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Economic Valuation of the Effect of the Shortlisted Tidal Options on the Ecosystem Services of the Severn Estuary

SUMMARY REPORT

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1. KEY POINTS

The key objective of this study, possibly the most extensive value transfer project in the UK, was to value the net ecosystem impacts that result from changes in the environment associated with the five shortlisted Severn Tidal Power (STP) schemes. This document summarises the key methodological steps, inputted information, results, assumptions, caveats and recommendations. The detailed application is presented in the technical report of the project. In short, the following key points shaped the methodology used and its results.

The Severn Estuary covers the upper reaches of the Bristol Channel on the west coast of Britain, between South Wales and the South West of England. The **affected geographical area** studied here is limited to the Bristol Channel. Likely impacts beyond this (the so called far field effects) are excluded as the detail currently available from the Strategic Environmental Assessment (SEA) (Black and Veatch, 2010) only permits a broad-brush assessment to identify these impacts rather than a more detailed assessment needed for economic valuation. However, given the nature and scale of the proposed project, these far field effects could be significant.

The **affected habitats** included in this project are intertidal (mudflat, sandflat, rock and shingle), saltmarsh and grassland. Likely impacts on other habitats (freshwater wetlands, rivers and streams and water column) are excluded due to lack of scientific and economic data. The impacts included are taken from the SEA work and are assumed to be the **residual impacts** after basic mitigation (prevent and reduce) measures are undertaken for all engineering options.

The **area of each of these habitats** gained or lost due to STP options is used as a **proxy for loss or gain of the ecosystem services** provided by the habitats. Not all ecosystem services are included in this though, due to the limited coverage of the economic value estimates available. For example, human health values of ecosystems, and archaeological and agricultural values are excluded.

The **economic value estimates** for saltmarsh and intertidal habitats come from a meta-analysis[1] (Brander et al., 2008). The key assumption made to use this (best available) estimate from the literature is that the Severn Estuary is a 'typical' European wetland. Given the ecological and cultural importance of the Estuary, this assumption is likely to lead to a significant underestimation of the values. The economic value estimate for grassland comes from Environmental Landscape Features model that generates values for this habitat in the South West England (Oglethorpe, 2005). Economic value for the changes in CO_2 equivalent flux uses the latest non-traded carbon value (DECC, 2010). The definition of the environmental resource, change, selection of the value estimates and its

[1] Meta analysis combines estimates from multiple valuation studies and generates a function that explains the WTP estimates in terms of all factors found to influence WTP. The statistically significant coefficients of each factor show the direction and significance of the factors. A negative sign shows that the factor reduces WTP and vice versa. The higher the coefficient number is, the more significant the influence.

adaptation to the STP scheme context follow best practice guidelines for value transfer (Defra, 2010[2]).

The **population affected** by the impacts of the STP scheme is assumed to be those living within the 50 km of the Severn Estuary. This assumption is based on the economic value estimates used rather than a commentary on what the affected population really is. Given the importance of the Estuary, the affected population is likely to be much larger. The exception to this is carbon. Given the global nature of the effect of carbon emissions, changes in the local emissions and sequestration affect the global population and this is reflected in the way unit economic values for carbon are estimated.

All parameters involved in the estimations (habitat availability, size of the affected population, unit economic value) are assumed to remain constant over the life time of the analysis. This is a simplifying assumption rather than a statement about the future.

Extensive **sensitivity analysis** is undertaken to test the implications of these key points and other assumptions in terms of the accuracy of the results. These are summarised in Section 7 of this summary report and in more detail in the technical report.

The environmental costs of STP options are estimated over the project lifetime of 120 years. The estimates range from present value of £5.9 million for the low damage scenario for Shoots Barrage to present value of £218.6 million for the high damage scenario for Bridgwater Lagoon. The scenarios are explained in Section 6. The results are significant underestimates and the scale of underestimate is not possible to assess. Therefore, more work would be required before economic values (and in fact environmental impact analysis) can fully inform decision making.

The rest of this summary report presents:

- The economic principles on which the estimates are based (Section 2);
- The definition of the Severn Estuary for the purpose of economic valuation (Section 3);
- The likely changes in the Estuary due to STP options - the definitions for the purpose of economic valuation (Section 4);
- The definition of the affected population (Section 5);
- Unit economic values and sensitivity analysis used (Section 6);
- The aggregated results, assumptions and caveats (Section 7);
- Commentary on compensatory measures (Section 8); and
- Recommendations (Section 9).

[2] http://www.defra.gov.uk/environment/policy/natural-environ/using/valuation/index.htm

2. ECONOMIC VALUATION OF ECOSYSTEM SERVICES

Environmental resources are increasingly becoming defined in terms of the ecosystem services they provide. MEA (2005) definition of ecosystem services is broadly used here, namely, provisioning, regulating, cultural and supporting services. All of these services contribute to human welfare or wellbeing directly or indirectly and as such have economic values as well as having social, cultural and ethical values and importance associated with them.

Economic values are the values placed by individuals on environmental resources and their ecosystem services. Economic values are expressed in relative terms based on individuals' preferences for given *changes* in the quality and/or quantity of resources and services. The unit used for economic valuation is money – as it is a common unit making the comparison of financial and environmental costs and benefits possible. Using this unit, preferences are measured in terms of individuals' willingness to pay (WTP) money to avoid an environmental loss or to secure a gain and their willingness to accept (WTA) money as compensation to tolerate an environmental loss or to forgo a gain.

People have several motivations for having positive WTP and WTA which are presented in the Total Economic Value (TEV) typology.

Use value involves some interaction with the resource, either directly or indirectly:

- *Direct use value*: The use of the Estuary in either a consumptive manner, such as industrial water abstraction or in a non-consumptive manner such as for recreation (e.g. fishing).
- *Indirect use value*: The role of the Estuary in providing or supporting key (ecosystem) services, such as nutrient cycling, habitat provision, climate regulation, etc.
- *Option value*: Not associated with current use of the estuary but the benefit of keeping open the option to make use of Estuary resources in the future. A related concept is ***quasi-option value*** which arises through avoiding or delaying irreversible decisions, where technological and knowledge improvements can alter the optimal management of a natural resource.

Non-use value is associated with benefits derived simply from the knowledge that the natural resources and aspects of the natural environment are maintained, i.e., it is not associated with any use of a resource. For example, individuals place a value to knowing that iconic locations such as the Severn Estuary will be protected even though they have no intention to visit or make any other direct or indirect use. Non-use value can be split into three parts:

- *Altruistic value*: Derived from knowing that contemporaries can enjoy the goods and services related to the Estuary.

- *Bequest value*: Associated with the knowledge that the Estuary as a resource will be passed on to future generations.
- *Existence value:* Derived simply from the satisfaction of knowing that the Estuary continues to exist, regardless of use made of it by oneself or others now or in the future.

Those who make direct and indirect use of an environmental resource, i.e. the users, are likely to hold both use and non-use values. Those who do not directly or indirectly use the resource but still hold non-use values are called non-users. While users are relatively easy to identify, there is no theoretical definition of non-users. The definition is an empirical question which can be answered by primary research.

Many goods and services provided by the ecosystem services of the Severn Estuary, are ***market goods***[3]. The market price at which a good is exchanged reveals some information on its economic value. In particular, for the buyer of a good, the price reveals the amount of money the buyer is at least willing to give up to obtain the good. For the seller, the price reveals the amount of money the seller is at least willing to accept as compensation for giving up the good. Thus, for example, the economic value of commercial fishing in, or supported by, the Estuary is estimated at the market value of the fish catch. Similarly, tourism revenues from visits to the Estuary, or to the region, because of the Estuary reflect the economic value of this service.

Many uses and services supported by environmental resources are not traded in markets and are consequently 'un-priced' or **'non-market' goods**. Two types of valuation methods are developed to estimate the economic value of these non-market goods and services in the absence of price information. The first type is called revealed preference methods. They use price and consumption information from markets that are affected by environmental quality. For example, hedonic property pricing method estimates the premium buyers pay for properties in environmentally high quality surroundings. Travel cost estimates the economic value of informal (free of direct charge) recreation by analysing the costs incurred by recreational visitors to travel to and from and at a recreational site. The second type is called stated preference methods which use questionnaires to elicit individuals' WTP and/or WTA. These methods are potentially applicable to any resource and decision context and the only methods that can estimate non-use values.

As an initial assessment, this project did not undertake primary valuation research but used the best practice value transfer guidelines to use existing value evidence from the literature. Value transfer is a process of finding the most appropriate value evidence from the existing literature and adjusting it for the purposes of the appraisal of concern. There

[3] Market price information, however, is an imprecise measure of the economic value of a particular good since it may not fully reflect WTP or WTA. For example, many buyers may be willing to pay more than the market price to obtain the good. The difference between the maximum amount a buyer is willing to pay and the actual price paid is termed *consumer surplus*, reflecting the element of benefit from obtaining the good that is 'gained for free'. Similarly the seller of the good may be willing to accept a lower amount than the market price to give up the good. The difference between the minimum amount a seller is willing to accept and the actual price received is termed *producer surplus*, reflecting the additional benefit in exchange gained (in effect 'economic profit'). Overall, in the case of market goods and services, economic value (WTP or WTA) is reflected by the market price paid or received plus any consumer or producer surplus.

are three approaches to value transfer: (i) unit value estimates are taken from the literature and used in the appraisal; (ii) unit value estimates are adjusted to update to the year or the conditions of the appraisal and (iii) value function that explains the value estimates in terms of influencing factors is run with the data from the appraisal context. All these approaches require establishing the context of valuation and appraisal. The following steps are designed to ensure this:

(i) **Define the environmental resource and its ecosystem services to be valued**. In this case, definition involves what kind of habitats there are in the Severn Estuary and what kind of services they provide in qualitative and quantitative terms. This information forms the baseline situation over which the change is defined (see Section 3 below).

(ii) **Define the *change* in the environmental resource and its ecosystem services to be valued**. This information relates to the changes each of the shortlisted STP options is likely to make in the Estuary and is assessed in the Strategic Environmental Assessment (SEA). The change is expressed both in qualitative (e.g. scales like high, medium, low) and quantitative (e.g. hectares of habitat lost or created) terms along with further information relating to quantity and quality changes in the environment.

A lot of simplifying assumptions are made here due to uncertainty about the change and partly because the SEA is not intended to generate the level of detailed information on the environmental change that is ideal for a more complete economic valuation.

There are two approaches to interpreting the change information for economic valuation. The first is **individual ecosystem services** whereby changes in the baseline ecosystem services due to STP options are expressed in terms of changes in each service separately which is the then valued using available economic valuation. There are various reasons why this is not the ideal approach, the most important of which are scientific uncertainty about the provision of each service, lack of change data even when there is scientific understanding, and the risk of double counting when individual services are valued separately and summed when their provision is interlinked.

The second approach is what the technical report calls the **bundled approach**. This uses the size of a habitat as a proxy for all ecosystem services typically provided by that habitat on the assumption that a given habitat provides a bundle of ecosystem services which are all lost when the habitat is lost. SEA, being a strategic tool, is more suitable to provide the overall changes in the habitats and also economic values are more readily available at the habitat than at the service level (for most services, carbon being one of the exceptions).

Given the availability of SEA information and economic value estimates, the following impacts are valued: (a) changes in the size of intertidal, saltmarsh and grassland habitats using the bundled approach and (b) change in the CO_2 flux using the single ecosystem service approach. If and when more information on change and values is provided in future, further application of individual ecosystem services approach could be considered even though risk of double counting will remain.

Section 4 below summarises the key change parameters used and assumptions made in valuing the change in the Severn Estuary (Bristol Channel only to be precise) due to STP options.

(iii) **Define the population affected by change.** Given that economic valuation is based on individuals' preferences, it is crucial to answer the question whose preferences should be included in the analysis. The simple answer is all those affected though this is not always easy to quantify in particular for non-users as there is no theoretical definition of this group. This empirical question is partly addressed by the economic value evidence selected from the literature for value transfer in Section 5.

(iv) **Select the appropriate economic value estimates from the literature and adjust these values to fit the context better.** After an extensive review of economic valuation literature including value estimates for individual ecosystem services, the following value estimates are selected:

For intertidal and saltmarsh habitats, a meta-analysis combining several hundreds of economic value estimates for wetlands is used as the most appropriate evidence (Brander et al., 2008). This function is selected as it is the most recent and most comprehensive study of wetland valuation with a European focus. For grassland habitat, another study that adjusts various estimates for South West England is used (Oglethorpe, 2005). Both these value estimates are used under the bundled approach, i.e., they are proxies to the total value lost / gained from the changes to individual ecosystem services.

Economic valuation of CO_2 equivalent flux is based on the quantitative estimates from the SEA work and economic value (non-traded carbon) estimates from the latest DECC guidelines (2010).

See Section 6 below for further information.

(v) **Conduct sensitivity analysis and report results**. Given the uncertainties in the scientific and economic analysis and the simplifying assumptions that have to be made, extensive sensitivity analysis is conducted. The analysis shows the extent to which the results are sensitive to the assumptions made (see Section 7).

See Section 2 of the technical report for a conceptual overview of economic valuation and ecosystem services approaches.

3. ENVIRONMENTAL RESOURCE VALUED

The Severn Estuary covers the upper reaches of the Bristol Channel on the west coast of Britain, between South Wales and the South West of England. The Estuary provides support for many wildlife species as a result of its 12 metre mean spring tidal range[4] which is one of the largest tidal ranges in the world. As a result of this tidal range the Severn Estuary could prove to be a significant resource for generating low carbon energy through tidal power (potentially contributing 5% of the UK's energy demand, depending on the STP option chosen (Parsons et al., 2008) and thus helping the UK government make inroads into its ambitious carbon reduction targets[5]. However, the Estuary's unique nature means that there are potentially significant environmental and social effects which may arise as a result of the construction and operation of a tidal power scheme.

The Estuary supports populations of wild birds that are of European importance[6] and contains several areas of habitat that are of international importance. These features are recognised by the designation of the Estuary as a Special Area of Conservation (Severn Estuary/Môr Hafren SAC) and as part of the Natura 2000 Network and also a Special Protection Area (SPA) under the Birds Directive[7]. In addition to these designations the Estuary is a Ramsar site due to its importance for migratory fish, its unusual estuarine communities and for supporting important populations of waterfowl. Furthermore the complexity of the entire Estuary system itself makes it a unique environment.

This economic valuation project included only the Estuary within Bristol Channel. Likely effects of the STP options outside the channel (the so called far field effects in the SEA) are excluded from the economic valuation as the detail currently available in the SEA (Black and Veatch, 2010) only permits a broad-brush assessment to identify key issues rather than the more detailed assessment needed for economic valuation. Within the area covered, only the changes in intertidal, saltmarsh and grassland habitats and changes in the CO_2 equivalent flux are included. All impact assessments are subject to several caveats.

The details of the Severn Estuary and the ecosystem services it provides as relevant for this analysis are presented in Sections 1 and 4.1 of the technical report.

4. ENVIRONMENTAL CHANGE VALUED

[4] Tidal range – vertical distance between the highest high tidal and the lowest low tide. http://severntidalpowerconsultation.decc.gov.uk/feasibility_study_overview - SDC Report 2007

[5] Specifically an 80% reduction in greenhouse gas emissions by 2050. In addition the draft EU Renewable Energy Directive (CEC, 2008) will require 15% of UK energy generation to come from renewable sources by 2020.

[6] http://www.jncc.gov.uk/page-23

[7] Bird species of importance include; Bewick's swan, Shelduck, Dunlin, Redshank, European white-fronted goose, Gadwall and Internationally important assemblage of wintering waterfowl.

The environmental change valued here is the result of the likely impacts of the STP options (as reported by SEA in Black and Veatch, 2010, version 16th March). Five shortlisted options are separately analysed, namely:

1. **Shoots Barrage** (B4) – located near the Severn road crossings;
2. **Beachley Barrage** (B5) – slightly smaller and further upstream than the Shoots Barrage (and upstream of the Wye);
3. **Welsh Grounds Lagoon** (L2) **-** an impoundment on the Welsh shore of the Estuary between Newport and the Severn road crossings;
4. **Bridgwater Bay Lagoon** (L3d) – an impoundment on the English shore of the Estuary between Hinkley Point and Weston Super Mare; and
5. **Brean Down to Lavernock Point Barrage** (B3) **-** located between Brean Down and Lavernock Point.

Likely impacts on intertidal (i.e., mudflat, sandflat, rock and shingle), saltmarsh and grasslands are included in the analysis. As mentioned above, a bundled approach is adapted here which uses the change in the habitat area as a proxy for the changes in the ecosystem services associated with each habitat type. The exception to this is the carbon cycle which is valued as a single service on its own. Changes in the CO_2 equivalent flux (changes in the sequestration and emissions) due to each STP option are also included in the analysis.

The following likely impacts are excluded due to lack of scientific and economic data:

- Those associated with freshwater systems flowing into the Estuary are not covered but fisheries impact is as it relates to the Estuary is included;
- Those associated with the water column are excluded from the analysis;
- Archaeology, health impacts and agricultural values associated with the Estuary; and
- Construction impacts.

The scale of the economic value of impacts excluded is not possible to assess due to lack of similar analysis in the literature. For construction impacts, there is evidence from large scale water infrastructure construction projects. Economic value of these construction impacts is a small fraction of the overall environmental and financial costs of a those projects. However, it is not clear how comparable those infrastructure projects are to the STP options and hence it is not possible to make a comment on the size of this gap in the analysis.

The change in each impact category included is measured from the current situation in 2010 and assumed future baseline 2014 (the same as 2010) onwards for the entire duration of the options' operational lifetime of 120 years. The net change includes both the losses and gains due to STP options.

Sections 5 and 6 of the technical report present qualitative and quantitative analysis of the environmental change (taken from the SEA), respectively. The analysis is taken from the SEA work.

5. AFFECTED POPULATION

The two population groups affected by an environmental change are:

- *Users*: consist of those making direct use of a resource (e.g. all visitors to the Severn Estuary). The group also includes those deriving indirect use values from the ecosystem services such as regulating and supporting services. Different elements of use value can be relevant at different spatial scales; recreation values may only be relevant at a local level, while others such as flood protection may confer benefit on a larger regional scale. Indirect use values in terms of carbon storage and sequestration are relevant at a global scale as a reduction of carbon emissions (and hence reduction in climate change potential) benefits the global population.

- *Non-users*: derive some wellbeing from a resource even though they do not make direct or indirect use of it. Instead economic values are associated with altruistic, bequest and existence value motivations. The Severn Estuary for example provides habitats for many migratory fish and important bird species for which individuals may hold non-use values. Indeed, the mere existence of the Estuary may be valued by individuals in its own right. There are no theoretical rules for determining who is likely to hold non-use values and hence it is usually not possible to define non-user population ex ante. It is an empirical finding that requires primary research.

Given the scale and importance of the Severn Estuary, it is likely that the population affected by changes to it will be the entire UK population which may hold use and non-use values. However, due to the lack of a theoretical boundary for non-use population and limitations of the only relevant value function from the literature, this project limits the affected population to two alternatives; 'local' (lower bound damage estimate) and 'regional' (higher bound damage estimate), (see Section 6 below for further details relating to the lower and higher bound estimates) within the 50km of the affected geographical area. Both use and non-use values are likely to be captured within this but it is not possible (neither it is necessary) disaggregate them.

Section 4.2 of the technical report discusses the affected population. Various detailed assumptions about the relevant characteristics of this population are presented in Sections 7 and 8 of the technical report on the application of the chosen value function.

6. ECONOMIC VALUES USED

As mentioned above, the economic value evidence selected from the literature as most appropriate for intertidal and saltmarsh habitats is the meta-analysis developed by Brander et al. (2008). Grassland estimates come from Oglethorpe (2005). The economic value for changes in CO_2 equivalent flux are estimated using the latest DECC guidelines (2010). This section summarises what these unit values are and the sensitivity analysis performed to generate ranges for the unit values, where possible.

Brander et al. (2008) provide a value function that reports the coefficients for factors that are found to influence people's WTP for (and hence economic value of) wetlands. The dependent variable of the function is WTP for wetlands in terms of £ per hectare per year. The explanatory factors include[8]:

- Definition of the wetland type (here intertidal and saltmarsh habitats are used);
- Whether the change in the wetland can be described by marginal or average values[9];
- Size of the wetland area affected;
- Whether the wetland provides
    - flood control services;
    - surface and groundwater services;
    - water quality improvement;
    - recreational fishing;
    - commercial fishing and hunting;
    - recreational hunting;
    - for the harvest of natural material;
    - material for fuel;
    - non-consumptive recreation;
    - amenity and aesthetic services;
    - biodiversity;
- GDP per capita for the affected area;
- Population within 50 km of the affected area; and
- Size of the wetland area within 50 km (including other wetlands that are not affected by the change valued to establish the availability of substitutes).

[8] A unique feature of the Brander et al (2008) function is that it recognises that the overall size of the wetland and the number of ecosystem services it provides affect not only the total value of the wetland but also the unit value in terms of £ per hectare per year. The smaller the area the more valuable each unit reflecting the scarcity value of the habitat. The fewer services it provides, the smaller the unit economic value reflecting the lower quality.

[9] The marginal value of the Severn Estuary is the additional economic value of its services (e.g. water in a particular use, such as abstraction for agriculture) generated by the last unit of wetland in the Estuary. The average value is the total economic value of the Estuary's services divided by the total hectarage. Thus the average value of a hectare of the wetland remains the same regardless of whether a hectare is gained or lost, while the marginal value increases as a hectare is lost and the wetland becomes scarcer. The per hectare value of each habitat type increases when the marginal value setting is used within the value calculation, thus increasing damage cost estimates when habitat is lost.

This project collected data (mainly from the SEA work) and made assumptions about the value these factors take in the area affected by the STP options.

The function is run once with the values for each explanatory factor for the current situation (Severn Estuary without any STP options) to estimate the unit economic value in the current situation (see Table 1 below). The function is then run separately for each of the five STP options to estimate the unit economic value for each of them.

As part of sensitivity analysis, lower and upper bound unit values are estimated using different values for the above factors for intertidal and saltmarsh valuation and also for the CO_2 equivalent flux.

The lower bound estimate comes from the 'low damage scenario' in which all relevant factors are defined so that the current unit value of the Severn Estuary is a lower bound estimate and the unit value of change under each STP option is also a lower bound estimate. In the 'high damage scenario', both the current unit value and the unit value of change are at their highest. In other words, the low damage scenario shows the case of losing a small value from an already low value resource, and high damage scenario shows the case of losing a high value from an already high value resource. This is demonstrated by the different unit values used for saltmarsh and intertidal habitats reported in Table 1.

The two scenarios used for unit economic value estimates are defined as follows:

The LOW damage scenario (lower bound damage estimates):

- There are wetlands available within the 50km diameter of the Estuary that could function as substitutes to the Severn Estuary.
- The affected population considered within this estimate relates to the 'local' population only, i.e., towns along the estuary up to Minehead on the English coast and Cardiff on the Welsh coast including: the local and unitary authorities of Cardiff, Newport, Bristol and Bath, and N.E. Somerset.
- The 'average' value estimates are used within the calculation of value change.
- The habitats that remain unaffected in the 'with STP option' case provide all the services they provide today, i.e., each 1 ha of a given habitat that remains continues to provide all its services.
- Central CO_2 equivalent flux in tonnes per year are valued at the lowerbound DECC non-traded unit value in £ per tonne.

The HIGH damage scenario (upper bound damage estimate):

- There are no substitute wetlands available within the 50km diameter area.
- The affected population considered within this estimate relates to the 'regional' population, i.e., the South West Region for England and E. Wales.
- The 'marginal' value estimates are used within the calculation of value change.
- The habitats that remain unaffected in the 'with STP option' case do not provide any of the services they provide today, i.e., due to the changes to the complex nature of the Severn Estuary that exist today, remaining habitats also lose their ecosystem services.

- Central CO_2 equivalent flux in tonnes per year are valued at the upperbound DECC non-traded unit value in £ per tonne.

For the unit values in the current situation, 'low damage' scenario has the same definition as it has for STP options. This is evident in similar unit values for current situation and the individual options, which only differ because of the change in the area of each habitat under the current situation and each STP option. As for the 'high damage' scenario, ecosystem services continue to be provided in the current situation (without the STP option) but are entirely lost in all STP Options. All other parameters of high damage scenario apply in the same way for the current situation as listed above for the STP options. The significance of the loss of ecosystem services is evident in the large differences between the unit value estimates in the current situation and those in the STP options.

Both damage scenarios use the same unit economic value for grassland. Other sensitivity analyses are also implemented as shown in Section 7 below.

In addition to unit value estimates, Table 1 also summarises what is included, excluded and what further caution needs to be exercised when interpreting the values. It is not possible to determine the scale of uncertainty around the unit estimates (e.g. in % terms around the estimates presented here).

Table 1: Unit change and unit economic value estimates used in the economic valuation of the environmental impacts of the STP Options within the Bristol Channel

Habitat – value type	Current situation	Immediate Effect (~2020)				
		Brean Down to Lavernock Point Barrage (B3)	Shoots Barrage (B4)	Beachley Barrage (B5)	Welsh Grounds Lagoon (L2)	Bridgwater Lagoon (L3d)
Saltmarsh						
Area (ha)	990	780	1,130	1,070	1,070	1,240
Change from current situation (ha)	-	-210	+140	+80	+80	+250
Unit value (£ per ha per yr)						
Low damage scenario	697	748	670	681	681	652
High damage scenario	1,337	36	32	33	33	31
Intertidal mudflat						
Area (ha)	29,930	13,700	26,480	27,030	22,600	27,150
Change from current situation (ha)	-	-16,230	-3,450	-2,900	-7,330	-2,780
Unit value (£ per ha per year)						
Low damage scenario	245	309	254	252	266	252
High damage scenario	466	15	12	12	13	12
Grassland						
Area (ha)	60	590	110	120	110	140
Change from current situation (ha)	-	+530	+50	+60	+50	+80
£ per ha per year	5.74	5.74	5.74	5.74	5.74	5.74
CO_2 equivalent flux (decrease in emissions after the STP option is implemented)						
Change in CO_2 equivalent tonne per year (decrease in emissions)	n/a	-1,706	-4,139	-1,981	-3,360	-376
Unit value (£ per tonne per year) (2020 – 2140)						
Low damage scenario	25-67	25-67	25-67	25-67	25-67	25-67
High damage scenario	75-469	75-469	75-469	75-469	75-469	75-469
Included:	Change in the area of saltmarsh, intertidal and grassland habitats and CO_2 equivalent flux. Saltmarsh and intertidal habitats (which includes: intertidal mudflat, intertidal sandflat, intertidal rock and intertidal shingle) represents area between the Highest Astronomical Tide (HAT) and the Lowest Astronomical Tide (LAT) . The predictions of initial habitat extent take account of short-term changes in water levels, bathymetry (water depth), sediment type, tidal curve and fetch. In this context the initial changes are in relation to the outputs of a spring neap cycle immediately post STP scheme. ***Low damage scenario:*** local population, wetland substitutes, average wetland values, and assumes that all services continue					

Table 1: Unit change and unit economic value estimates used in the economic valuation of the environmental impacts of the STP Options within the Bristol Channel	
	being provided by the habitat areas remaining following the STP scheme. ***High damage scenario:*** regional population, no substitutes, marginal wetland values, and assumes that all services are lost (even those of the remaining habitats) following the STP scheme. The estimates of CO_2 equivalent flux include: The effect of the loss of potential carbon sequestration, i.e., the change in the amount of habitat (ha) is assumed to lead to a year on year loss of the ability to sequester carbon, Siltation (averaged over the project lifetime to obtain an annual value), and Methanogenesis.
Excluded:	Saltmarsh and Intertidal habitat estimates do not include intertidal areas of sub-estuaries and changes arising from long term morphological processes. Change in the area of freshwater wetlands, changes to Rivers and Streams and the Water column, i.e., subtidal are likely to be affected by each STP scheme. The following factors that are likely to have an effect on the unit economic value estimate but are excluded from the analysis due to lack of data: • Ecosystem services of archaeology and health effects of wetlands, • Population (users and non-users) outside the 50 km diameter area, and • Far field effects (beyond Bristol Channel). Ecosystem services excluded because STP scheme is likely to lead to no change or no significant change in an ecosystem service include: habitat provision for bees, subsistence cropping, subsistence shell fishing and catch, wildfowling, water for industrial cooling, air quality, other recreation, and renewable energy (i.e., fuel for biomass). Ecosystem services included within other technical reports (i.e., aggregate extraction and navigation/port services) are excluded here. The total flux in annual CO_2 equivalent emissions exclude: • Any changes as a result of the Nitrogen cycle, • The loss of sequestered Carbon as a result of a change in intertidal, saltmarsh and grassland, and • Ecological changes that are likely to take place where an STP option is installed, for example, an increase in algal growth which may lead to an increase in sequestration.
Further caution	Caution should be used if comparing values between STP options as these represent estimates for the comparison of different optimisation strategies within STP options. As such these values maybe subject to different levels of reliability. In addition different design factors may have been taken into account for different options and current optimal solutions may change. The effects on sequestration and methanogenesis are extremely sensitive to ecological factors which could be altered by different design options/optimisation for each option. Values relating to the total flux in annual CO_2 equivalent emissions should be used with caution as they are subject to high levels of uncertainty. Negative values relating to total flux in annual CO_2 equivalent emission relate to decreases in emissions. The unit values presented here relate to habitat information obtained from the SEA on the 16th March 2010; and CO_2 emission estimates from 23rd March 2010.
Source:	Based on Table 8.2 and 8.3 of the technical report.

For the intertidal and saltmarsh habitats, total annual change in the value of Severn Estuary due to each STP option is calculated as the change in the total annual value from the current situation in the following terms:

(Unit value for STP option x hectare left under the STP) - (Unit value for the current situation x hectare in current situation)

FOR EXAMPLE - for Brean Down to Lavernock Point Barrage, saltmarsh, low-damage estimate, the numbers in Table 1 result in:

= 780ha * £748 per ha per year – (990ha * £697 per ha per year)

= £583,440 per year – £690,030 per year

= - £106,590 per year

The negative sign denotes environmental costs. See Table 2 for annual values.

For grassland, the total annual value change uses the same calculation of unit value (£ per hectare per year) multiplied with size of the area (hectare per year) but the same unit value applies to current situation and STP options (see Table 2).

For CO_2 equivalent flux, total annual value change is estimated by multiplying the unit value, which varies according to the reference year (DECC, 2010) (£ per tonne per year) with the annual change in the flux (tonne per year). However, since the unit economic value estimate vary each year (according to DECC 2010 guidelines), total annual values for CO_2 equivalent flux are not shown in Table 2. Table 3 shows the total value of the change in CO_2 equivalent flux in present value terms for the project lifetime.

Table 2: Total annual value of the intertidal and saltmarsh habitat change within Bristol Channel (based on Brander et al., 2008) and grassland change based on Oglethorpe (2005); (£2008-2009)

Habitat - value type	Current value	Immediate Effect (~2020)				
		Brean Down to Lavernock Point Barrage (B3)	Shoots Barrage (B4)	Beachley Barrage (B5)	Welsh Grounds Lagoon (L2)	Bridgwater Lagoon (L3d)
Saltmarsh (total annual results in thousands)						
Ha remaining	990	780	1,130	1,070	1,070	1,240
£/ ha / year low-high	+697 - +1,337	+748 - +36	+670 - +32	+681 - +33	+681 - +33	+652 - +31
£ Total Value / yr (thousands) low-high	+690 - +1,323	+583 - +28	+757 - +36	+728 - +35	+728 - +35	+808 - +39
£ value change / yr (thousands) from current situation low-high	0	(-106) - (-1,295)	+67 - (-1,287)	+39 - (-1,288)	+39 - (-1,288)	+118 - (-1,284)
Intertidal mudflat (total annual results in thousands)						
Ha remaining	29,930	13,700	26,480	27,030	22,600	27,150
£ / ha / yr; low-high *Value change from updates +0.7% - 0% across all options*	+244 - +464	+309 - +15	+254 - +12	+252 - +12	+266 - +13	+252 - +12
£ Total Value / yr (thousands) low-high *Value change from updates -1% across all options*	+7,329 - +13,959	+4,231 - +204	+6,725 - +324	+6,822 - +329	+6,016 - +290	+6,844 - +330
£ value change /yr (thousands) low-high	0	(-3,098)-(-13,755)	(-605) - (-13,635)	(-507) - (-13,631)	(-1,313)-(-13,670)	(-485) - (-13,630)
Grassland						
Ha remaining	60	590	110	120	110	140
£ / ha / yr	5.74	5.74	5.74	5.74	5.74	5.74
£ Total Value / yr	+344	+3,387	+631	+689	+631	+804
£ value change /yr from current situation	0.00	+3,042	+287	+344	+287	+459
Total value change £ per yr nearest 10,000 (thousands) low-high	0.00	(-3,201) - (-15,050)	(-537) - (-14,920)	(-468) - (-14,920)	(-1,274)-(-14,960)	(-367) - (-14,910)
Included:	See Table 1					
Excluded:	See Table 1					
Caution:	See Table 1 The unit values presented here relate to information obtained from the SEA on the 16th March 2010. These values were updated after the original project cut-off date for inputs, the impact of this update was to change the annual value of the change					

Table 2: Total annual value of the intertidal and saltmarsh habitat change within Bristol Channel (based on Brander et al., 2008) and grassland change based on Oglethorpe (2005); (£2008-2009)	
	associated with intertidal habitats by +1% - -1% across STP Options, this in turn changed the total annual value of habitat change by +0.3 - -1.8% across all STP Options. The affect of these changes has been documented here and within the technical report as the accompanying sensitivity analyses relating habitat estimates have not been updated within the technical report due to the magnitude of the associated change (Steering group meeting 23rd March, 2010).
Sources:	Based on Table 9.1 of the technical report

Section 7 of the technical report presents the economic valuation literature review. Details of the value function selected and how it is applied here can be found in Section 8 of the technical report. Unit values that could be used to estimate the cost of construction impacts are presented in Section 12 of the technical report. However, as these are not used for aggregate results, they are not summarised here.

7. AGGREGATE RESULTS, ASSUMPTIONS AND CAVEATS

This is possibly the most extensive application of value transfer function in such a large scale investment decision in the UK. Therefore, a significant amount of effort has gone into combining the outputs from SEA and economic value evidence from the literature and making the latter more specific to the environmental conditions of the Severn Estuary with and without the STP options.

The results aggregated across type of impact, affected population and time are reported in Table 3. These results show that:

- All five STP options lead to net environmental costs.
- Environmental cost estimates are expressed as present value (PV) terms over the operational lifetime of 120 years starting from 2020. Discounting requirements by the Treasury Green Book are applied here.
- The economic valuation shows that the lowest cost is associated with the Shoots Barrage for the 'low damage' scenario. The cost increases for Beachley Barrage, Bridgwater Lagoon, Welsh Grounds Lagoon and Brean Down to Lavernock Point Barrage options, respectively. Looking at habitat only related changes this order remains similar for the 'high damage' scenario with Shoots Barrage, Beachley Barrage and Bridgwater Lagoon producing very similar estimates. However, accounting for the 'high' cost estimate of CO_2 emissions changes Bridgwater Lagoon to the highest cost option. This change is driven by the fact that the change in CO_2 emissions associated with this option is estimated to be at least 80% lower than for all other options.
- The estimates range from PV cost of £5.9 million for the low damage scenario for Shoots Barrage to PV cost of £218.6 million for the high damage scenario for Bridge Water Lagoon. PV combines the change in the area of habitat (in both low and high damage scenarios) and change in the amount of ecosystem services provided by remaining habitat (same as current situation in low-damage scenario, no provision in high damage scenario).
- Changes to the area of saltmarsh, intertidal and grassland habitats and CO_2 equivalent flux are included in these estimates.
- In physical impact terms:

- The area of saltmarsh declines under Brean Down to Lavernock Point Barrage but increases under the other four STP options compared to the current situation.

- The area of intertidal habitat declines under all five STP options compared to the current situation.

Table 3: Summary of present values of selected environmental impacts of STP options in the Bristol Channel (applying standard discount rates, HMT, 2003 in £ millions, rounded to the nearest £10,000)					
Habitat – value type	**Immediate Effect (~2020)**				
	Brean Down to Lavernock Point Barrage (B3)	**Shoots Barrage (B4)**	**Beachley Barrage (B5)**	**Welsh Grounds Lagoon (L2)**	**Bridgwater Lagoon (L3d)**
MAIN ESTIMATE	PV over the project lifetime £ million (120 years)				
Saltmarsh: low-high	(-2.40) - (-19.17)	+1.51 - (-19.05)	+0.87 - (-19.07)	+0.87 - (-19.07)	+2.66 - (-19.01)
Intertidal mudflat: low-high	(-69.73) - (-203.63)	(-13.61) - (-201.85)	(-11.41) - (-201.78)	(-29.52) - (-202.36)	(-10.93) - (-201.77)
Grassland	+0.07	+0.01	+0.01	+0.01	+0.01
Total change in habitats: low-high	(-72.06) - (-222.73)	(-12.09) - (-220.89)	(-10.53) - (-220.84)	(-28.68) - (-221.42)	(-8.26) - (-220.77)
Carbon costs: low-high	+2.55 - +10.60	+6.18 - +23.46	+2.96 - +11.23	+5.02 - +19.05	+0.56 - +2.13
TOTAL – MAIN ESTIMATE RANGE: low-high	**(-69.51) - (-212.13)**	**(-5.91) - (-197.43)**	**(-7.57) - (-209.61)**	**(-23.66) - (-202.37)**	**(-7.70) - (-218.64)**
SENSITIVITY ANALYSIS – total value is shown with percentage change from the original estimate underneath (+ showing an increase in value lost, - showing a decrease) - **Sensitivity analyses are not updated with new values for intertidal marsh.**					
Total change in habitats using Ghermandi et al. (2008) function (ITM, SM): low-high	(-104.0) - (-1,788.0)	(-19.7) - (-1,766.8)	(-16.5) - (-1,766.0)	(-43.8) - (-15.2)	(-14.8) - (-1,765.5)
Applying a lower discount rate (ITM, SM, GL): low – high	-85.6 (+18%) - -414.0 (+184%)	-14.5 (+18%) -410.6 (+184)	-12.4 (+18%) - -410.5 (+184)	-34.3 (+18%) - -411.6 (+184%)	-9.7 (+18%) - -410.3 (+184%)
Testing the effect of losing a single ecosystem service on unit values (£ per hectare): 'Low damage scenario' assumes that ALL ecosystem services of habitats remaining after STP options will continue to be provided. In this test, the effect of a single service being lost while others continue is shown. For example, the 'flood protection' row shows that if this service alone is lost, the cost estimate for Brean Down to Lavernock Point under the low damage scenario will increase by 67%.					
Flood protection	67%	67%	+67%	+67%	+67%
Biodiversity	60%	60%	+60%	+60%	+60%
Water Quality	59%	59%	+59%	+59%	+59%
Non-consumptive	29%	29%	+29%	+29%	+29%
Aesthetics	53%	53%	+53%	+53%	+53%
Included:	Same as Table 1				
Excluded:	Same as Table 1				
Caution:	Same as Table 1 The main estimate values presented here relate to information obtained from the SEA on the 16th March 2010. These values were updated after the original project cut-off date for inputs, the impact of this update was to change the total value of the change associated with intertidal habitats by +0.2% - -1.6% across STP Options. The affect of these changes has been documented here and within the technical report as the accompanying sensitivity analyses relating habitat estimates have not been updated within the technical report due to the magnitude of the				

Table 3: Summary of present values of selected environmental impacts of STP options in the Bristol Channel (applying standard discount rates, HMT, 2003 in £ millions, rounded to the nearest £10,000)	
	associated change (Steering group meeting 23rd March, 2010).
Sources:	Table 13.1 in the technical report.

- The area of grassland habitat increases under all five STP options compared to the current situation.
- The changes in the CO_2 equivalent annual flux mean that STP options will save CO_2 emissions. This is relative to the Severn Estuary's net CO_2 annual flux in the current situation. It includes – the effect of the loss of potential carbon sequestration, i.e., the change in the amount of habitat (ha) is assumed to lead to a year on year loss of the ability to sequester carbon, and siltation (averaged over the project lifetime to obtain an annual value), and Methanogenesis. The avoided emissions from other fuel sources, if STP options are used instead to generate electricity, are not included in this analysis.

- In economic value terms, the unit value estimates reported in Table 1 are used for aggregation. Caveats associated with what is included and excluded as reported in that table apply here too.

However, these results are significant underestimates for the following key reasons:

- PHYSICAL IMPACTS: Assessment of physical impacts tends to be an underestimation for the following reasons:
  - Geographical coverage of the impact assessment is limited:
    - Only the impacts on saltmarsh, intertidal and grassland habitats in the Bristol Channel are included; and
    - Far field effects such as the changes to the flows in Irish Sea, or the changes to the sea level along the Western coast of the UK are exclude.
  - Coverage of habitats included in the analysis is limited:
    - Impacts on freshwater wetlands, rivers and water column are excluded; and
    - CO_2 equivalent flux estimates exclude: any changes in the nitrogen cycle, loss of sequestered carbon as a result of a change in intertidal, saltmarsh and grassland habitats, other ecological changes such as an increase in algal growth which may lead to an increase in sequestration.
  - Some ecosystem services are excluded from the analysis due to a lack of scientific data on impacts and economic data on values – not likely to be a significant impact:
    - Human health services of wetlands;
    - Archaeological services of wetlands;
    - Agricultural values; and

  - Physical impacts during the construction phase are excluded.

- UNIT ECONOMIC VALUES: Unit economic values used are underestimates for Severn Estuary:

  - The Brander et al. (2008) function used is developed for a typical wetland in Europe. Severn Estuary is not a typical wetland and hence the unit use and non-use values from the function are likely to be significant underestimates.

  - The Brander et al. (2008) function limits the population (user and/or non-user) to that within the 50km radius of a given wetland. This area used in this analysis assumes that no one outside this area has any preference for the Severn Estuary and changes to it from the STP options. This cannot be correct and the implication is that the main estimates here are underestimates.

- AGGREGATED ECONOMIC VALUES: Assumptions about how the Estuary is likely to change over time and how the unit values should be aggregated over time also lead to main results that are on the whole underestimates:

  - Estimates do not allow for any potential recovery within the Severn Estuary. Despite this, the aggregated results are still likely to be underestimates given that the environmental change as a result of STP will be irreversible and continue into perpetuity.

  - The aggregation over time assumes that the change in habitats and annual CO_2 equivalent flux starts in 2020 at the end of the construction period. Thus, until then the value (cost or benefit) of change is assumed to be zero. This is likely to lead to an underestimate as (a) impacts of the construction itself are excluded and (b) environmental impacts in the Estuary as a whole will start as soon as the construction starts.

  - The main discount rate recommended by the Treasury Green Book is used to reach the aggregate values in the table. The lower discount rate recommended by the Green Book for intergenerational effects is used in sensitivity analysis. The implication for the main results is that they are underestimates.

  - The future baseline (i.e. how the current situation will change over time) is assumed to remain unchanged and there is no scientific or economic data relating to the value of potential ecosystem services that maybe provided (without STP) in the future – the implication is that the results are likely to be underestimates.

  - The unit economic value estimates remain constant over the lifetime of the project. Sensitivity analysis tests this assumption by assuming GDP growth from 2020 to 2140 which therefore increases the per-hectare per year value of both intertidal and saltmarsh habitat over time. The implication for the main estimates is that they are underestimates. The £ per-hectare per year value of grassland is not changed overtime even in the sensitivity analysis.

Given these caveats, extensive sensitivity analyses are undertaken:

- Low damage and high damage scenarios as described above. Table 2 shows that there are large differences between low and high scenarios including for saltmarsh habitats, where the low scenario shows a net benefit, while high scenario shows a net cost (a negative sign in the table). The reason behind this discrepancy is the assumption about whether the habitats in existence after a given STP option continue to provide ecosystem services. In the 'low damage' scenario they do, hence increase in the area of saltmarsh results in an increased total annual value. In the 'high damage' scenario, all ecosystem services of the remaining habitat post STP option are lost. The decrease in value due to lost ecosystem services outweighs the increase in the area of saltmarsh habitat.

- Using the Ghermandi et al. (2008) value transfer function instead of Brander et al. (2008) for intertidal and saltmarsh habitats increases the estimate of the cost of STP options. This is because the coefficients reported in Ghermandi et al. for the factors affecting economic value are higher than those in Brander et al. While it is not clear exactly what drives this difference, it is likely because habitats of higher ecological value worldwide (e.g. mangroves) are included in the Ghermandi et al. and excluded from Brander et al.

- Using a lower discount rate over time increases the present value of the cost of STP options, as expected.

- To test the cost estimates between low and high damage scenarios, the value function from Brander et al. is run several times each time with one of the ecosystem services turned off. The effect is increased costs compared to low damage scenario, as expected.

While such extensive sensitivity analysis has been performed on the unit value estimates, this does not address the key caveat of the overall value transfer which assumes that the Severn Estuary is a typical European wetland.

Section 9 of the technical report presents further detail on the aggregation process. Section 10 provides a detailed account of the sensitivity analysis conducted which is not summarised here in its entirety. Section 11 of the technical report provides an introduction to how economic valuation in general, and work completed in this project in particular, can contribute to the discussions on compensation measures. Section 13 summarises the above caveats and implications for the results.

8. OFFSETTING AND COMPENSATORY MEASURES

As mentioned above, the impacts valued here are residual after likely mitigation measures are factored into the STP option design as part of the SEA. The SEA process requires consideration of measures to prevent, reduce or offset negative environmental effects. Separate work is undertaken on considering possible offsetting and compensatory measures. This work is at the strategic level at present with details such as the location and exact nature of all offsetting and compensatory measures unknown.

A sub-set of work on offsetting is a consideration of how the requirements of the Habitats Directive for compensation might be met should a scheme be developed. Subject to other tests being met, the Directive requires compensatory measures to be taken to protect the coherence of the network of Natura 2000 sites. Commission guidance says that compensation should refer to the site's conservation objectives and to the habitats and species negatively affected in comparable proportions in terms of number and status. This approach uses ecological criteria for establishing equivalency between compensatory measures and environmental damage caused. Location of compensatory measures is also required to be as close as possible to the damaged site.

Habitat Directive compensation is not based on estimates of economic value to determine equivalency i.e. the comparison between the economic benefit of the environmental improvements from compensatory measures and economic cost of environmental damage. However, a value transfer combining economic values and ecosystem services or primary research using stated preference methods could contribute to decision making about compensatory measures. For example, these valuation approaches could be used to assess the relevant goods and services offered by compensatory measures to the populations that they affect. Such valuation approaches can be used both at the strategic level of compensatory measure design to assess individuals' priorities amongst generic habitat types and ecosystem services, and at the detailed project level to assess their priorities for location and detailed characteristics of the measures. To reiterate while economic values can be useful in bringing individuals' preferences to decision making, they are not recommended to design of compensatory measures in the context of Habitats Directive.

Section 11 of the technical report provides further detail on the ecological and economic methods that are used to assess equivalency between compensatory measures and environmental damage, and how they do or do not apply in the context of the Habitats Directive.

9. RECOMMENDATIONS

This project is possibly the most extensive value transfer applied in the UK. There are, however, several significant caveats that make the results insufficient (on their own) as input to final decision making.

Even the high damage scenario results reported here are significant underestimates. Substantial elements relating to the carbon cycle, specific ecosystem services such as health benefits and archaeology, and the effects of STP schemes on subtidal and freshwater ecosystems are excluded from the value transfer due to lack of scientific and economic data. In addition those elements of the carbon cycle, and the ecosystem services of intertidal, saltmarsh and grassland habitats that have been valued are subject to a great degree of uncertainty both within an economic and scientific context. Most importantly, the value transfer and sensitivity analyses are based on the assumption that the Severn Estuary is a typical wetland which is incorrect. It is therefore not possible even to estimate the exact level of uncertainty associated with these figures.

As more information about the impacts of the STP options becomes available, the bundled approach used here can be repeated. In addition, single ecosystem services approach could also be used utilising the literature review of economic values presented in the technical report.

A better alternative could be implementing a stated preference study. There are two significant advantages of this approach over value transfer. The first is that a stated preference study (by surveying a large area and even nationally) can determine the extent of the non-user population that is likely to hold preferences for the Severn Estuary. Even if unit values held by non-users are low, the large (and much larger than value transfer assumption of 50 km radius) population means that aggregate values would likely be substantially higher than the estimates reported here. The second advantage of stated preference is that it can be conducted even in the presence of significant uncertainty. Better value transfer application requires better scientific impact information. Stated preference surveys could elicit individuals' preferences about uncertain impacts of STP options, i.e. their indifference to uncertainty or their aversion to uncertainty. Information about how affected population views significant uncertainty would be helpful to decision makers.

Section 13 of the technical report suggests a methodology for primary economic valuation that can support further work.

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