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Valuing Environmental Impacts: Practical Guidelines for the Use of Value Transfer in Policy and Project Appraisal

Case Study 7 – Using GIS in Valuing Ecosystem Impacts

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Case Study 7: Using GIS in Valuing Ecosystem Impacts

- *Case Study 7 presents work completed in-house by Defra in parallel to the development of the guidelines and Case Studies 1-6.*
- *It is intended to demonstrate Defra's internal GIS capacity to support the level and detail of analysis that is presented in Case Studies 3 and 4.*
- *The example focuses on a hypothetical case of valuing environmental impacts from aggregates extraction.*

INTRODUCTION

This case study demonstrates how geographic information systems (GIS) can be used in valuing impacts to ecosystems. The case study is for illustrative purposes and is purely **fictional**. It refers to a theoretical quarry in the centre of a National Park which has created a large intrusive scar on the Park's landscape. Government wishes to close the quarry but will need to purchase the mineral rights. To calculate the benefits of this action the impacts of the proposed action on the landscape must be valued, and in order to do this a combination of economic valuation evidence and GIS is applied.

Willingness to pay (WTP) values used in this case study are applied for illustrative purposes based on London Economics (1999) 'The External Costs and Benefits of the Supply of Aggregates' and Bateman et al. (2006) 'The Aggregation of Environmental Benefit Values: Distance decay and total WTP'. There are two set of willingness to pay values available from the London Economics study (**Table 1**). The first is for 'local' residents who live within five miles of the quarry. The second is a national WTP value for quarries specifically within National Parks.

Table 1: WTP to avoid environmental effects of quarries

*WTP per household**	*1999 prices*	*2009 prices****
Local residents	18.11	21.00
Confidence Intervals**	-	18.26 - 24.15
National survey (non residents)	5.09	5.90
Confidence Intervals	-	5.13 - 6.79

Notes:
* This study estimates WTP per year for a five year period. Although not ideal, for the purposes of this case study this is applied to represent *annual* WTP.
** 95% confidence interval is estimated at approximately +/- 15%
*** Inflated using consumer price index (CPI).

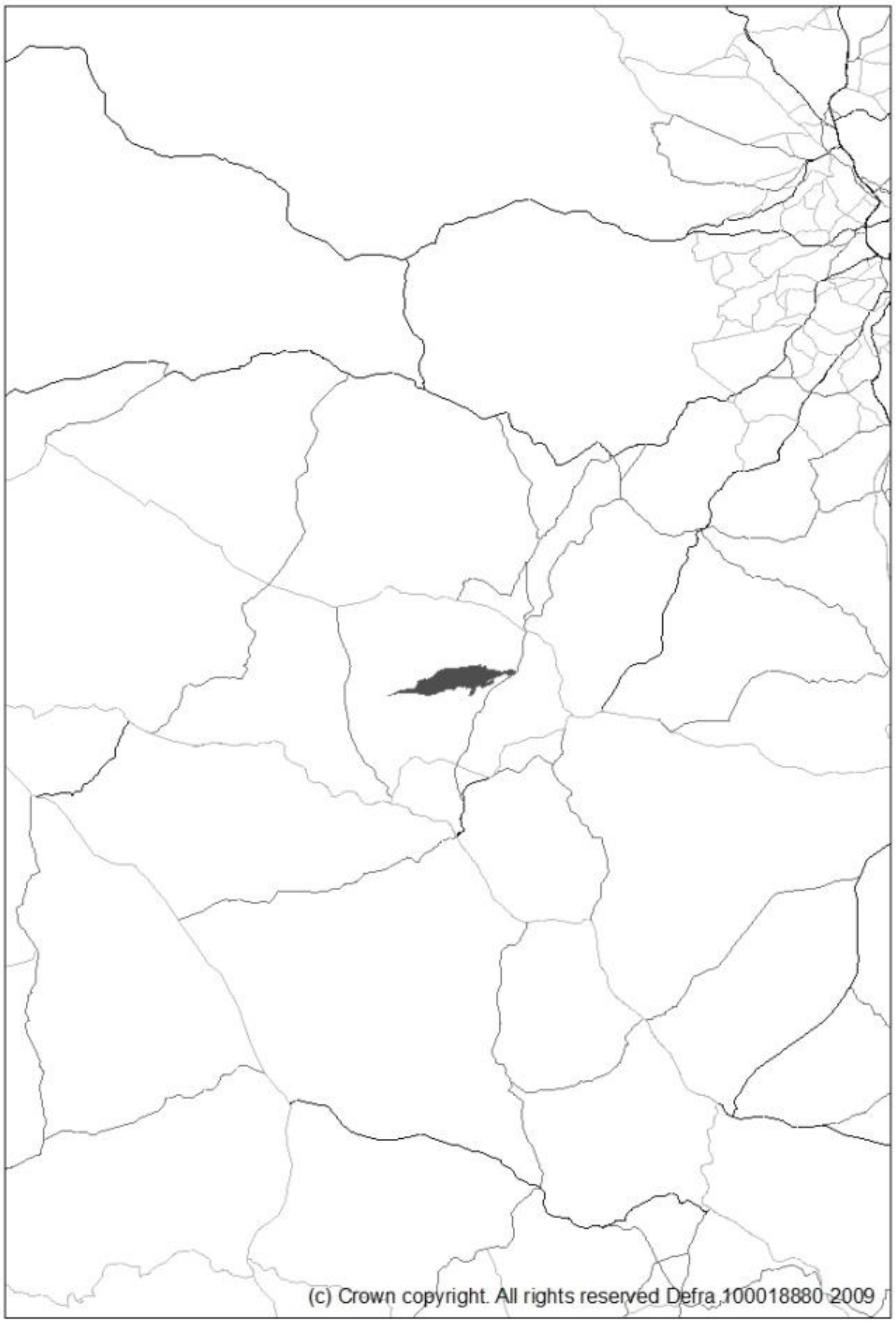
The analysis begins with a basic approach and works up to a more sophisticated methodology which utilises WTP values with a distance decay function and those with an income function.

STEPS IN APPLYING GIS TO ECONOMIC VALUATION OF IMPACTS

1. Using a GIS to identify the quarry

The first use of GIS is in spatially identifying the policy site in question, in this case the quarry (**Figure 1**). This allows for the potential for impacts to be quantified using the quarry as spatial data, around which valuation analysis can be based.

Figure 1: Spatial identification of quarry[1]



[1] These maps are illustrative.

2. Aggregating values method: within and outside five mile buffer around quarry

The first, most simple approach to valuing cessation of quarrying at the site is by using GIS to form a simple buffer around the site to calculate the number of households within five miles of the quarry. A buffer is drawn and matched to the National Statistics Postcode Directory (NSPD) (**Figure 2**). We then capture all postcode areas falling within five miles of the quarry (**Figure 3**).

Figure 2: Five mile buffer around quarry

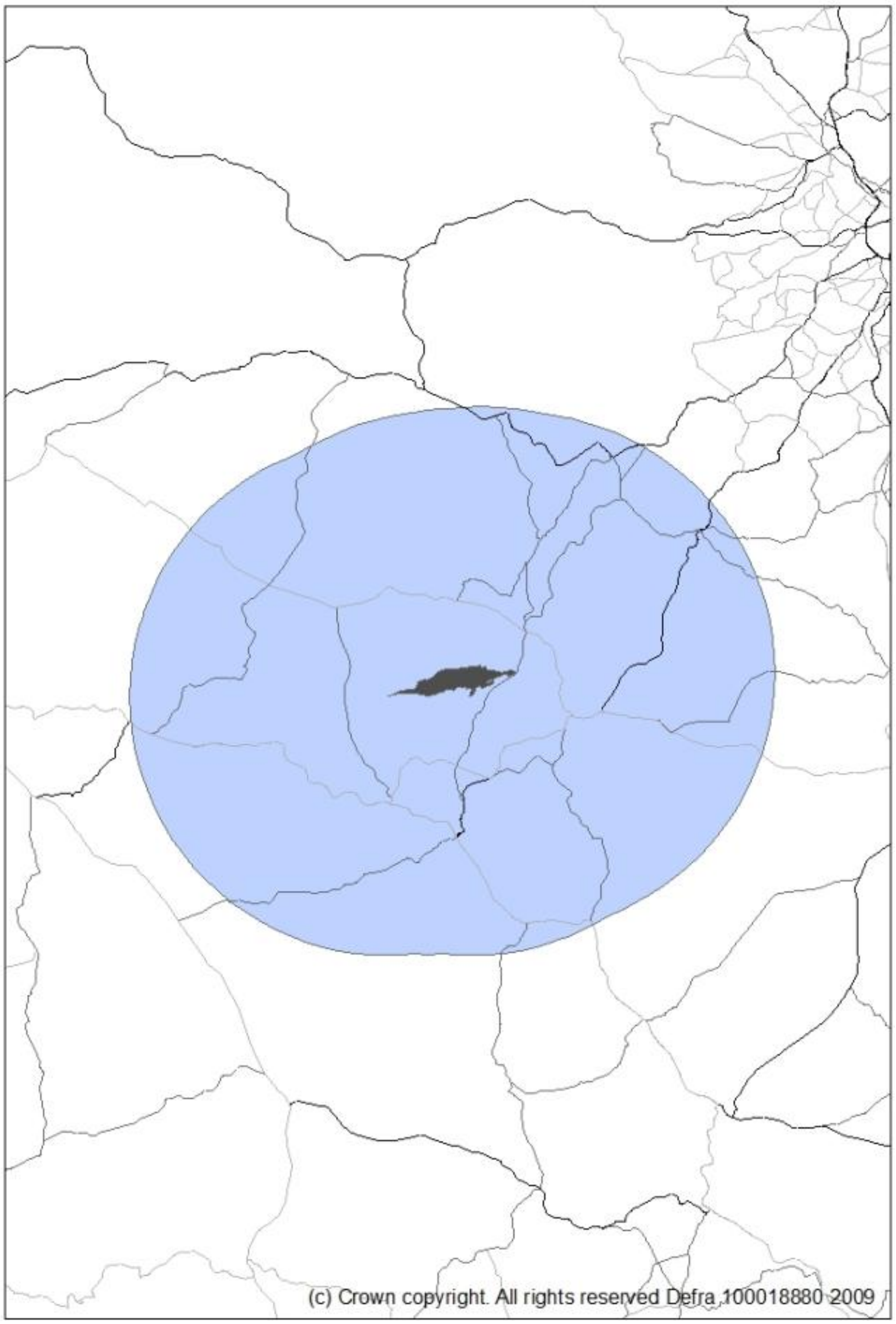
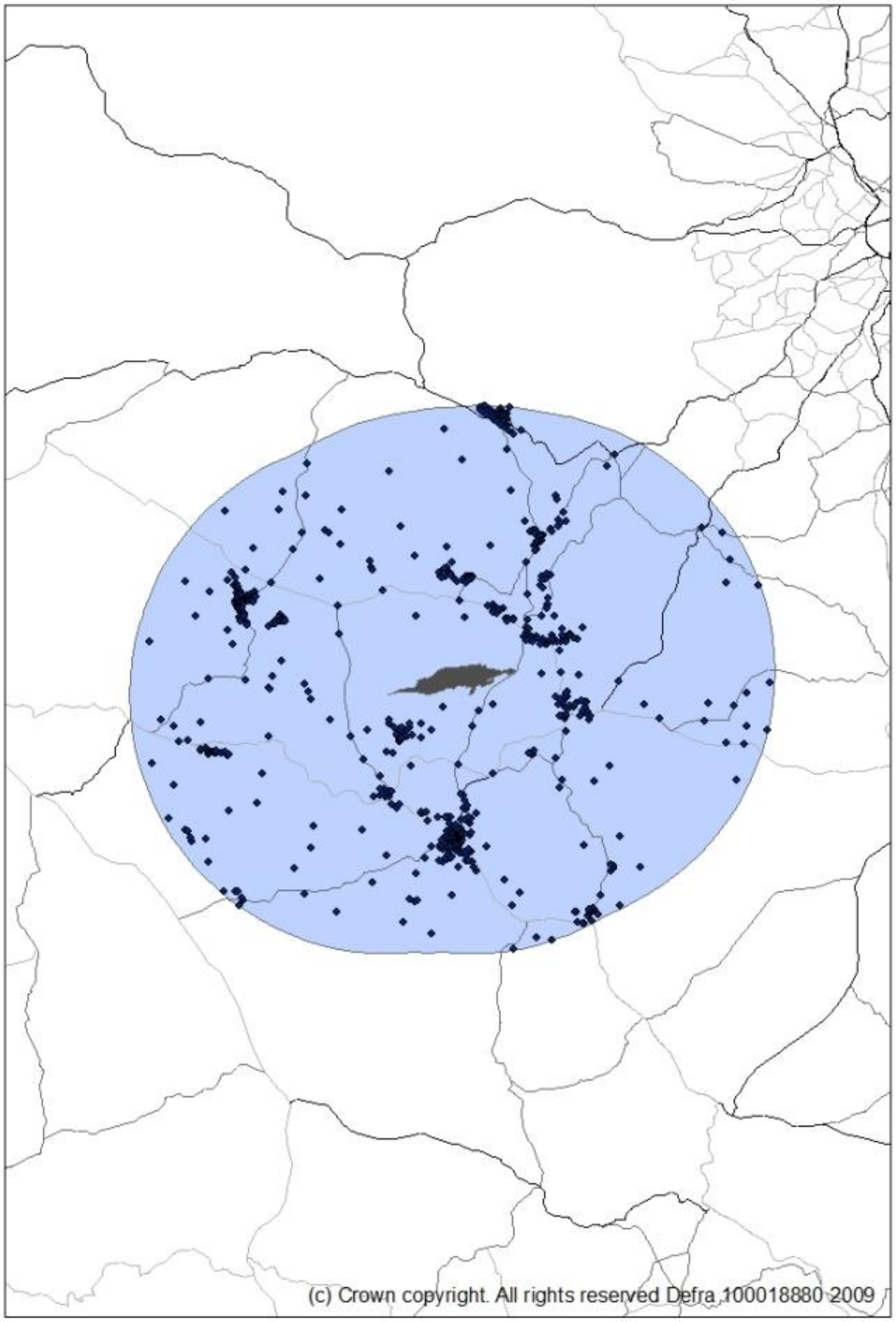


Figure 3: All postcode areas within five mile buffer of quarry



Summing the number of residential households within these postcode areas gives a unit by which the transferred WTP values can be multiplied by. The value can be calculated for both local residents (within 5 miles) and non-residents (outside 5 miles). These values are then summed (**Table 2**).

Table 1: Total annual WTP using unit values			
	Households (000s)	*Mean WTP per year (£)*	*Total WTP (£000s)*
	(a)	(b)	(a)*(b)
Within 5 miles of quarry	8.3	21.00	175
Outside 5 miles from quarry:			
England	22,169	5.90	130,860
Wales	1,240		7,320
Scotland	2,310		13,636
Total (£000s)	**25,727**		**151,990**

This gives a total WTP value of just under £152m per year.

3. Aggregating values including sensitivity analysis

By using the confidence intervals on the WTP per household values, a range of values for the quarry can be calculated (**Table 3**). This uses the same GIS methodology as the previous approach.

Table 3: total annual WTP using aggregates method and sensitivity analysis					
	Households (000s)	*Mean WTP per year (£)*	*Total WTP (£000s)*	*Range*	
	(a)	(b)	(a)*(b)	(a)*((b)/1.15)	(a)*((b)*1.15)
Within 5 miles of quarry	8.3	21.00	175	152	201
Outside 5 miles from quarry:					
England	22,169	5.90	130,860	113,791	150,489
Wales	1,240		7,320	6,365	8,417
Scotland	2,310		13,636	11,857	15,681
Total (£000s)	**25,727**		**151,990**	**132,165**	**174,788**

This places total WTP as between £132m and £175m per year.

4. Distance decay function

A more refined analysis is an extension of the notion in the previous section that people close to the quarry give higher WTP values than those living far away. A study incorporating a distance decay function, where WTP decreases as distance from the policy site increases, gives more scope for GIS to be used to calculate a more sophisticated estimate of a site's total value.

The relationship between distance and willingness to pay might be:

$$WTP = a_0 + B_d(Distance) \qquad (1)$$

Where:

- a_0 is a positive number (equal to the WTP of a household next to the quarry, i.e. where Distance = 0); and
- B_d is a negative number describing the fall in WTP as distance from the quarry increases.

Using a hypothetical[2] valuation study based on the above, this could give the model:

$$WTP = 26.46 - 2.60(\text{distance measured in km}) \qquad (2)$$

Therefore a household 8km away (around 5 miles) from the quarry would give a WTP value of:

$$26.46 - 2.60(8) = 5.66.$$

This equation also shows that after a given point, a household is too far away from the quarry to have a positive WTP value; α/β gives us the point beyond which people are willing to pay, or the economic jurisdiction, in this case 10.18km.

By using a GIS, we can capture both the number of postcode areas falling within 10.18km of the quarry and the distance that each postcode area within this ‘buffer’ is from the quarry. Then for each postcode area a willingness to pay value can be calculated using the equation above. Multiplying this value by the number of households within the postcode area and summing all postcode areas within the economic jurisdiction.

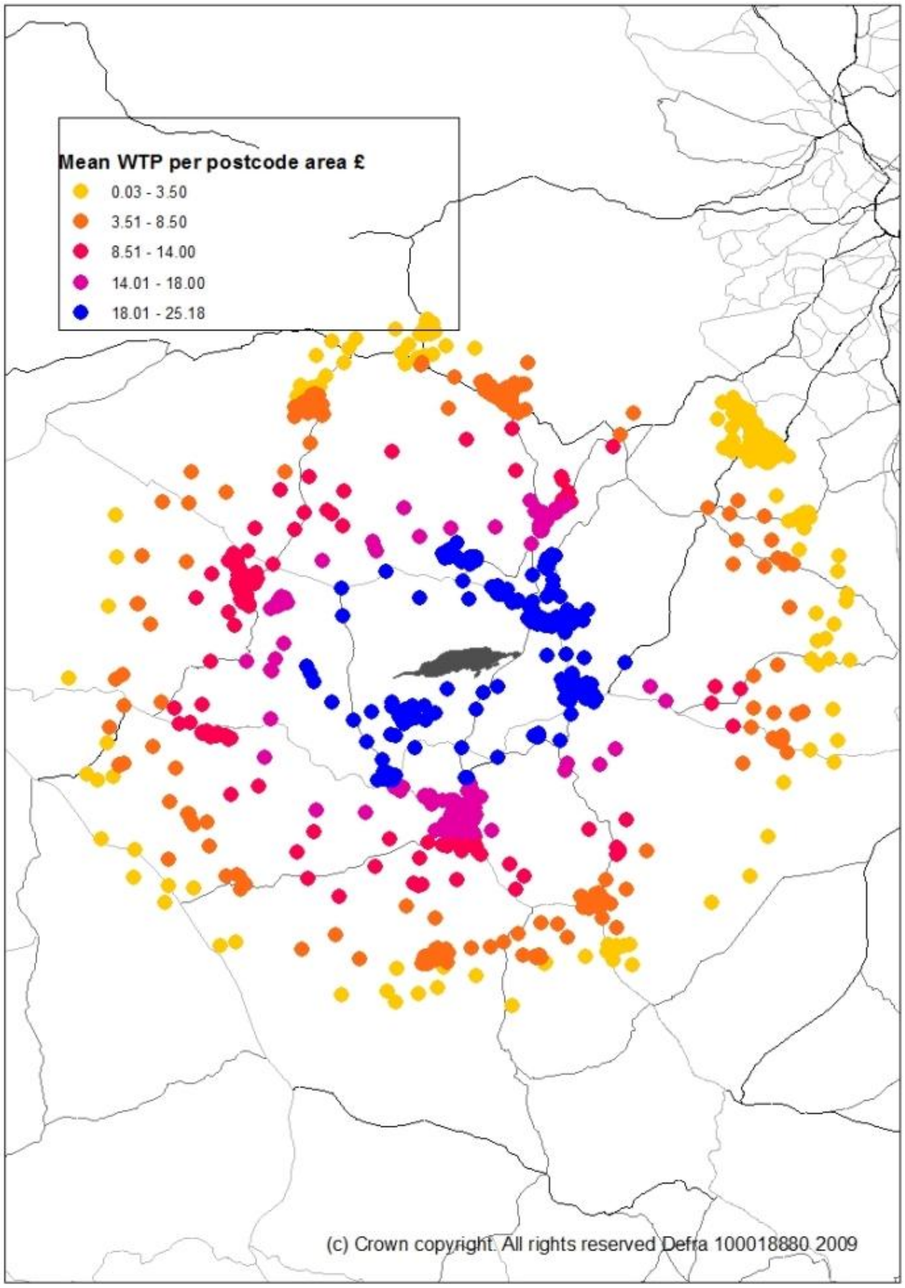
This gives a total WTP of £138,900 per year for the quarry.

Crucially, a comparison of the values given in Section 3 and those in Section 4 shows that simple unit value transfers and aggregation which do not account for distance decay (Section 2) can potentially vastly over-estimate the aggregate value of a good. The basic approach in Section 3 values the quarry’s impacts at around £152m, or between £132m and £175m. The model using a gradual distance decay function values the impact as around £139,000, or approximately £150m less than the aggregates study. This results mainly from the fact that the Section 2 approach includes no ‘end point’ to the number of households; that is, the non-local survey gave a mean WTP value for every household outside of the five mile ‘local’ area. As there are over 25 million households in Great Britain this quickly produces a very high estimate.

Figure 4 gives a graphical representation of the effects of distance on average household WTP.

[2] In practice, this is an empirical question that a valuation study should address in its analysis and report as part of the main findings (see **Annex 1**).

Figure 4: Reduction in average household WTP as distance from the quarry increases



5. *Further analyses*

Use of GIS enables further analysis to be demonstrated, particularly based on the count of households and their distance from the quarry.

Varying distance from the quarry

In Section 4 the analysis stopped at the extent of the economic jurisdiction of the quarry (i.e. the point after which the distance decay function meant that the WTP became zero). It is important that this economic jurisdiction is calculated correctly, as **Table 3** shows. By changing the jurisdiction of the quarry, the value changes considerably.

Table 3: Aggregate WTP using distance decay function and differing distances from quarry

Distance from quarry	*Average WTP per household (£)*	*Count of households*	*Aggregate WTP*
10km	10.46	13,232	138,463
8km	15.29	8,268	126,420
6km	17.20	6,677	114,858
5km	18.45	5,257	96,978
4km	20.29	3,514	71,313
2km	22.73	1,418	32,230

This table also shows that the aggregate WTP does not double simply because the distance to the quarry doubles (e.g. from 5km to 10km).

More valuable goods

The previous example dealt with a good with a value of 26.46 immediately next to the quarry, decreasing by 2.60 for every kilometre of distance from it (2). Therefore a household 8km would have a value of 26.46 – (2.60 * 8) = £5.66. If the public good in question was more 'valuable' however – for example if it was on a site of great historical or cultural importance (as could well be the case for a National Park) – the model may look more like:

$$WTP = 32.50 - 1.90(\text{distance measured in km}) \qquad (3)$$

The economic jurisdiction in this case is 17.1km. The example given above would therefore result in a value of 32.50 – (1.90 * 8) = £17.30. **Table 4** shows the effects on the aggregate WTP of the different values. The more valued good has a higher estimated value of just over £1 million compared to £139,000.

Table 4: Comparison of aggregate WTP for different quality sites						
	Distance decay function		*Economic jurisdiction (distance in km where WTP falls to zero)*	*Average WTP per household (£)*	*Count of households*	*Aggregate WTP (£)*
Site	Intercept (α)	Slope (distance decay) (β)				
Less valuable	26.46	2.60	10.2	10.04	13,845	138,949
More Valuable	32.50	1.90	17.1	6.33	167,181	1,057,783

Introducing an income as a determinant of WTP

Because willingness to pay is linked to ability to pay it is usually expected that income will be a determinant of WTP for public goods. Extending equation 1 above, then:

$$WTP = \alpha_1 + \beta_d(Distance) + \beta_Y(Income) \qquad (4)$$

Where:

- α_1 is a positive number (equal to the WTP of a household next to the quarry with an average income; note that this is different to α_0);
- β_d is a negative number describing the fall in WTP as distance from the quarry increases (note that this will differ from its previous value in Equation (1) because now some of the variation in WTP is being described by changes in income); and
- β_Y is a positive number describing the higher WTP of richer individuals. Note that this does not mean that richer people gain more utility from better environments, it simply reflects their higher ability to pay for the things they want. As such this reflects the relationships of WTP for almost all goods (e.g. the rich can pay more for better cars, food, clothes etc.). Cost-benefit analyses can be adjusted to take account of variations in ability to pay

For example, a theoretical empirical study might yield the following function:

$$WTP = 22.35 - 1.05(Distance) + 0.0001(Income) \qquad (5)$$

Where:

- Distance is measured in km; and
- Income is measured as the household annual pre-tax income in £s.

For example a household in a postcode area 10km from the quarry with an average income of £25,000 would have an average household WTP of:

$$22.35 - (1.05 * 10) + (25{,}000 * 0.0001)$$
$$= 22.35 - 10.50 + 2.5$$
$$= £14.35$$

If there were 50 households within this postcode area, the total WTP for the postcode area would be £717.50.

Here the economic jurisdiction is larger – 21.29km. Using equation 4 and a GIS to capture all postcode areas within 21.29km of the quarry, the total value of the quarry is estimated at approximately £2.6 million.

Concluding remarks

A simplified approach to valuing public goods can potentially give a crude and often inaccurate over-valuation of aggregate benefits, especially when aggregating up values to produce total benefits of a policy action. Provided the valuation study includes the relevant functions it is possible, using relatively simple GIS techniques, for a more sophisticated valuation analysis to be carried out that takes into account how WTP can vary by distance from the policy site and other characteristics that can affect WTP such as household income levels.

REFERENCES

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