9 – 20% reduction in sedimentation may result in a 5 – 10% reduction in oxygen depletion. Nutrients: When farm management plans (including riparian fencing and agricultural land use management) are taken up, studies suggest a 40-50% reduction in polluting nitrogen and phosphorous, if all farmers take up suggested plans - although this is dependent on levels and sources of agricultural pollutant used in the first place. Studies suggest that around 30% of farmers take up plans, suggesting an overall 12 – 15% reduction.

Many projects (and indeed WRT's River Improvement Projects) do not implement a single measure in isolation. Rather, multiple activities are undertaken at the same time within a given catchment. The combination of measures can have additive or synergistic effects, greatly affecting the ecological effects of the measures as well as the economic return on investment gained by the restoration.

Table 7 presents the ranges of impacts identified in the existing literature, which can be expected as a consequence of WRT's intervention.

Table 7: Estimated impact

Variable	Impact (median estimate)
Fish	0 – 416% (80%)
Other biota	0 – 10% (5%)
Dissolved O2	5 – 10% (7%)
Nutrients	12 – 50% (30%)

The literature suggests there is a wide variation in terms of the magnitude of impact of similar interventions in other sites. For example, fish concentration can be expected to increase from zero to 400% - depending on the site, the external factors enabling and preventing this change from occurring and the wider conditions of the ecosystem. Despite the uncertainty, this study has used the median estimate (among a variety of previous research) for forecasting potential impacts of the projects on chemical and biological conditions.

3.2. Estimating impacts of the River Improvement Projects

3.2.1. Impact on water quality

The Environment Agency regularly samples multiple indicators of water quality on several sites within River Improvement Catchments for the rivers Axe, Exe, Teign, Avon and Taw. Yearly data is available up to 2012. Data includes all indicators the Water Framework Directive specifies to determine the physic-chemical characteristics of ecological status (pH, Dissolved Oxygen, ammonia and soluble reactive phosphorous.)

Data for 2012 (when the projects started) is used as a baseline, and WFD thresholds are applied to determine initial ecological status. In each case, the levels of phosphorous are the limiting factor.

Table 8: chemical indicators of ecological status in 2012, Environment Agency data

	Values				*Classification*				
River	pH	Dissolved oxygen	Ammonia	Phosphorous	pH	Dissolved oxygen	Ammonia	Phosphorous	**Overall chemical classification**
AXE	8.0	95.8	0.09	93.9	High	High	High	Moderate	**Moderate**
EXE	7.8	100.2	0.03	22.8	High	High	High	Good	**Good**
TEIGN	7.6	96.7	0.03	43.5	High	High	High	Good	**Good**
AVON	7.8	96.5	0.03	24.1	High	High	High	High	**High**
TAW	7.7	95.0	0.03	20.5	High	High	High	High	**High**

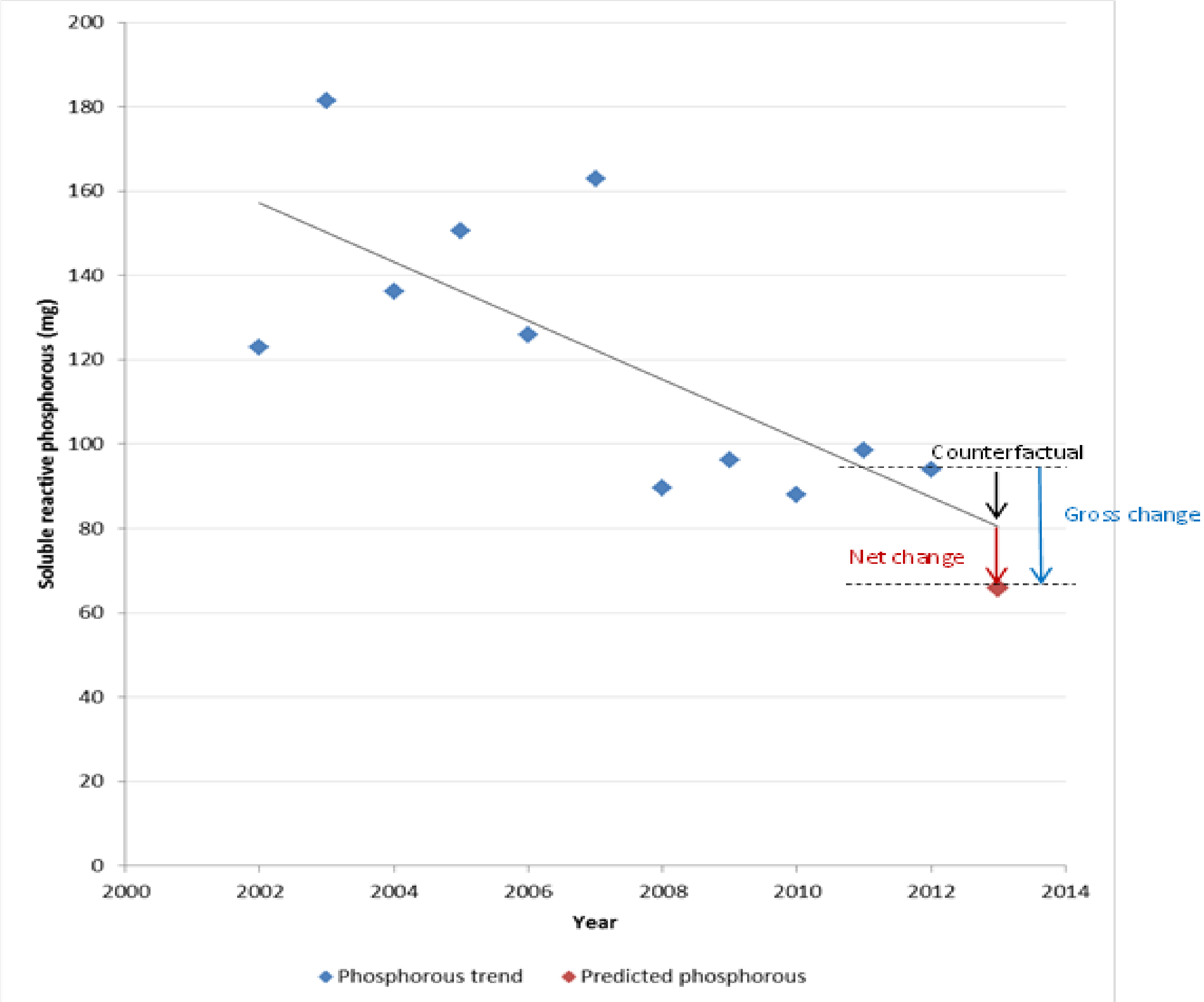
Gross change of the river improvement projects is calculated using the median estimates of river restoration measure impacts detailed above. Literature was not found for the impacts on pH, and it is not a limiting factor for these rivers so is not included. The results are positive, and suggest that the river improvement projects will lead to an increase in chemical ecological status for the Axe and the Exe.

Table 9: predicted gross impact of projects on chemical indicators of ecological status

	Change in variable			Classification			
River	7% reduction in oxygen depletion	30% reduction in ammonia pollution	30% reduction in phosphorous pollution	Oxygen	Ammonia	Phosphorous	**Overall chemical class**
AXE	96.09	0.06	65.74	High	High	Good	**Good**
EXE	100.16	0.02	15.98	High	High	High	**High**
TEIGN	96.88	0.02	30.45	High	High	Good	**Good**
AVON	96.75	0.02	16.86	High	High	High	**High**
TAW	95.36	0.02	14.35	High	High	High	**High**

However, the data above does not present the full story. We also need take into account what would have happened regardless of whether WRT carried out river improvement activities (the counterfactual). For example, phosphorous levels in South West rivers have been decreasing over the course of the last decade. Therefore it is reasonable to predict that even without WRT's intervention, phosphorous levels would have decreased – although not as much as with WRT's involvement.

Figure 5: Illustrating the counterfactual trend for phosphorous using the river Axe as an example



Counterfactual predictors for all indicators were calculated using average data from all rivers over time. If we assume rates of improvement continue following intervention at a similar rate as before, the counterfactual can also be used to forecast continued change, as in the continuation in the graph above of the trendline.

3.2.2. Impact on fish

WRT has collected data on most of the rivers in 2012 and/or 2013, which provides a baseline for our study. All projects have data for at least one river except SCRIP. A semi-quantitative electrofishing survey method is used to establish the relative abundance of salmon fry, classified by the number of fry caught within five minutes, following Crozier and Kennedy[21] (table 10). Rivers are sampled across multiple points, and results have been averaged across each river for the purposes of this study. Table 11 displays the results in the baseline year compared to 2014.

Table 10 – Semi-quantitative abundance and their relationship to quantitative electrofishing densities (Crozier and Kennedy[22])

Density classification	Semi-quantitative (number caught in 5 minutes)	Quantitative abundance equivalent (number per 100m^2)
A (excellent)	> 23	> 114.7
B (good)	11 – 23	69.1 – 114.6
C (fair)	5 – 10	41.1 – 69
D (poor)	1 – 4	0.1 – 41.0
E (absent)	0	0

Table 11 – Average salmon fry caught in electro-fishing surveys, baseline years (where available) and 2014

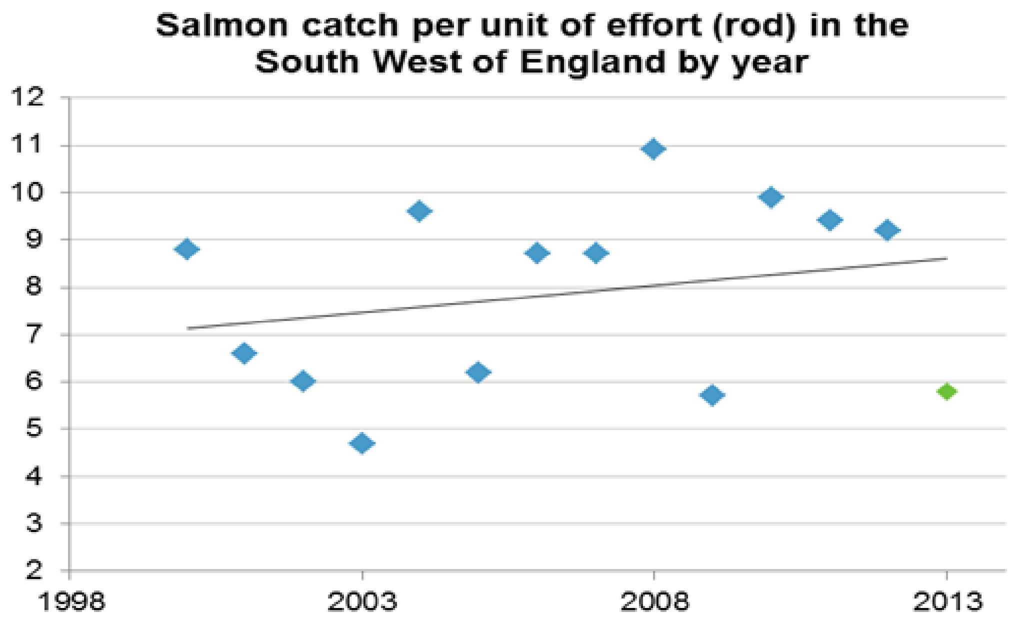
River	Baseline year	Average salmon fry caught	Classification (baseline)	Average salmon fry in 2014	Classification (2014)	Gross change
Axe	2012	0.0	ABSENT	0.2	ABSENT	0.2
Exe	-	-	-	7.5	FAIR	-
Dart	2012	9.6	FAIR	18.1	GOOD	8.5
Teign	2012	11.5	GOOD	4.1	POOR	-7.4
Avon	2013	3.9	POOR	5.2	FAIR	1.3
Erme	2013	4.0	POOR	3.6	POOR	-0.4
Yealm	-	-	-	2.25	POOR	-
Taw	2013	4.0	POOR	9	FAIR	5.0

Results are mixed: the Axe, Avon and Erme show little change, whilst the Dart has seen an increase and the Teign a decrease. It is worth noting that this data is a measure of the change in the average number of salmon fry caught in a 5 minute window at various sites across each river, but the sites measured do not always remain the same between years. In addition, in the case of several rivers (for example the Erme), data is only available for one site in the baseline year and thus data may not provide an accurate picture of the whole river. Nevertheless, this is the best data we have to work from.

In general, salmon levels are poor. Salmon are highly sensitive to multiple river conditions, including hydromorphology, spawning habitat quality and water quality, and thus multiple factors may be impacting these results. As physico-chemical conditions in the river improve, there may be more consistent increases in the number of salmon.

In addition, examination of trend salmon rod catch data in the South West from the Centre for Environment, Fisheries and Aquaculture Science's (CEFRA)[23] annual report, suggests that there may have recently been some kind of adverse shock for salmon in the region, such as heavy water flows. The data reveal a recent dip in the number of salmon: mean catch per 100 days fished – a measure known as catch per unit of effort – fell in the South West 2013 by 36%, despite an overall year on year increasing trend.

Figure 6: Evolution of catch per unit of effort



To predict possible future impacts, results from 2014 are converted from relative abundance to absolute abundance using table 11 and data on river length, assuming an average width of 3 meters. A conservative multiplier based on the secondary literature is applied (see section 3.1 above) to give the gross outcome. The net outcome due to WRT's activities (ie.net of what would have happened with no intervention) is calculated using long term trend data from CEFRA (as above) suggests an average increase of 11% of salmon due to river improvement projects as a sensible estimation. This trend is also used to model ongoing increases in fish levels.

3.3. Caveats on environmental projections

No attempt has been made to distinguish location of interventions. Position on water course, upstream or downstream, can have a significant effect on the efficacy of an intervention. However, studies do show that interventions can have an impact upstream as well as down. For example, water pollution can diffuse in both directions. In addition, fish passes have been shown to aid fish passage both up and downstream[24].

Some variables may present limits. For example, nutrients are unlikely to be reduced at a constant rate forever before hitting zero, and it is unlikely that the chemical response (and indeed the biological response) is linear.

This section outlined the approach used for calculating quantitative estimations of environmental impacts. The large uncertainties regarding key environmental impacts are due to the lack of reliable longitudinal data for gauging the actual impacts – comparing indicators before the projects and after the projects. Despite these uncertainties, the existing literature suggests that environmental impacts of similar projects are significant; the only question mark relates to the magnitude of the change to be expected.

Even when using conservative estimates, the impacts of the projects on water quality and fish density are likely to be non-negligible. For those rivers for which quantitative information was unavailable, we used an average drawn from other rivers' indicators.

4. COST-BENEFIT ANALYSIS

This section brings together the information and analysis presented in the previous sections: it translates environmental improvements into socio-economic benefits and subsequently contrasts those with costs to derive a range of potential socio-economic returns of river improvement projects.

As aforementioned, although there is certainty that river improvement projects will translate into positive environmental and socio-economic impacts the magnitude of that change is more uncertain. For avoiding "false accuracy" we provide a range of estimate through extensive sensitivity analysis. Sensitivity analysis aims to answer the following questions: under which conditions can river improvement projects be considered socio-economically efficient from a Cost-Benefit standpoint? Do river improvements projects pass a Cost-Benefit test even under a worst case scenario (i.e. whereby the most pessimistic assumptions materialize)?

4.1. Benefits and costs

Table 11 outlined how benefits were measured, and Figure 7 graphically presents the way we modelled benefits, by linking ecological data to socio-economic impact data and finally monetary values.

Table 11: Description of benefits measured

Ecosystem Service	Benefit	Outline description
Provisioning	Value of additional fish catch (commercial fisheries)	Based on the estimation on increase of fish population in respective rivers (section 3) & estimations of current commercial fish catch (if and where applicable), we modelled 1) the value of increased catch and 2) the knock-on regional economic effects of this increase (gross value added) and employment multipliers)
	Value of clean freshwater (consumers and public utility companies)	Based on the estimations on improved water quality (section 3) we used a previous study estimating the willingness to pay of local residents for a) reductions in Ammonia and Biological Oxygen Demand and b) increase in dissolved oxygen, to calculate the value of improved water quality. Due to a lack of available data, the value to public utility companies could not be estimated (see Appendix 3 for the rationale)
	Value of increased farm revenue (farmers)	Based on estimations on a) reduced soil loss due erosion, b) reduction of chemical fertilizer input and manure (reduced nitrogen and phosphates), and c) other savings (water, spray etc.) we calculated the increased economic returns to farmers
Cultural	Value of recreational angling (Anglers)	Based on empirical research, we obtained an estimation of the additional number of anglers that may visit respective rivers if river ecosystems are improved. Combining this empirical data with secondary research, we calculated the additional amount Anglers would be willing to pay (on top of their current expenditures) for improvements in fish density and water quality
	Value to other recreational visitors	Based on empirical research, we obtained an estimation of the additional number of non-angler recreational users that may visit respective rivers if river ecosystems are improved. Combining this empirical data with secondary research, we calculated the additional amount non-Anglers would be willing to pay (on top of their current expenditures) for improvements in fish density and water quality
	Value of total tourism supported (tourism industry and wider SW economy)	We used the data obtained for recreation (empirical) in order to estimate the additional Gross Value Added (GVA) flowing to the SW economy, and the additional FTE employment supported – as a consequence of river improvement projects
All services	Existence, bequest and option values	Using secondary research, we estimated the average willingness to pay per household in the SW for improving river conditions to WFD standards. This represents to willingness to pay of households which do not necessarily use rivers – and as such are a good indication of non-use values supported

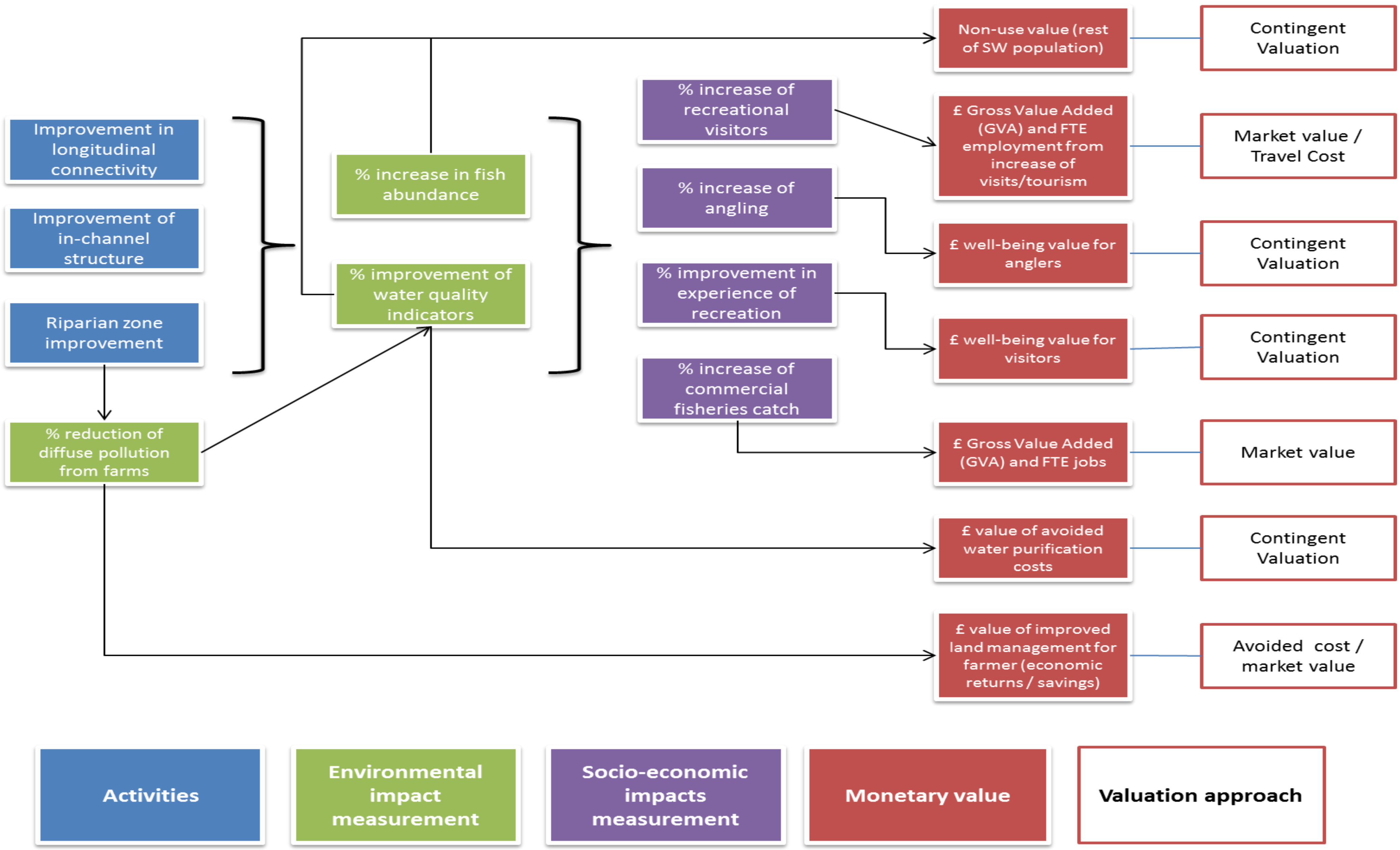
All percentage increases are net increases, i.e. they take into account the counterfactual as explained in Section 3. Appendix 3 explains in further detail the assumptions required for measuring and valuing socio-economic impacts.

The indicators selected combine both market and non-market valuation. For example, tourism supported reflects additional visitor expenditures in the local areas, and its potential knock-on effects in terms of Gross Value Added and employment. This is calculated through an estimation of anglers' and other recreational visitor expenditures. On the other hand, the recreational (well-being) value accruing to anglers and other recreational users is calculated through the Willingness-to-Pay of anglers and other recreational users for improved river quality. This is on top of their actual expenditures to reach and enjoy the respective sites.

The avoided market costs of water purification, such a Nitrates removal, could not be estimated due to a lack of publicly available information (see Appendix 3 for details). As such, we used previous estimations on the annual willingness to pay of local residents for improvements in water quality, such as decreased Ammonia content. In addition to this benefit for local residents (who are also water consumers), there are benefits accruing to Southwest Water via a reduction of water treatment costs. However, this benefit was left out of the equation given the lack of reliable data for respective catchment areas.

This model was used for measuring both the benefits generated by respective individual projects and the total benefits of WRT's projects in conjunction. The model equally allowed us to vary some key assumptions derived from secondary research in order to elicit the sensitivity of benefits, i.e. examining the variation of benefits depending on the assumption used.

Figure 7: Overview of the model for calculating benefits



In some scenarios, some of the most uncertain benefits were left out of the equation to examine whether their exclusion is critical or not. Some key assumptions, however, could not be avoided:

- **Linearity**: Both ecological and socio-economic developments may be non-linear. Equally, the relationship between ecological and socio-economic developments may be non-linear (non-proportional). In this study we assume both linearity and proportionality.

- **Incrementality**: The benefits (over and above the counterfactual) are assumed to be constant over time, i.e. there is not distinction between, say, the impacts of the projects in year 3 and the impacts in year 5. Clearly, there may be an incremental impact, e.g. on fish density or reduced diffuse pollution, since developments are not necessarily linear.

- **Sampling**: In order to obtain an empirical sense of the impacts of change in river quality on visitors and visitor numbers, we undertook primary research by contacting businesses (hotels and tourism-related businesses) and applying a questionnaire in respective catchment areas. The results of this empirical research informed our analysis on visitor numbers, recreational users, and impacts on the tourism industry. However, we used a convenience sample, i.e. our sample may not be representative of the total number of hotels and other tourism businesses in catchment areas.

- **Use of extant data and literature**: Because of limited possibilities for primary research, numerous assumptions are derived from extant data and literature. This is particularly the case for valuation data, for which benefit transfer (value transfer) was used. As mentioned in Section 1, Benefit Transfer is a standard approach used for environmental valuation. However, there are uncertainties involved with transferring values from one site to another.

A particular emphasis was put on avoiding double counting. For example, the impacts of visitor expenditures on the economy (GVA and FTE jobs) include travel costs. The use of a travel cost method was consequently excluded for valuing the well-being impacts of river improvements on additional visitors, since these expenditures are already captured in the benefits.

The benefits obtained through the model were contrasted with the costs of undertaking respective interventions. Costs include WRT's investment and other stakeholders investment, in this case farmers input into the interventions. Farmer's inputs in the interventions were directly factored in the calculations for increased farm revenues (avoided losses). This is further explained in Appendix 3. Table 12 presents WRT's financial input into respective projects i.e. the costs involved for undertaking the projects.

Table 12: Project budgets

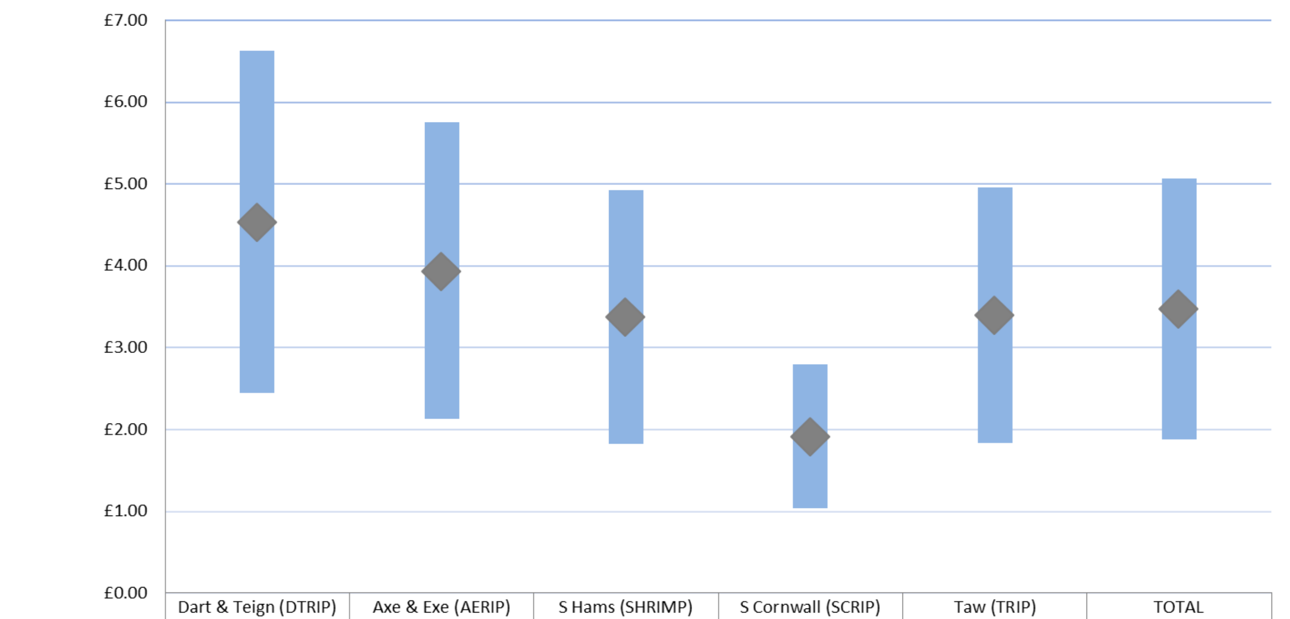
	2012/2013	2013/2014	2014/2015	TOTAL INVESMENT
Dart & Teign (DTRIP)	£171,242	£206,859	£167,553	**£545,656**
Axe & Exe (AERIP)	£144,403	£252,090	£219,376	**£615,870**
S Hams (SHRIMP)	£180,323	£333,474	£206,809	**£720,608**
S Cornwall (SCRIP)	£104,122	£167,678	£158,143	**£429,944**
Taw (TRIP)	£589,854	£695,377	£715,272	**£2,000,504**

4.2. Results

For calculating the Net Present Value and the Benefit-Cost ratio (return on investment), we used a 3.5% discount rate as per Treasury Guidance. The benefit differs across different activities and outcomes, notably based on the life cycle of different interventions (e.g. fencing). WRT has been engaging with stakeholders to guarantee the sustainability of measures. The average benefit period is of 10 years, which is consistent with standard practice in Cost-Benefit Analysis measurement.

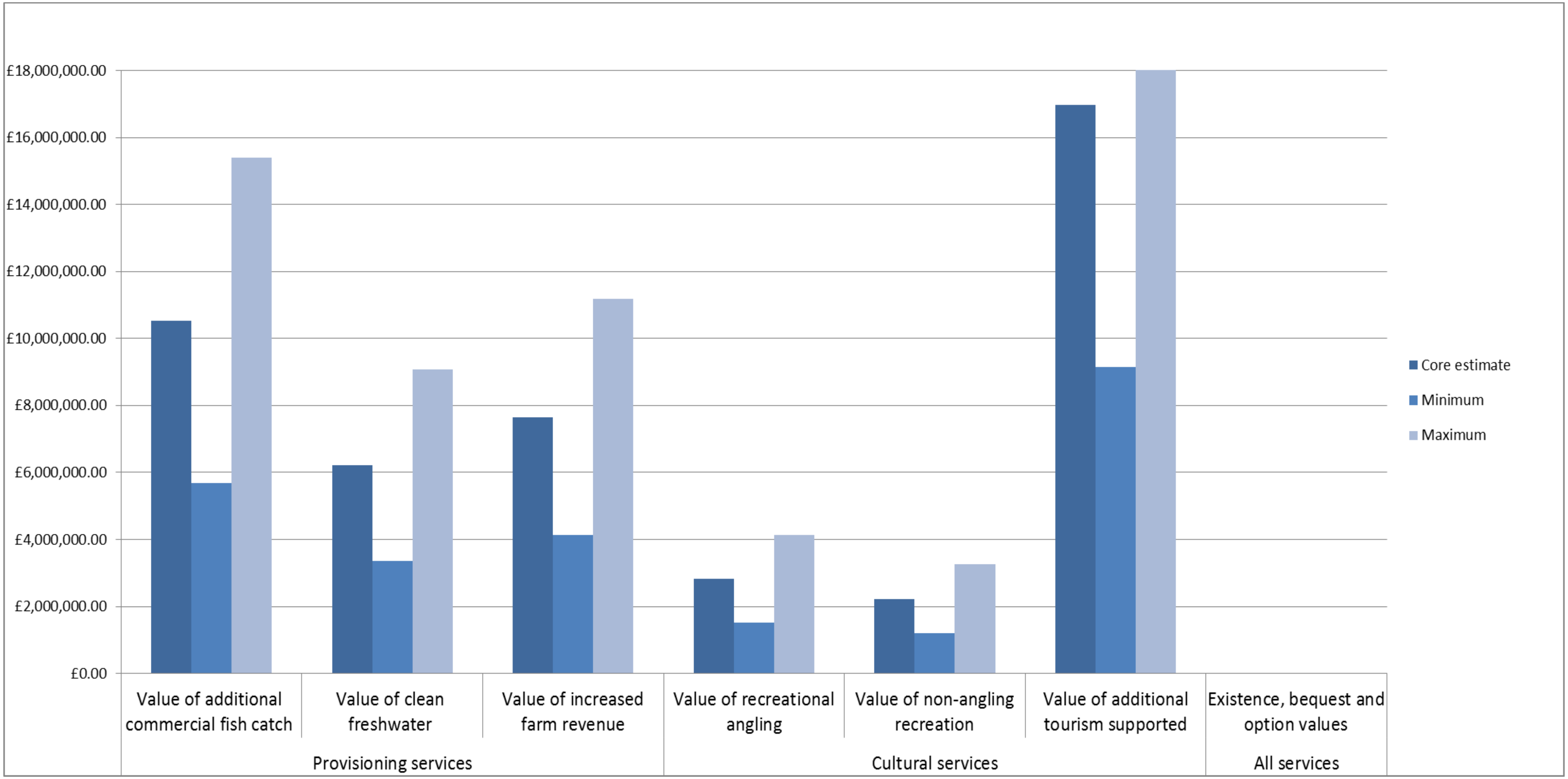
Overall, we find that NPV is positive for all projects. Aggregate benefits range from a Net Present Value of £3.6 million (under a worst case scenario) to £16 million (in a best case scenario). These figures represent the additional Ecosystem Services value created as a consequence of WRT's projects, net of costs. Put differently, Figure 7 presents the range of returns on investment for respective projects. Overall, for each £1 invested, WRT's river improvement projects generate between £1.87 and £5.06 as a consequence of improvements in key ecosystem services considered in this analysis. The detailed benefits breakdown for each project is available in Appendix 4.

Figure 8: Benefit:Cost ratios obtained under different assumptions



	Dart & Teign (DTRIP)	Axe & Exe (AERIP)	S Hams (SHRIMP)	S Cornwall (SCRIP)	Taw (TRIP)	TOTAL
Low return	£2.44	£2.12	£1.82	£1.03	£1.83	£1.87
High return	£6.62	£5.74	£4.92	£2.78	£4.95	£5.06
◆ Core estimate	£4.53	£3.93	£3.37	£1.91	£3.39	£3.46

Figure 9: Distribution of Net Present Value among different Ecosystem Services (all projects combined)



Overall, we find that the greatest value is generated through a) additional recreational visitor spend and b) additional catch for commercial fisheries. Both estimations include the direct and indirect Gross Value Added and employment supported. Increased farm revenue (through avoided costs) is also an important contributor to the total value supported by the projects. Non-use values represent a very minor fraction of the benefits, i.e. an annual value of £1,945 or a Net Present Value of £14,800 assuming a 10 year benefit period and a 3.5% discount rate. This is because non-use values represent the value accruing to non-users, and reflects what households would be Willing-To-Pay per km of river for increasing environmental quality[25].

The returns are not evenly split among the different projects. The variations observed are largely down to two key factors:

1) **The extent of commercial fisheries in respective catchment areas**.

Commercial fish catch, and its knock on impacts on Gross Value Added and jobs, makes up for a substantial fraction of total benefits (Figure 9, above). However, commercial fisheries are not evenly distributed among respective catchment areas. The Dart, the Teign, the Axe, the Exe and the Taw have a high number of reported commercial Salmon and Seat Trout catches. Such is not the case of rivers and water courses improved through the SHRIMP (South Hams) and the SCRIP (South Cornwall) projects. The rivers and water bodies improved by the latter, in particular, have no commercial fish catch at all. This reduces the value of the benefits generated through that project.

2) **The empirical research with hotels and tourist businesses in respective catchment areas.**

The value of additional tourism supported through anglers and other recreational visitors spend is the largest benefit generated by the projects. As aforementioned, the estimations regarding the total number of visitors under different river quality scenarios was derived through empirical research. However, our sample is not representative and there may be response biases involved in some (or all) catchment areas. This affects the estimations for the number of recreational visitors, given that it is dependent on the responses we received. Moreover, since a part of those visitors are recreational anglers, and (as with commercial fisheries) angling is not evenly distributed across catchments, the value of additional angling activities is not evenly split across catchments.

To these factors should be added the exclusion of other potential benefits from the analysis. Their inclusion may have altered the discrepancies observed between respective projects. The implications of the inclusion of some benefits and the exclusion of other potential benefits are further detailed in section 5.

For these reasons, results should be interpreted with caution. The fact that some projects present larger returns does not mean they are “worth” more than others. Indeed, discrepancies may simply mean a) that some catchments support larger benefits due to their more intense use by humans (for recreation and extractive activities) and b) that some of the impacts excluded from the analysis are more relevant to some catchments and projects compared to others – while not being captured in quantitative estimates.

5. DISCUSSION AND CONCLUSION

5.1. Overall results

The objectives of this report were to:

- Investigate how WRT's river intervention projects (and their components) affect human welfare and support the improvement of Ecosystem Services provided by rivers and catchments in selected rivers of Devon and Cornwall

- Provide an estimation of the value of Ecosystem Services supported by WRT's river improvement projects in Devon and Cornwall

- Assess whether WRT's river improvement projects are efficient and effective from a socio-economic standpoint, when considering both economic and social welfare impacts

Our core estimate suggest that all projects generate more benefits than resources invested in restoring respective rivers, with the wide majority of benefits arising in the form of increase in provisioning and cultural ecosystem services in catchment areas. Even under a worst case scenario (using more pessimistic impact assumptions), all projects still generate positive returns, albeit lower ones.

Table 13: Overview of results, assuming a 10 year benefit period and a 3.5% discount rate.

	Net Present Value	Benefit:Cost Ratio
Dart & Teign RIP	£1,088,572	4.53
Axe & Exe RIP	£979,908	3.93
South Hams RIP	£948,471	3.37
South Cornwall RIP	£211,324	1.91
Taw RIP	£2,652,016	3.39
TOTAL	£5,880,291	3.46

Nonewithstanding the importance of these results, it is equally important to outline the limits of the analysis, and the uncertainty involved in these results. It is also important to assess the likelihood of these results to hold, by considering both the limits of assumptions used and the exclusion of key impacts and benefits from the equation

5.2. Implications

As already demonstrated by previous research on the benefits of investing in river improvement projects, our results suggest that rivers of the South-West are worth restoring not only from a strict environmental standpoint but equally from a socio-economic angle.

As aforementioned, tourism (of which nature-based tourism is prominent) represents 22% and 11% of total FTE jobs in Cornwall and Devon respectively. Angling recreation alone supports £51 million of yearly Gross Value Added and 2300 FTE jobs in the South-West. A study of the Environment Agency determined that if Salmon and Sea Trout fishing were to stop in the South-West, the household income loss would be of £1.7 million per year[26]. Finally the South West's saltwater fisheries, which represent 50% of England's fisheries, are also partly dependent on freshwater quality, and thus on river ecosystems. These elements point to the fact that a substantial amount of the South West's economic activity is dependent on the health of its river ecosystems, even when disregarding biodiversity *per se*.

As such, rather than asking whether we can afford to invest in river quality improvements is it perhaps more sensible to ask whether we can afford not to. Within the mark of this debate, our research illustrates, at a micro scale, that river improvement projects can yield significant benefits even if considering "hard" economic benefits only (namely tourism and commercial fishing revenues and jobs).

5.3. Assessment of the analysis: Limits and uncertainty

5.3.1. Benefit period

This research has used a 10-year benefit period, as is standard practice when applying Cost-Benefit Analysis. This is the timeframe we expect the impacts of the projects to be at work. We consider this is a conservative estimate. For example, eel and fish passes installations can be expected to last 25 years[27]. Similarly, a water course fence can be expected to have a life cycle of 15 years. Finally, because WRT is working closely with riparian farmers and fish clubs by capacitating them in conservation, we can expect the interventions to be sustainable on the long run – ensuring the renewal of activities when the life cycles of installations reach their end. Such is the case of farm plans and other riparian installations.

We thus do not consider that a 10-year benefit period is likely to overestimate the impacts of the projects, or the benefits supported. If anything, some of the impacts and benefits may be underestimated, as the activities and installations supporting them have a longer life cycle.

5.3.2. Excluded benefits

Numerous potential benefits were excluded from the analysis, due to a lack of sufficient (primary of secondary) data and information.

Firstly, river improvement projects may improve saltwater quality and coastal ecosystems. For example, the SCRIP project, aiming to improve rivers draining to the St Austell bay, may impact on Shellfisheries which have been assessed to be at risk due to pollution discharges in the bay[28]. An improvement in Sweetwater water quality may thus generate additional socio-economic returns for example via an improvement in the quality of Shellfisheries. Similarly, improvements in coastal ecosystems may reduce the likelihood of beach closures due to pollution. For instance, improved livestock farming practices (through farm management plans) may reduce the risks of microbiological pollution. According to the Environment Agency, about half of the South West's bathing waters are affected by diffuse pollution[29]. Reducing this risk may generate additional benefits to coastal recreational activities. This is a likely impact of the projects, which has not been assessed.

Secondly, river improvement projects may reduce soil erosion and loss through improved farming practices and stabilization of the river banks. In turn, this may reduce the discharge of soil in respective estuaries. For example, Le Quesne estimated that soil management in riparian farms of the Fowey River may prevent the discharge of 790 tons of soil in the Fowey estuary. The avoided dredging costs in the harbour may represent an annual saving of £1665[30]. The benefits of avoided dredging in estuaries and harbours were not included in our analysis.

Thirdly, channel improvements and restoration of riparian vegetation cover may improve rivers' base flow and thus reduce flood risks[31]. However, measuring the flood probability reduction (and thus avoided losses) attributable to specific upstream measures is challenging. As such, this potential benefit was also excluded from the analysis.

Fourthly, improved river and riparian ecosystems may yield positive benefits for the local communities (and wider inhabitants). These benefits may come in the form of improved well-being (great enjoyment of recreation) or in the form of increased value of properties in catchment areas[32]. These benefits have been quantified nationally for the UK-NEA (National Ecosystem Assessment). However, measuring them empirically was not made possible in the context of this study.

Fifthly, our estimations on angling recreational benefits and additional tourism revenue include salmon and sea trout angling only. This is because we found no comprehensive data on coarse fishing. However, it is very likely that coarse angling may be affected, and thus that we under-estimate the impacts of the projects in terms of additional spend and angling benefits.

Finally, the combination of improved water quality, improved riparian ecosystems and increased fish population may also increase overall provisioning ecosystem services (including biodiversity) in catchment areas. Nonetheless, measuring and valuing provisioning services is notoriously difficult without substantial primary environmental analysis and extensive ecological modelling. These were thus left out of the equation.

The exclusion of these potential additional impacts and benefits from the analysis means that the total value created by respective projects may be considerably underestimated. Indeed, only a fraction of the ecosystem services supported by WRT's river improvement projects, could be quantified and valued.

5.3.3. Assumptions used

This research has relied on a number of secondary assumptions, used for deriving environmental impacts and socio-economic benefits. The limits entailed by forecasting environmental impacts have already been outlined throughout Section 3. Section 4 has also outlined some of the key assumptions sitting behind the modelling framework, namely the assumptions of linearity, incrementality of impacts, and sampling of tourism businesses in catchment areas.

In addition to those limits, secondary data was used to measure some key impacts and benefit transfer to value those impacts. Despite the use of sensitivity analysis to examine the extent to which changing the assumptions affects the results (particularly in a "worst case" scenario), laying out uncertainties is necessary. Table 14 presents the confidence we place in the values derived.

Placing a low confidence is not necessarily synonymous of an over-valued impact. Indeed, an estimate derived through primary research could have been higher. Rather, a low confidence placed in the figures means that the estimation used is uncertain in this context.

For example, recreational users' Willingness-To-Pay for improved river quality is based on benefit transfer, i.e. by using a previous empirical study applied in a different UK region (see Appendix 3 for further details). If one was to replicate such a study in WRT's projects' catchment areas, the results may be different – lower or higher. Other estimations based on secondary data, such as households' Willingness-To-Pay for achieving WFD targets, are deemed less uncertain. Indeed, this study is UK-wide and entails figures specific to South West rivers.

Table 14: Confidence placed in the estimations of benefits (values)

Indicator description	Annual value (£)	Confidence placed
Value of additional fish catch (Salmon and Sea Trout)	£535,477.78	High
Regional Gross Value Added supported by additional catch	£480,646.75	High
Value of local / regional FTE jobs supported by additional catch	£369,238.56	High
Value of improved water quality indicators	£816,939.08	Low
Value of reduced soil loss (erosion) and of reduced fertilizer use	£1,006,145.94	High
Anglers' WTP for improved river quality, over and above current expenditures	£372,893.01	Low
Recreational users' WTP for improved river quality, over and above current expenditures	£292,746.24	Low
Value of additional GVA to tourism businesses	£1,033,191.93	Medium
Indirect Gross Value Added supported by additional tourism visits / expenditures	£826,204.65	Medium
FTE jobs supported by additional by additional tourism visits / expenditures	£371,327.93	Medium
Households WTP for achieving WFD targets (non-users)	£1,945.65	Medium

5.4. Recommendations

This research employed a large number of quantitative assumptions for gauging the links a) between project activities and environmental impacts and b) between environmental impacts, ecosystems services and other socio-economic benefits. The combination of these assumptions means that there are multiple uncertainties associated with the results of this research. Future research on WRT projects could sensibly reduce these uncertainties through additional environmental socio-economic monitoring. As such, our two key recommendations would be the following:

- To this date, environmental data (water quality and fish data) is primarily collected for targeting projects and interventions to sensitive locations in river catchments. This means that the data collected is not necessarily tailored for tracking the environmental impact of projects. Collecting pre-intervention (baseline) and post-intervention data in the same locations can allow future research to derive more accurate estimations of environmental outcomes and impacts.

- There is currently a lack of socio-economic monitoring in the areas where interventions are undertaken. Improving monitoring (and data collection systems) is necessary for an empirical evaluation of impacts, and for undertaking more accurate (less assumptions-based) impact analyses. Working in partnerships with other organizations (public or third sector) to track socio-economic developments in catchment areas may sensibly reduce the costs of doing so. This would notably allow having a better understanding of the wider impacts of WRT's projects on the various stakeholders benefitting from the projects, such as local communities, recreational users, anglers and commercial fishermen. WRT could apply baseline and post-intervention questionnaires for having a better understanding of the change experienced by these stakeholders as a consequence of the projects. This would help inform future socio-economic assessments.

Appendix 1: Selected studies reviewed for scoping the analysis

Study	Beneficiaries	Benefits considered in the analysis	Value type	Valuation technique	Monetary value
Value of inland waterways in England and Wales (15 canals and rivers) **Value of improving quality, as well as value lost if funding removed** **Jacobs, 2007[33]**	Local communities	Property premium, boating, towpath visits, angling, visiting heritage sites, volunteering,	Total economic value	Hedonic pricing (property premium), willingness to pay, benefits transfer	£730,000 - £109,000 per km of waterway depending on the canal
River Clyde (Scotland); River Wear (England) **Value of improving river quality** **Hanley et al, 2006[34]**	Local residents	River ecology (fish levels, diversity of water plants, birds and insects); aesthetics (absence of sewage and litter); river banks (trees and plants, only natural erosion); cost (water rates payments to local sewerage operator)	Use values, non-use values	Choice experiments	£100.26 - £169.54 (River Clyde) and £36.93-£37.81 (River Wear) per person to improve levels from 'fair' to 'good' (£2003)
River Darent (Kent) **Value of improving river quality** **Garrod et al, 1996[35]**	Local residents; visitors	River flow, recreational use	Direct use value	Contingent valuation (open ended WTP)	£12.32 (per resident) and £9.76 (per visitor) to improve flow levels (£1995)
River Tame (Birmingham) **Value of improving river quality** **Bateman et al, 2006[36]**	Local residents	Fishing (no. and type of fish); plants and wildlife; recreational use (boating and swimming); cost (council tax increase)	Use values	Contingent valuation; contingent ranking (random utility)	WTP £18.86 - £23.28 per person for a large improvement (£2004)
River Tamar catchment **Environment Agency[37]**	Undefined stakeholders (implicitly local residents, farmers and the state)	Fresh water; food eg. crops; fish stocks; climate regulation; storm protection; erosion regulation; recreation and tourism; water and nutrient cycling	Direct use value, indirect use value	Market prices and cost-based proxies	Approximately £3.8 million value for the river total per year
Restoration of Mayes Brook	Undefined stakeholders (implicitly	Climate regulation; flood protection; erosion regulation; employment; tourism; community activities eg.	Direct use value, indirect use value	Market prices and cost-based	Lifetime value (40 years) of £15.2 million; includes HP value of £7.8m for increased value of

Environment Agency[38]	local residents and the state)	fishing; education resources; nutrient cycling; provision of habitat to wildlife; increase in house values		proxies, hedonic pricing	properties
Implementation of the water framework directive in England and Wales (all English and Welsh rivers) **Nera and Accent, 2007[39]**	English and Welsh households (population)	Biodiversity, recreation, freshwater provision	Use values and non-use values	Contingent Valuation	£55 per year, with a range between £45 (min) and £85 (max) per household per year (£2007)
Value of surface water quality in rivers and transitional waters **Jacobs, 2008[40]**	Recreational users, public utility companies, boating	Freshwater provision, biodiversity, recreational use.	Direct use values	Damage cost	£5.988 per km per year
Value for water quality enhancement **Moran et al, 2004**	Scottish households	Fresh water; food e.g. crops; fish stocks; recreation and tourism; heritage values, non-use values	Use and non-use values	Choice experiment	Different values for different parts of Scotland that ranges: £43.56-66.90 (£2003)
Value of UK's freshwater fish population **NEA scientific team report, 2010[41]**	Angling industry, recreational fishermen	Value added, recreational use	Use values (consumptive only)	Market prices	Value of coarse fisheries: £850 million Angling industry turnover:£191 million Value of fishing rights for migratory salmonids: £165 million

Appendix 2: Studies and assumptions used for measuring the ecological impacts of interventions

Study	Description and findings
Fish passages	
Calles and Greenberg, 2005[42]	Studies in Sweden found that the density of brown trout (Salmo trutta) yearlings was nearly twice as high after the construction of fishways, and the number of spawning fish and recolonization rates were expected to increase.
Glen, 2002[43]	Removal of culverts, Wauchope Burn and other Scottish streams. Salmon fry found upstream of former culvert immediately after removal and numbers went from 0 before removal in 2000 to a mean of .35/m2 in 2001 and .20/m2 in 2002
Kiffney et al, 2008	Fish ladder installed on a dam on the Cedar River, Washington, USA. Density of salmon increased by 0.009 fish/m2 in the main river in the year immediately following. Salmon densities approximately doubled in the reaches above the dam over the course of the next three years.
Burns et al, 2011	Review on efficacy of fish passes found that efficiency (i.e. proportion of fish able to get upstream using passage) depended on design, but varied from 55-77% improvement in efficiency.
Noonan et al, 2012[44]	Fish passage efficiency works both ways
River Dee Trust	Installation of fish passes in a dam. After installation, 32 salmon moved upstream in that season where none had previously. In the following season, juvenile salmon were present 9.6km upstream of the dam.
In water woody debris management	
Testa et al, 2010[45]	Large wood structures were placed along 2km of a stream in mort-central Mississippi, USA and macro invertebrate abundance and richness was measured in the 2 years prior and 2 years following, although it was suggested that this was related to bed sediment composition and a high level of water flows over the duration of the study.
Brooks et al, 2004[46]	Engineered log jams created in Australian river. Macro invertebrate richness increased by 10%, no increase in abundance.
Avery, 2004[47]	An evaluation of multiple trout stream habitat interventions in Wisconsin, including large woody debris, boulders and brush removal. Found on average a 63% increase in trout biomass.
Binns, 2004[48]	Effect of introduction of boulders and large woody debris on wild salmonids in Wyoming streams, summary of over 30 projects. Mean abundance of trout increased by 77%, and biomass by 62%.
Chapman, 1996[49]	Summary of multiple structural manipulations of inserted habitat in the Columbia river basin. There was no significant difference in preferences for treatments tested between salmon and trout. Measures included gravel augmentation and in LWD addition; gave an overall increase of 80% biomass.

Gargan et al, 2002[50]	Response of juvenile salmon and trout to a variety of inserted treatments (including revetments, weir removal, riffle pool creation and LWD) at treatment and control sites. Significantly high levels of Atlantic salmon parr (0.19 vs. 0.06 fish/m) and brown trout parr (0.127 fish/m difference), but no differences for fry.
Roni et al. 2006[51]	Detected no difference in macroinvertebrate density or diversity in enhanced (by addition of various boulder and log structures) and untreated stream reaches.
Gravel augmentation	
Merz et al, 2004[52]	Effect of spawning-bed enhancement on salmon survival in a Californian stream. On the unenhanced sites, survival was 22%, whereas on the enhanced sites, survival was 29% (a 32% increase).
Palm et al, 2007[53]	Assessing density of brown trout in stream in northern Sweden, which was restored using two different schemes: in one section, stream was restored by the addition of boulders and reconstruction of gravel beds, whereas the other received boulder addition only. Mean density of trout in the boulder only sections was not affected, whereas it increased by 44% in areas with gravel enhancement.
DEFRA[54]	Studies carried out in the River Itchen in England (a chalk stream) found cleaning to significantly reduce silt loads in the spawning gravel. This resulted in increased salmonid survival from 40-66% in the first two years, but survival was reduced to 6-20% in the third year showing the benefits deteriorated as sediment levels build up again.
Riparian fencing	
Whitehead et al [55]	study simulated sediment response in the River Lugg. 40% land use change achieved a 19% reduction in sediment levels; buffer strips achieved a 9% reduction.
Bergfur et al [56]	Riparian fencing in the Tarland Catchment Initiative in Scotland achieved an approximate 40% reduction in levels of ammoniacal nitrate and soluble reactive phosphorous. However, minimal effects were found on macro invertebrate indices.
Management plans for farms	
Parkyn et al. (2003)[57]	Parkyn et al. (2003) examined riparian fencing and replanting in New Zealand and demonstrated that replanted riparian buffers provided improvements in water quality and channel stability; however, nutrient and fecal contaminant responses were variable, and a shift towards less-tolerant, clean-water macroinvertebrate species was not observed. Parkyn et al. (2003) suggested that larger or longer buffers were needed to effect changes in water temperature and macroinvertebrate communities.
	Studied provision of information to farmers in New Zealand regarding best management factors, in particular related to land use. Found that 29% of farmers began using at least some elements of the plans within two years

Appendix 3: Measurement details

Measurement of the value of increased fish catch

The Environment Agency publishes statistics on inland fisheries, reporting both commercial and recreational fish catch in South West Rivers[58]. We combined the figures for commercial fish catch with our expected increase in fish numbers (see: Section 3) to forecast the potential a) increase in salmon and seat trout numbers and b) increase in commercial fish catch. The increased fish catch was then translated into additional turnover (market price sell) and Gross Value Added (GVA) for commercial fisheries in respective catchments. By using ONS data, we then measured the labour intensity per unit of GVA for freshwater fisheries. This allowed us to estimate the *direct* additional FTE jobs to be expected as a consequence of an increase in GVA.

We then calculated the *indirect* effects of an increase in commercial fisheries GVA and employment. For this, we used ONS input-output tables to obtain GVA and employment multipliers i.e. the effects of an increase of a unit of GVA and a unit of employment on the rest of the supply chain. This provided us with an estimation of the *indirect* GVA and FTE jobs respectively increasing as a consequence of additional fish catch.

FTE jobs were finally valued at the official minimum wage. This is a conservative estimate, given that the actual wages supported may be higher.

Measurement of the value of cleaner freshwater

There are numerous estimates on the costs associated with treating water to remove pollutants such as nitrates and phosphates. By reducing the concentration of pollutants, improved farm management practices can reduce treatment costs. This avoided cost is a benefit which can be used as a proxy for cleaner freshwater.

Previous national estimates suggest the following: according to the UK Water Industry Research , the total amount that water companies in England and Wales spend on water treatment is of £439 million (£2013) per annum[59]. Pretty et al have suggested that water companies spend £20.5 million (£2013) per annum for nitrate removal; £73.1 million (£2013) for phosphate removal per annum; finally, £134.4 million (£2013) per annum for pesticide removal[60]. On a more micro scale, Le Quesne reports different treatment costs of water in two distinct South West Water (SWW) reservoirs; one presenting good water quality and another poor water quality. The chemical and sludge treatment costs are respectively 49% and 67% higher in the latter[61]. Similarly, by extrapolating from limited SWW publicly available information, the Environment Agency reports that the Tamar 2000 project could result in cost savings of £304,000 per annum through a 5% reduction of pollution load from the Tamar[62].

The information available by SWW did not allow for a granular estimation of avoided water treatment costs to estimate the value of clean freshwater. Indeed, there is no information on abstraction levels from respective rivers, and only three of the rivers targeted by WRT seem to contribute directly to SWW major reservoirs (the Exe, the Axe and the Taw). We equally found no publicly available information on minor abstractions from the river (e.g. water permits in smaller water flows etc.). As such, the estimates originally derived for avoided treatment costs were therefore too uncertain to be included in the analysis.

We consequently used the results of a comprehensive study by Georgiou et al, measuring the willingness to pay of local residents for reduction in Amonia content, biological oxygen demand and dissolved oxygen in the river Tame[63].

Table I: WTP for changes in water quality indexes, results of Georgiou et al[64]

Unit change in water quality index	Mean WTP per annum per household £ (confidence intervals - £)
1% Saturation Increase in Dissolved Oxygen	0.30 (0.25 - 0.34)
1mg/litre Decrease in Biological Oxygen Demand	1.39 (1.17 - 1.61)
1mg N/litre Decrease in Total Ammonia	1.77 (1.47 – 2.07)

We combined this data with the projected decrease in Ammonia and Oxygen depletion, as calculated in Section 3 of the report. We subsequently identified all urban centres located nearby catchment areas (<20 miles of distance from respective rivers) and collected population data for these urban areas (number of households) to then multiply the WTP figures with the number of households. Choosing a less than 20 miles distance is not arbitrary: Georgiou et al. find a "distance decay" in their study: WTP is sensibly reduced at between 17 and 35 miles from the Tame. For convenience, we thus used a 20 miles limit in our study.

Measurement of agricultural benefits

WRT collects data on 1) farm plans, 2) targeted farms size, 3) recommended actions and 4) actions undertaken in respective farms. Previous research conducted for WRT calculated the estimated savings and gains for farmers participating in WRT's projects[65]. It has also calculated farmer's investments into the projects (e.g. changes in land management, riparian work etc.). This financial input of farmers is on top of WRT's expenditures and budget. We used these estimations to derive average costs and benefits per hectare, and applying them to respective River Improvement Projects, assuming an uptake of 50% in the core scenario, 30% in the pessimistic scenario and 70% in the optimistic one.

Table II: Estimated average benefits to farmers and costs borne by farmers

	Average benefits and costs (£) *per hectare of farmland*
Avoided soil loss (£15 / ton)	£8.14
Annual reduction of fertilizer use	£3.08
Annual efficiency increases, arable and livestock through appropriate fertilizer application	£15.79
Fencing	£0.95
Ditch clearing	£0.09
Water savings	£3.08
Spray savings	£0.49
Cost to farmer	£4.95

Measurement of the value of increased tourism (recreational expenditures)

General recreational visitors (non-Anglers)

For measuring the effects of improved river quality on recreational activities we collected primary data in respective river catchments. More specifically, we applied a questionnaire through telephone interviews with owners of hotels and campsites in catchment areas (Appendix 5 below). Through these questionnaires we were able to determine the current number of visitors and the likely impacts of an improvement or a deterioration of river quality on the number of visitors.

Table III: Responses in river catchment

Catchment area	Number of businesses willing to respond
Dart and Teign RIP	15
Axe & Exe RIP	10
South Hams RIP	12
South Cornwall RIP	9
Taw RIP	13

This provided us with an estimation of the likely reduction of visitors if river quality and wider riparian ecosystems are further deteriorated, and the likely increase if river quality and riparian ecosystems are improved.

We subsequently used district-level average tourism expenditure data, available for both Cornwall and Devon, for estimating the additional expenditures in respective catchment areas[66]. The reports for Cornwall and Devon estimate the expenditures (or turnover), rather than GVA. As such, we used ONS data to estimate the ratio of GVA to turnover in the tourism sector. This gave us the GVA impact per district (location of catchment area). Finally, employment impacts for each district were directly provided by the original South West Research Company reports[67]. It is worth noting that both GVA and employment impacts include both *direct* and *indirect* (supply chain) effects. FTE jobs were valued at the official minimum wage. This is a conservative estimate, given that the actual wages supported may be higher.

None of the businesses we surveyed reported hosting Anglers regularly. As such, the above steps were used to measure the impacts of non-Angler recreational users only.

Anglers

Because we obtained no data for Anglers through the empirical research, another approach was taken for measuring the potential increase in Anglers' visits in respective catchment areas. The Environment Agency publishes statistics on inland fisheries, reporting both commercial and recreational fish catch in South West Rivers.[68] It has also published a report analysing the economic value of inland fisheries per region, and using extensive data on Angling visits and expenditures[69].

We combined both sets of data to obtain the ratio of number of angling visits to catch for the South West. We then used the expected increase in fish numbers (see: Section 3) to forecast the potential increase of recreational catch in respective catchments. Combining this increase with the ratio (number of angling visits to catch), we obtained the likely increase of Angler's visits in respective rivers.

Finally, we used estimates provided by the Environment Agency[70] for measuring the additional regional GVA and FTE jobs supported by this increase in angling visits. As with previous estimates, FTE jobs were translated in monetary terms by using official minimum wage.

Measurement of the value of additional recreational users' well-being from improvements in river quality

Additional visitor expenditures reflect the benefits accruing to local and regional social economies. However, improvements in river quality may also create an additional well-being (cultural) benefit for current and future recreational users: an improvement in river quality and riparian areas may improve the experience of the site, even if no actual additional expenditure is involved. By and large, the best way to value this "consumer's surplus" is by means of contingent valuation. This involves asking recreational visitors how much they additional money they would be Willing-To-Pay, on top of their existing expenditures to reach and experience the site, for different sets of improvements in water quality, riparian quality or fish abundance. There are numerous Contingent Valuation studies which have valued the consumer surplus gained with improving river quality (see Appendix 1).

For this study, the most appropriate estimation was considered to be the one of Spurgeon et al. who measured the additional Willingness-to-Pay of English and Welsh anglers for maintaining the existing level of fishes (quality and density) in their most familiar water body[71]. Their results suggest that Anglers would be willing to pay an additional £2.5 to £3.5 per visit (Coarse angling) and £3.2 to £4.7 per visit (Salmon and Sea Trout angling) in £2001. In £2013, figures would be of £4.5 (min) to £6.6 (max) per visit for Salmon and Sea Trout angling – which are the included in this study. These are the values we used for measuring the angler's consumer surplus generated through improved river quality. Because we found no study dealing with other (non-angler) recreational users, we assumed that (the lower) willingness-to-pay estimates for coarse anglers represent the consumer surplus of non-Angler visitors. As such, the consumer surplus value placed on non-angler visitors is of £3.5 (min) and £.4.9 (max).

These figures were combined with data on average number of visits to calculate the total value of the consumer surplus.

Measurement of the non-use values associated with improvements of river quality

All the previous values considered in this analysis are use values, i.e. they measure the benefits accruing to users of the ecosystems in question, and the knock-on effects of this use. However, there are also non-use values associated with improvements in river ecosystems. Indeed numerous studies show that even individuals not using an ecosystem may be willing to pay for its conservation (or its improvement). This may be out of inter-generational considerations (bequest value) or even wider considerations (existence value) such as the well-being felt by the knowledge an ecosystem exists. The latter may be linked to an option value, i.e. the possibility of visiting or experiencing that ecosystem in the future.

In short, beyond the benefits accruing to users of rivers and aider catchment areas, there may be non-use values accruing to the wider South Western or British population. Because there are previous estimates of the amount British households are willing to pay for meeting the WFD targets, we included non-use values in the analysis[72]. Based on Nera's study, the Environment Agency has measured the benefits of improvements in water quality per kilometre for the main river basins in England and Wales. These benefits represent the willingness to pay of British for water bodies to achieve WFD objectives.

Table IV: Average willingness to pay for improved water quality through upgrade in ecological status per km per year (WFD classification)

	Low to Medium quality	Medium to high quality	Low to high quality
South West	£10.2 per km	£11.9 per km	£22.1 per km

We used the figures for the South West (Table IV) to calculate the non-use value of improving river quality, by multiplying this figure with the km of rivers in improved conditions in respective catchment areas. For simplicity, we assumed quality passes from medium to high, although in some locations (projects) an improvement from low to high or from low to medium is likely.

Appendix 4: Detailed results by project

Dart and Teign River Improvement Project

Ecosystem Service	Type of benefit	Stakeholder	Indicator description	Annual value (£)	Total Present Value of benefits
Provisioning	Value of additional commercial fish catch	Commercial fishermen	Value of additional fish catch (Salmon and Sea Trout)	£99,500.65	£756,969.76
		Wider economy	Regional Gross Value Added supported by additional catch	£85,854.85	£653,156.77
			Value of local / regional FTE jobs supported by additional catch	£65,954.72	£501,762.81
	Value of clean freshwater	Consumers and public utility companies	Avoided treatment cost of water for removing nitrates	£143,849.51	£1,094,362.00
	Value of increased farm revenue	Farmers	Value of reduced soil loss (erosion) and of reduced fertilizer and manure expenditures	£172,960.56	£1,315,829.72
Cultural	Value of recreational angling	Anglers	WTP for improved river quality, over and above current expenditures	£73,919.94	£562,359.72
	Value of recreation	Recreational users	WTP for improved river quality, over and above current expenditures	£31,214.78	£237,472.23
	Value of additional tourism supported	Tourism industry	Value of additional GVA to tourism businesses	£165,284.80	£1,257,434.91
		Wider SW economy	Indirect Gross Value Added supported by additional tourism visits / expenditures	£132,488.35	£1,007,929.82
			FTE jobs supported by additional by additional tourism visits / expenditures	£59,545.32	£453,002.16
All services	Existence, bequest and option values	Wider UK population (non-users)	Households WTP for achieving WFD targets (non-users)	£208.25	£1,584.30

Axe and Exe River Improvement Project

Ecosystem Service	Type of benefit	Stakeholder	Indicator description	Annual value (£)	Total Present Value of benefits
Provisioning	Value of additional commercial fish catch	Commercial fishermen	Value of additional fish catch (Salmon and Sea Trout)	£95,315.09	£725,127.35
		Wider economy	Regional Gross Value Added supported by additional catch	£82,243.31	£625,681.32
			Value of local / regional FTE jobs supported by additional catch	£63,180.29	£480,655.85
	Value of clean freshwater	Consumers and public utility companies	Avoided treatment cost of water for removing nitrates	£137,798.39	£1,048,326.98
	Value of increased farm revenue	Farmers	Value of reduced soil loss (erosion) and of reduced fertilizer and manure expenditures	£165,684.87	£1,260,478.52
Cultural	Value of recreational angling	Anglers	WTP for improved river quality, over and above current expenditures	£68,000.51	£517,326.57
	Value of recreation	Recreational users	WTP for improved river quality, over and above current expenditures	£30,170.15	£229,525.01
	Value of additional tourism supported	Tourism industry	Value of additional GVA to tourism businesses	£152,048.97	£1,156,740.91
		Wider SW economy	Indirect Gross Value Added supported by additional tourism visits / expenditures	£121,878.83	£927,215.91
			FTE jobs supported by additional by additional tourism visits / expenditures	£54,777.00	£416,726.25
All services	Existence, bequest and option values	Wider UK population (non-users)	Households WTP for achieving WFD targets (non-users)	£446.25	£3,394.93

South Hams River Improvement Project

Ecosystem Service	Type of benefit	Stakeholder	Indicator description	Annual value (£)	Total Present Value of benefits
Provisioning	Value of additional commercial fish catch	Commercial fishermen	Value of additional fish catch (Salmon and Sea Trout)	£72,775.66	£553,654.42
		Wider economy	Regional Gross Value Added supported by additional catch	£81,400.93	£619,272.72
			Value of local / regional FTE jobs supported by additional catch	£62,533.16	£475,732.69
	Value of clean freshwater	Consumers and public utility companies	Avoided treatment cost of water for removing nitrates	£136,386.98	£1,037,589.39
	Value of increased farm revenue	Farmers	Value of reduced soil loss (erosion) and of reduced fertilizer and manure expenditures	£180,548.33	£1,373,555.10
Cultural	Value of recreational angling	Anglers	WTP for improved river quality, over and above current expenditures	£33,476.80	£254,681.03
	Value of recreation	Recreational users	WTP for improved river quality, over and above current expenditures	£72,601.96	£552,332.94
	Value of additional tourism supported	Tourism industry	Value of additional GVA to tourism businesses	£163,159.24	£1,241,264.35
		Wider SW economy	Indirect Gross Value Added supported by additional tourism visits / expenditures	£130,784.55	£994,967.88
			FTE jobs supported by additional by additional tourism visits / expenditures	£58,779.57	£447,176.57
All services	Existence, bequest and option values	Wider UK population (non-users)	Households WTP for achieving WFD targets (non-users)	£714.00	£5,431.89

South Conrwall River Improvement Project

Ecosystem Service	Type of benefit	Stakeholder	Indicator description	Annual value (£)	Total Present Value of benefits
Provisioning	Value of additional commercial fish catch	Commercial fishermen	Value of additional fish catch (Salmon and Sea Trout)	n/a	n/a
		Wider economy	Regional Gross Value Added supported by additional catch	n/a	n/a
			Value of local / regional FTE jobs supported by additional catch	n/a	n/a
	Value of clean freshwater	Consumers, other users and and public utility companies	Avoided treatment cost of water for removing nitrates	£11,617.04	£88,378.79
	Value of increased farm revenue	Farmers	Value of reduced soil loss (erosion) and of reduced fertilizer and manure expenditures	£21,289.13	£161,961.02
Cultural	Value of recreational angling	Anglers	WTP for improved river quality, over and above current expenditures	£34,801.75	£264,760.83
	Value of recreation	Recreational users	WTP for improved river quality, over and above current expenditures	£32,136.09	£244,481.28
	Value of additional tourism supported	Tourism industry	Value of additional GVA to tourism businesses	£106,448.94	£809,830.16
		Wider SW economy	Indirect Gross Value Added supported by additional tourism visits / expenditures	£84,353.53	£641,735.20
			FTE jobs supported by additional by additional tourism visits / expenditures	£37,911.70	£288,420.31
All services	Existence, bequest and option values	Wider UK population (non-users)	Households WTP for achieving WFD targets (non-users)	£148.75	£1,131.64

Taw River Improvement Project

Ecosystem Service	Type of benefit	Stakeholder	Indicator description	Annual value (£)	Total Present Value of benefits
Provisioning	Value of additional commercial fish catch	Commercial fishermen	Value of additional fish catch (Salmon and Sea Trout)	£267,886.37	£2,037,995.51
		Wider economy	Regional Gross Value Added supported by additional catch	£231,147.67	£1,758,498.99
			Value of local / regional FTE jobs supported by additional catch	£177,570.39	£1,350,899.88
	Value of clean freshwater	Consumers and public utility companies	Avoided treatment cost of water for removing nitrates	£387,287.15	£2,946,359.23
	Value of increased farm revenue	Farmers	Value of reduced soil loss (erosion) and of reduced fertilizer and manure expenditures	£465,663.05	£3,542,618.49
Cultural	Value of recreational angling	Anglers	WTP for improved river quality, over and above current expenditures	£162,694.00	£1,237,724.96
	Value of recreation	Recreational users	WTP for improved river quality, over and above current expenditures	£126,623.28	£963,310.19
	Value of additional tourism supported	Tourism industry	Value of additional GVA to tourism businesses	£446,249.98	£3,394,929.98
		Wider SW economy	Indirect Gross Value Added supported by additional tourism visits / expenditures	£356,699.40	£2,713,657.19
			FTE jobs supported by additional by additional tourism visits / expenditures	£160,314.34	£1,219,621.21
All services	Existence, bequest and option values	Wider UK population (non-users)	Households WTP for achieving WFD targets (non-users)	£428.40	£3,259.13

Total value (all projects combined)

Ecosystem Service	Type of benefit	Stakeholder	Indicator description	Annual value (£)	Total Present Value of benefits
Provisioning	Value of additional commercial fish catch	Commercial fishermen	Value of additional fish catch (Salmon and Sea Trout)	£535,477.78	£4,073,747.05
		Wider economy	Regional Gross Value Added supported by additional catch	£480,646.75	£3,656,609.79
			Value of local / regional FTE jobs supported by additional catch	£369,238.56	£2,809,051.23
	Value of clean freshwater	Consumers and public utility companies	Avoided treatment cost of water for removing nitrates	£816,939.08	£6,215,016.39
	Value of increased farm revenue	Farmers	Value of reduced soil loss (erosion) and of reduced fertilizer and manure expenditures	£1,006,145.94	£7,654,442.86
Cultural	Value of recreational angling	Anglers	WTP for improved river quality, over and above current expenditures	£372,893.01	£2,836,853.12
	Value of recreation	Recreational users	WTP for improved river quality, over and above current expenditures	£292,746.24	£2,227,121.65
	Value of additional tourism supported	Tourism industry	Value of additional GVA to tourism businesses	£1,033,191.93	£7,860,200.32
		Wider SW economy	Indirect Gross Value Added supported by additional tourism visits / expenditures	£826,204.65	£6,285,505.99
			FTE jobs supported by additional by additional tourism visits / expenditures	£371,327.93	£2,824,946.51
All services	Existence, bequest and option values	Wider UK population (non-users)	Households WTP for achieving WFD targets (non-users)	£1,945.65	£14,801.90

Appendix 5: Questionnaire applied to hotels and campsites

General information

This questionnaire is strictly confidential. We will not share your name or the name (location) of your business if you do not wish to.

- Average (approximate) number of visitors of year: ……………..

- Average (approximate) length of stay of visitors: ……………….

- How dependent is your business on the River ……..…. and the surrounding ecosystem (natural environment)?

    - None
    - A bit
    - A lot
    - I don't know

Scenarios

I will now describe you two scenarios outlining what might happen to the River …………….. in the future. I would like to know how <u>you think</u> this may affect your business / the number of visitors in the area.

<u>**Scenario 1**</u>**: Water quality of the river is improved. The river is less polluted by human activity, supports a greater number of species and fish. Fish can spawn with more safety and are able to migrate more easily, thus ensuring their reproduction. Finally, the support of more aquatic species also attracts a larger number of birds.**

From your standpoint, how would such a scenario affect your business?

- *The number of visitors will stay the same anyway*
- *The number of visitors will increase by 1%*
- *The number of visitors will increase by 5%*
- *The number of visitors will increase by 10%*
- *The number of visitors will increase by 25%*
- *The number of visitors will increase by 50%*
- *More…*

<u>**Scenario 2**</u>**: Water quality of the river is degraded. The river continues to be polluted by human activity, and less species are able to survive in that environment. The artificial barriers on the river prevent the fish from migrating and spawning sites are not sufficiently protected. The river thus supports a lesser number of fish and other species. In turn, this limits the number of birds in the area.**

From your standpoint, how would such a scenario affect your business?

- *The number of visitors will stay the same anyway*
- *The number of visitors will decrease by 1%*
- *The number of visitors will decrease by 5%*
- *The number of visitors will decrease by 10%*
- *The number of visitors will decrease by 25%*
- *More…*

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