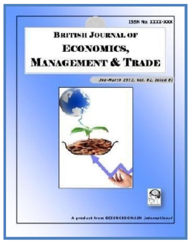

British Journal of Economics, Management & Trade
2(2): 109-124, 2012

SCIENCEDOMAIN *international*
www.sciencedomain.org

Wetlands Ecosystem Services Value in Constructed Wetlands: The Case of the George W. Shannon Wetlands Water Reuse Project

Memory Machingambi[1] and James W. Mjelde[2*]

[1]Centre for Environmental Economics and Policy in Africa, University of Pretoria, South Africa.
[2]Dept. of Agricultural Economics, Texas A&M University, College Station, TX, U.S.A.

Authors' Contributions

All authors contributed equally to the study, read, and approved the final manuscript.

Research Article

Received 29th March 2012
Accepted 12th June 2012
Online Ready 15th June 2012

ABSTRACT

Aims: To determine the value of constructed wetlands for water reuse projects.
Study Design: Replacement/Avoided cost modeling and benefit transfer.
Place and Duration of Study: George W. Shannon Wetlands, Texas.
Methodology: Two approaches are compared, replacement costs and willingness-to-pay (WTP) for wetlands. Replacement costs of the constructed a wetland is based on engineering estimates and modeling. Replacements costs are compared to benefit transfer of WTP from previously estimated meta-analysis functions.
Results: The replacement cost of the constructed wetlands is estimated to be $1,688/acre/year. Using three previously published meta-analysis transfer functions, mean WTP are $843, $999, and $1,169 / acre / year. Estimated 95% confidence interval is $95 to $7,435 / acre / year.
Conclusions: The estimated values indicate constructed wetlands have value to society. The confidence interval clearly indicates the uncertainty associated with valuing ecosystem services and goods. Confidence intervals or sensitivity analysis is clearly warranted in valuing ecosystem services and goods. The three transfer functions are within 20% of each other. As expected, the replacement cost value is higher than the transfer functions and may represent an upper bound.

**Corresponding author: Email: j-mjelde@tamu.edu;*

Keywords: Constructed wetlands; natural wetlands; economic valuation; ecosystem services values; meta-analysis; benefit transfer.

1. INTRODUCTION

Expanding urbanization is increasing the demand for high quality water. Wastewater recycling can effectively increase the supply of water to municipalities to meet increasing demand. One way of recycling wastewater is through the use of constructed wetlands (CWs), which may offer a potential cost effective method of treating municipal, industrial, agricultural, and urban runoff wastewater (U.S. EPA, 1993; Knight, 1997; Brix, 1999; Cardoch et al., 2000; Knowlton et al., 2002; Carlsson et al., 2003; Day et al., 2004; Rousseau et al., 2008; Gustavson and Kennedy, 2010). CWs are generally designed to imitate natural wetlands in their form and functions (United Nations Environment Program [UNEP] 2008); they offer many of the functions of natural wetlands that sustain ecosystems (U.S. EPA, 1993; Knight, 1997; Knowlton et al., 2002; Gustavson and Kennedy, 2010). Wetlands ecosystem benefits include nutrient removal from point and nonpoint source pollution, flood control, species habitat, erosion control, and recreation (U.S. EPA, 1993; Cronk, 1996; Knowlton et al., 2002; U.S. EPA, 2007). The passing of regulations and public policies influencing wetlands management (Bergstrom and Stoll, 1993; Wetlands Reserve Program, 1999; Gustavson and Kennedy, 2010) and relatively low costs of developing CWs, along with their ecological and economic performance has led to the growing interest in the creation of CWs.

Woodward and Wu (2001), Brander et al. (2006) and Ghermandi et al. (2009) review wetland valuation studies. Machingambi (2010) provides a review of the value of ecological services including natural and constructed wetlands. As noted in these reviews, most previous studies valued natural wetlands; only a few studies valued CWs. Day et al. (2004) summarize the cost of treatment analyses conducted to evaluate the economic implications of using CWs instead of a conventional wastewater treatment plant at Breaux Bridge and Thibodaux in south Louisiana, USA. Cost savings over 30 years in 1992 dollars are estimated at $1.4 million for Breaux Bridge and $500,000 for Thibodaux. In another southern Louisiana avoided cost study, Cardoch et al. (2000) estimate that if CWs were used to pre-treating wastewater from shrimp processing, the cost savings would be about $1.5 million (1995 dollars) over 25 years. In comparing a two-cell domestic wetland treatment with that of sand filter systems over 20 years in Ohio, USA, Steer et al. (2003) estimate CWs had costs of $500 - 3,000 less than that of sand filter systems. Their ecological footprint, however, is larger than that of sand filter systems. Recreational activities associated with CWs increase their appeal to society. For example, in southern Sweden, biodiversity and walking facilities are the greatest welfare contributors of the CWs (Carlsson et al., 2003). Other examples of recreation value of CWs in the USA include the Arcata Marsh and Wildlife Sanctuary in California, which in 1993 had an estimated 1,600 human use days (HUD) per hectare / year (HUD / ha / y), Show Low in Arizona (7 HUD / ha / y), and the Iron Bridge in Florida (4,800 HUD / ha / y) (U.S. EPA, 1993).

As a pioneer project in alternative wastewater reuse, the George W. Shannon Wetlands Water Reuse Project being developed by the Tarrant Regional Water District (TRWD) makes for an interesting case study to value CWs. TRWD is one of the largest raw (nonpurified) or wholesale water suppliers in Texas, providing water to more than 1.8 million people in 11 counties of north central Texas, USA (TRWD, 2010). Major wholesale customers are the cities of Fort Worth, Arlington and Mansfield and the Trinity River Authority (TRWD, 2010). The number of people served by the TRWD is expected to increase to over 4.3 million by 2060 (TRWD, 2010). Faced with an expected increased water demand from 363,000 acre-feet / year in 2000 to 491,000 acre-feet per year in 2050 (Frossard et al., 2006), TRWD concluded that the District should pursue the option of diverting water from the Trinity River into District reservoirs in its 1990 Long Range Plan (D. AndrewsEastern Division Water Quality Manager, Tarrant Regional Water District, Personal Communication 2008). The Trinity River is largely treated wastewater flows with up to 90% of the flows during parts of the year being wastewater flows (Frossard et al., 2006). Water flows in the Trinity River have been increasing, especially in the summer, because of increased water use, therefore runoff, caused by an increasing population and development in the Dallas-Fort WorthMetroplex (J. Gunnels Wildlife Biologist, Richland Creek Wildlife Management Area, Texas Parks and Wildlife Department, Personal Communication, 2008). To maintain and improve the quality of water in their reservoirs, cleansing the river water before diverting into reservoirs is desirable. After evaluating different treatment options, a wetlands treatment system (George W. Shannon Wetlands Water Reuse Project) was selected (D. Andrews Eastern Division Water Quality Manager, Tarrant Regional Water District, Personal Communication 2008) to create high quality water that can be reused by the TRWD. Water from the Shannon Reuse Project will be pumped into the Richland - Chambers Reservoir. Water from the Richland-Chambers Reservoir can be pumped to Lake Arlington for use in The Dallas – Fort Worth metroplex area. Once fully developed, the Project will also provide wildlife habitat, and recreational facilities.

The main objective is to estimate and compare the values of ecosystem services from CWs using replacement cost and benefit transfer valuations. Because the George W. Shannon Wetlands Water Reuse Project was mainly designed for wastewater purification for reuse, replacement cost method may be the most appropriate valuation method to approximate the value of the wastewater cleansing. Because the CWs have other secondary uses, benefit transfer using three previous meta-analyses is also employed to obtain a values for the CWs based on ecosystem services.

2. METHODOLOGY

2.1 Study Area: The George W. Shannon Wetlands Water Reuse Project

The George W. Shannon Wetlands Water Reuse Project is located approximately 60 miles south of the Dallas-Fort WorthMetroplex (Fig. 1) on the Freestone-Navarro county line (Frossard et al., 2006). The wetlands were constructed for several reasons including: the proximity to both the Trinity River and Richland - Chambers Reservoir; a raw water pipeline already in place from the reservoir to Lake Arlington; availability of floodplain land and the CWs being located approximately 60 miles from the wastewater source to address the issue of society's lack of acceptance of the use of recycled wastewater for municipal use (D. Andrews Eastern Division Water Quality Manager, Tarrant Regional Water District, Personal Communication, 2008). The George W. Shannon Wetlands Water Reuse Project is a partnership between TRWD and the Texas Parks and Wildlife Department (TPWD). The Richland Creek Wildlife Management Area was created to compensate for habitat losses associated with the construction of Richland - Chambers Reservoir (TPWD, 2008a). The George W. Shannon Wetlands Water Reuse Project is part of this management area. Land for the wetlands was supplied by the TPWD (Frossard et al., 2006). TPWD's interest in the CWs is in the creation of high quality ecological wetlands that can be used for recreational purposes.

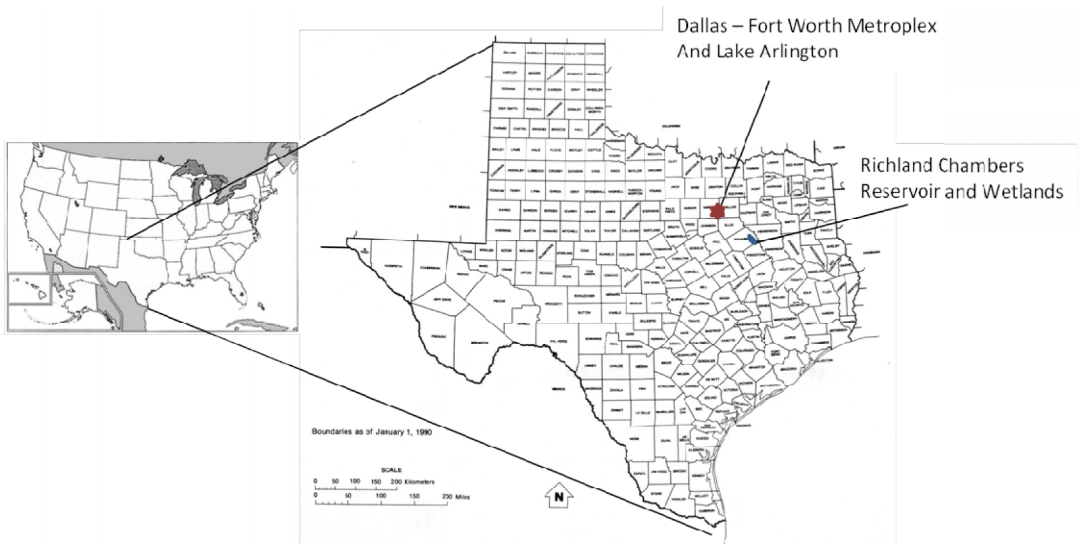

Fig. 1. Location of the Richland – Chambers reservoir and the constructed wetlands in relation to the Dallas-Fort Worth metroplex

Small-scale CW projects were conducted between 1992-2000, which processed 75,000 gallons of water / day. The small-scaled studies' wetlands outperformed many previous CWs in terms of nutrient and sediment removal (Frossard et al., 2006). The CWs' current size is approximately 250 acres, but the CW is expected to expand to 3,000 acres (TRWD, 2010). Although there is no projected lifetime for these particular CWs, the TRWD acknowledges that it is currently facing challenges with phosphorus removal (D. Andrews Eastern Division Water Quality Manager, Tarrant Regional Water District and Personal Communication, 2008). Field-level studies are seeing similar sedimentation removal, but nitrogen and phosphorous removal percentages have decreased.

The objectives for developing the George W. Shannon Wetlands Water Reuse Project are the production of high quality water and wetland habitat for wildlife through simulating natural wetlands functions (Locke et al., 2007). Benefits from these CWs are improved water quality through the water recycling operation and recreation. The CWs are expected to provide opportunities for bird watching, water fowl hunting and fishing. Because development is still on-going, no significant numbers of visitors have used the CWs, but the TPWD expects an increase in the number of visitors to the CWs once the size is increased (J. Gunnels Wildlife Biologist, Richland Creek Wildlife Management Area, Texas Parks and Wildlife Department, Personal Communication, 2008).

The Reuse Project operates by pumping water from the Trinity River to a sedimentation basin and then through a series of wetland cells (Fig. 2). As water moves through these cells it is filtered by the vegetation before it is pumped into the Richland - Chambers Reservoir (Alan Plummer Associates Inc., 2008). The sedimentation basin and cells lower the sediment load and nutrient level of the water, allowing higher quality water to be pumped into the reservoir. Cleansed water from the wetlands (Fig. 3) can be pumped directly into the reservoir but this mainly depends on the reservoir capacity at the time. For example in summer 2010, because of high rainfall that filled the reservoir to capacity, cleansed water from the wetlands was not pumped into the reservoir but returned to the Trinity River. Whenever the reservoir levels drop, water is pumped from the wetlands into the reservoir. Between and along the cells are gates and canals used to control the flow and depth of the water in the wetlands. Because water flows through the CWs are controlled, a consistent flow can be maintained; therefore, water in the CWs is not stagnant as is the case with many natural wetlands. Natural wetlands water flows are dependent on many factors including weather conditions, groundwater inflows and vegetation with many wetlands going dry during part of the year. Further, because the CWs rely on water pumped from the Trinity River, the CWs can be drained for maintenance. The George W. Shannon Wetlands Water Reuse Project differs from natural wetlands in these aspects of a high level of control of water flows and the consistency of flows.

An additional challenge facing these CWs is that because the diversion point on the Trinity River is 60 miles downriver, the river picks up additional sediment from runoff and streams entering the river. This increased sediment increases the load of the water, above what it would have been if the CWs were located closer to Fort Worth. Increased sediment results in an increased retention time in the CWs; water pumping costs back to Lake Arlington are also increased because of the distance from Fort Worth.

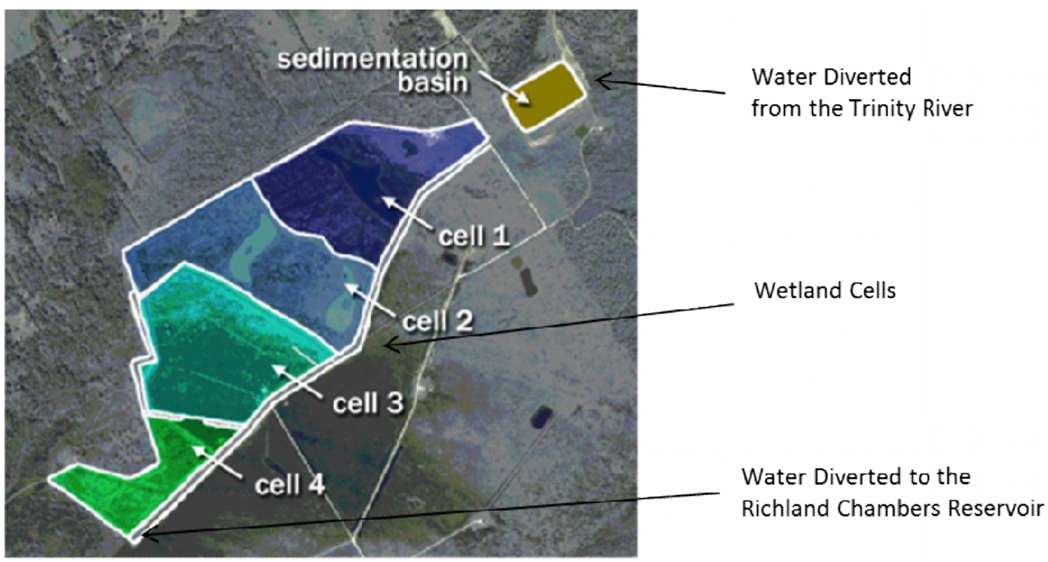

Fig. 2. George W. Shannon constructed wetlands cell layout
Source: D. Andrews Eastern Division Water Quality Manager, Tarrant Regional Water District, Personal Communication 2008

2.2 Valuations Methods

Two valuations methodologies are used to estimate the value of the CWs. First, replacement cost approach is used to estimate the value of the water quality aspects of the CWs. Second, using previous meta-analyses of natural and constructed wetlands valuations, estimates for the George W. Shannon Wetlands Water Reuse Project are provided. These estimates assume that the constructed wetlands provide similar services to natural wetlands. This assumption is reasonable for most wetlands amenities, but may not be appropriate for water flows.

Fig. 3. Trinity River water before entering the constructed wetlands treatment and water at the end of treatment.

Source: D. Andrews Eastern Division Water Quality Manager, Tarrant Regional Water District, Personal Communication 2008

2.2.1 Replacement cost analysis

The value of the CWs is the reduction in costs in cleansing the Trinity River water over the next best alternative. A waste water treatment facility is assumed to be the next best alternative. To properly value the CWs, the quality of water leaving the CWs and treatment facility must be similar in quality. Publicly accessible data on the cost of building such treatment facilities is limited; having not been collected and distributed by the U.S. government since the 1980s. To overcome this limitation, an engineering cost estimation program, CapdetWorks, is used to provide cost estimates of a replacement treatment facility. Cost estimates of developing CWs are obtained from Frossard et al. (2006), Andrews (D. Andrews Eastern Division Water Quality Manager, Tarrant Regional Water District, Personal Communication, 2008) and Rister (2008). An estimate of the replacement value of the CWs is then obtained by subtracting the annualized costs of the wastewater treatment facility from the annualized costs of the CWs.

2.2.1.1 Wastewater treatment facility

CapdetWorks Version 2.5 is state-of-the-art software for the design and preliminary cost estimates of wastewater treatment facilities (Hydromantis, Inc. 2008). Capdet model, originally developed by the U.S. Army Corps of Engineers for the U.S. EPA in 1973, has undergone extensive revisions and updates over the years to become CapdetWorks. Based on industry standard engineering equations, CapdetWorks uses a two-step procedure to obtain costs. First, CapdetWorks calculates the design of the facility based on user supplied unit processes in the facility and influent quality to the process. Second, the cost of the design is calculated. Costs categories include construction, operation, maintenance, material, chemical, and energy, along with legal and engineering costs. Cost estimates are based on a unit costing approach using inflation cost indices based on discussions with manufacturers, suppliers, and consultants (Hydromantis, Inc. 2008). Default values are provided for all necessary inputs, both physical and economic. The user is able to override the defaults as necessary for their design. In calculating the replacement costs, default values are used except as noted. Replacement costs are based on the September 2007 U.S. average cost indices in CapdetWorks with the exception of land value. Land value is assumed to be $3,000 / acre based on 2007 real estate land market values in the area around the Richland-Chambers reservoir.

The wastewater treatment facility used to obtain the replacement costs contains the following processes (this facility was designed with discussion with a civil engineer (B. Batchelor, Professor, Department of Civil Engineering, Texas A&M University, Personal Communication,2008):

1. influent pump station – used to pump the water from the Trinity River to the treatment facility;
2. screening device – used to remove large objects that may damage pumps and other equipment, obstruct pipelines, or interfere with the normal operations of the facility;
3. lagoons – two for sediment settling and nutrient removal because they require relatively unskilled operators and have low operating and maintenance costs, similar to CWs; and
4. pump station – used to pump the effluent from the treatment facility to the Richland –Chambers Reservoir.

Influent Trinity River and effluent wetlands water parameters are set to average values provided by Alan Plummer and Associates, Inc. (2008). Maximum, average and minimum flows from the Trinity River are set at a 15, 12.6, and 0 million gallons per day (MGD). Influent total suspended solids, total nitrogen, and total phosphorous are set at 206, 3.85, and 0.98 mg/L (Table IV-1 found in Alan Plummer and Associates Inc., 2008). All other contaminates are set equal to zero as these are not the main contaminates of interest in constructing the wetlands. These assumptions provide a conservative replacement cost estimate.

2.2.1.2 CWs costs

Frossard et al. (2006) provide cost estimates for constructing the George W. Shannon Wetlands Water Reuse Project. These CWs cost estimates are much less detailed than those provided by CapdetWorks for replacement costs. Construction and operating costs in Frossard et al. (2006) are inflated using inflation adjustment factors from the U.S. Department of Labor Bureau of Labor Statistics (2008) to obtain costs in 2007 U.S. dollars. Andrews (D. Andrews Eastern Division Water Quality Manager, Tarrant Regional Water District and Personal Communication, 2008) noted the estimated project costs in Frossard et al. (2006) are low; further they do not contain land, legal, engineering and pump station costs. An additional $4 million plus land costs are added to the construction costs in Frossard et al. (2006) based on CapdetWorks estimate of $2.4 million in engineering costs for the treatment facility and conversations.

Table 1. Costs for constructing a wastewater treatment facility and the George W. Shannon wetlands water reuse project in 2007 dollars

Cost category	Treatment facility[1]	George W. Shannon[2]
Total construction	18,401,900	12,814,000
Land $3,000 / acre	98,100	750,000
Number of acres	32.7	250 for project 243 in wetlands
Total project	18,500,000	13,564,000
Amortized over 30 years @ 5%	1,203,452	882,358
Yearly operating cost / 1000 gallons	0.105645	0.082038
Total yearly operating @ 12.6 MGD 93% efficiency	451,850	350,882
Annual cost per gallon	0.000387	0.0002883
Total annual costs	1,655,302	1,233,240
Annual cost per acre based on 250 acres	6,621	4,933
Replacement cost = treatment costs – George W. Shannon costs/acre/year using 250 acres	$1,688	

[1]*Calculated using CapdetWorks (Hydromantics, Inc. 2008).*
[2]*Sources: Frossard et al. (2006); D. Andrews Eastern Division Water Quality Manager, Tarrant Regional Water District, Personal Communication 2008; and Rister (2008).*

The CWs costs provided in Table 1 take this additional information into account. Total construction costs are approximately $1 million more than Rister (2008) calculated for CWs that are similar in size but with less pumping needs that may be developed on creeks that provide inflow to Richland – Chambers Reservoir.

2.2.2 Wetlands meta-analysis

Three meta-analyses studies (Woodward and Wui, 2001; Brander et al., 2006; Ghermandi et al., 2009) are used. These studies are used in a benefit transfer function approach to provide estimates of the willingness-to-pay (WTP) for the CWs. A transfer function uses an estimated equation to predict a WTPunder a different application. Although there are different meta-analysis approaches, all three previous studies use valuations obtained from earlier studies to estimate a valuation equation based on explanatory variables. An objective in all three studies was to assess the factors that determine a wetland's value through evaluating whether any systematic trends exist in the previous studies. These factors consist of both characteristics of the wetlands and study related factors.

The three studies provide statistically-estimated wetland valuation functions using results from previous studies as the data. For purposes of comparisons, the main difference between the studies is that Woodward and Wui (2001) included only U.S. studies, while Brander et al. (2006) and Ghermandi et al. (2009) included studies from around the world. Ghermandi et al. (2009) updated the data set used by Brander et al. (2006) with new observations from recently published studies. Of the 46 studies Woodward and Wui (2001) reviewed, 39 are used because they had common features which could be used as explanatory variables. From these 39 studies, 65 observations are derived. Brander et al. (2006) reviewed 191 studies conducted over the past 25 years. Eighty of the studies contained comparable information providing 215 observations. The studies represent 25 countries from all continents. Ghermandi et al. (2009) expanded the data set and included studies not published in English to derive 418 observations from 170 studies and 186 wetland sites and also some that explicitly value constructed wetlands.

Specifically, the equation from the three studies estimated is of the form:

$$\ln(\mathrm{y}_i) = \mathrm{a} + \mathrm{b}_a \ \ln(\mathrm{x}_a) + \mathrm{b}_s x_{si} + b_w \, x_{wi} + b_e x_{ei} + \text{«}_i \tag{1}$$

Where y is the annual wetland value per acre in U.S. dollars, i represents observation, x_a is the size of the wetland in hectares, x_s is a matrix of variables describing the primary study including year and location variables and methodology used, x_w are the characteristics of the wetland studied including services provided and x_e are the socio-economic and demographical characteristics of the study and μ is the assumed normally distributed error term with a mean of zero, a is the intercept and b's are matrices of estimated coefficients on respective explanatory variables. Additional description of the variables and estimated coefficients from each study are provided in Table 2. Woodward and Wui (2001) stress the variability present not only in the primary data, but also in confidence intervals from their meta-analysis regression is large. They state, "Clearly it would be highly speculative to use a single point from this distribution in a benefits transfer exercise" (Woodward and Wui 2001, p. 268). As such, their program and data were obtained to obtain both a point estimate and a confidence interval. Similar to Woodward and Wui (2001), variability in Brander et al. (2006) and Ghermandi et al. (2009) data sets is large.

2.2.2.1 Explanatory variables used in benefit transfer estimates of CWs WTP

Using the functions developed by Woodward and Wui (2001), Brander et al. (2006) and Ghermandi et al. (2009), benefit transfer wetland WTP for the George W. Shannon Wetlands Water Reuse Project are obtained. Besides the estimated coefficients from the meta-analysis, Table 2 also contains the values for the explanatory variables used to represent the George W. Shannon Wetlands Water Reuse Project.

Table 2. Meta-analysis coefficients and independent variable values used to provide estimates of the WTP for the George W. Shannon wetlands water reuse project[1]

Variable	Woodward and Wui (2001)	Values used	Brander et al. (2006)	Values used	Ghermandi et al. (2009)	Values used
Intercept	7.945	1	-6.98	1	1.245	1
Year	0.052	14.908			-0.029	
Coastal	-0.523	0				
Flood	-0.358	0	0.14	1		
Quality	1.494	1				
Recreational fishing	0.395	1			-0.060	1
Commercial fishing	0.669	0				
Bird hunting	-1.311	1				
Bird watching	1.704	1				
Producer surplus	-2.416	0				
Quantity	0.514	1				
Ln hectares	-0.168	5.493	-0.11	4.588	-0.245	1
Amenity	-3.352	1	0.06	1		
Habitat	0.577	1				
Storm	0.310	0				
Publish	0.769	0	0	0		
GDP per capita			1.16	9.547	0.237	1
Population density			0.47	7.074	0.321	1
Latitude			0.03	32.77		
Latitude squared			-0.0007	1073.9		
South America			0.23	0		
Europe			0.84	0		
Asia			2.01	0		
Africa			3.51	0		
Australasia			1.75	0		
Urban			1.11	0		
Marginal			0.95	0	0.643	1
Mangrove			-0.56	0		
Unvegetated sediment			0.22	0		
Salt/brackish marsh			-0.31	0		
Fresh marsh			-1.46	0		
Woodland			0.86	1		
Biodiversity			0.06	1		
RAMSAR proportion			-1.32	0		
Fuel wood			-1.24	0	-0.842	1
Materials			-0.83	0	-0.143	1
Hunting			-1.1	1		
Fishing			0.06	1		
Water quality			0.63	1	0.720	1
Water supply			-0.95	1	-0.430	1
Habitat & nursery			-0.03	0.35		

Table 2. Continues…..

Hedonic pricing	-0.71	0		
Net factor index	0.19	0		
Replacement cost	0.63	1		
Travel cost	0.01	0		
Opportunity cost	-0.03	0		
Market prices	-0.04	0		
Production function	-1	0		
Contingent valuation method	1.49	1		
Estuarine			0.452	1
Marine			0.789	1
Riverine			0.434	1
Palustrine			-0.280	1
Lacustrine			0.364	1
Constructed			1.188	1
Flood control, storm buffering			0.286	1
Commercial fishing & hunting			0.344	1
Recreational hunting			-0.743	1
Non-consumptive recreation			0.287	1
Amenity & aesthetics			0.969	1
Natural habitat, biodiversity			1.168	1
Medium-low human pressure			1.167	1
Wetland area in 50km radius			-0.076	1

[1]*In this table, entries listed under each study are the coefficients associated with that studies estimated equation. Entries under values used represent the independent variables used to provide a WTP from each of the three studies. Most entries are either zero or one, as the meta-analyses used 0-1 qualitative variables. No entry in a column indicates that independent variable is not used in that particular study.*

Based on Weitzman (2001), the mean of 2,160 economists' social discount rate estimate of 3.96% is used in these calculations.

Necessary values for the explanatory variables in the meta-analysis equations come from several sources. Based on communications with the TPWD and TRWD personnel on the design of the CWs and projected uses, a value of 1 is assigned to the features associated with the CWs (Table 2). The size of the CWs is 243 acres (Frossard et al. 2006). Woodward and Wui (2001) transfer function requires the date of the study, the mean value of this independent variable from their study is used in valuing the CWs. Brander et al. (2006) and Ghermandi et al. (2009) require additional independent variables. Latitude of the CWs was obtained from PlaceNames.com (2008). Given the CWs lies near the border of Navarro and Freestone Counties, population density is taken as the simple average of the two county densities. Texas state level per capita income for 2006 inflated to 2007 values is used as the per capita GDP (U.S. Department of Commerce2008). In line with Ghermandi et al. (2009), anthropogenic pressure on the George W. Shannon Wetlands Water Reuse Project is "medium-low" as measured by it being a controlled hydrology, rural and not protected wetland. To assess the substitution effect of other wetlands within a 50 km (32-mile) radius, spatial techniques were employed for the George W. Shannon Wetlands Water Reuse Project. An ArcView map for the Richland Creek Management area was obtained from the General Land Office website and a 32-mile buffer was placed around the Richland Creek wildlife management area. The 2001 NLCD wetland area was calculated inside the buffered area. There are 242,693 acres or 98,214 hectares of wetland area around the Richland Creek wildlife management area.

Inflation adjustment factors from the U.S. Department of Labor Bureau of Labor Statistics (2008) are used to inflate the WTP derived from the meta-analysis to 2007 U.S. dollars. For the Woodward and Wui (2001) model, a factor of 1.59 is used to convert from 1991, while a factor of 1.36 is used to convert Brander et al. (2006) 1995 and a factor of 1.13 is used to convert Ghermandi et al. (2009) 2003 U.S. dollar values to 2007 dollars. To make the results comparable, hectares are converted to acres using 0.4046 hectares/acre. Because policy decisions often require valuation based on several years and not annual values, the annual values are converted to 30-year horizon and perpetuity values.

3. RESULTS AND DISCUSSION

CapdetWorks provides much more detail, but because much less detail is provided for the CWs costs, a similar level of detail is provided for both the CWs and the treatment facility. The treatment facility requires 32.7 acres compared to 250 for the CWs (243 for the wetlands and 7 for administration). Two eight acre lagoons are used in the treatment facility. Total project costs are approximately $5 million more for the treatment facility than for the CWs. Annual operating costs are slightly more than $100,000 for the treatment facility. Calculations from CapdetWorks indicate the treatment facility removes slightly less nitrogen and sediment than the CWs are obtaining, but more phosphorus is removed in the treatment facility. To make the replacement costs comparable to the meta-analyses, the costs per acre are normalized based on the 250 acres necessary to provide the CWs. Annualized wastewater treatment costs are $6,621/acre, whereas, the CWs annualized costs are $4,933/acre. The replacement cost valuation of the services provided by the George W. Shannon Wetlands Water Reuse Project (Table 3) is $1,688/acre/year ($42,032 into perpetuity and $29,331 for a 30-year horizon). This replacement costs valuation of the wetlands services can be viewed as the cost savings of creating the CWs over a conventional wastewater treatment facility; the cleaning services provided by the wetlands.

Table 3. Estimated values of the George W. Shannon water reuse project in 2007 dollars per acre

Valuation Method	Annual	30-Year Horizon	Perpetuity
Replacement Cost			
CapdetWorks	$1,688	$29,331	$42,032
Benefit Transfer			
Woodward and Wui (2001)	$843 $95 to $7,435[a]	$14,648	$21,298
Brander et al. (2006)	$999	$17,358	$25,235
Ghermandi et al. (2009)	$1,169	$20,312	$29,531

[a]*95% Confidence Interval*

Using the Woodward and Wui (2001) model, a mean WTP of $843/acre/year ($21,298 into perpetuity and $14,648 for a 30-year horizon) is obtained for the George W. Shannon Wetlands Water Reuse Project CWs. The 95% confidence interval is $95 to $7,435/acre/year. Consistent with Woodward and Wui (2001)'s statements, this confidence interval is huge. Brander et al. (2006) model gives a mean WTP of $999/acre/year ($25,235 into perpetuity and $17,358 for a 30-year horizon). Ghermandi et al. (2009) function gives a mean WTP of $1,169/acre/year ($29,531 into perpetuity and $20,312 for the 30-year horizon).

Unfortunately, confidence intervals cannot be obtained from information in Brander et al. (2006) and Ghermandi et al. (2009). As expected given the large range, estimates using Brander et al. (2006), as well as, Ghermandi et al. (2009) fall within the 95% confidence interval suggested by Woodward and Wui's (2001) meta-analysis.

4. CONCLUSIONS

Ecosystem service WTPs obtained from the three meta-analyses varies by less than 20% (using Woodward and Wu's obtained value as a base). These three WTPs are closer than anticipated. The confidence interval obtained from Woodward and Wu's estimated function, the large differences in the number of observations and differences in studies included indicate one would expect large variations in service values for the CWs obtained from the meta-analyses. Although the "truth" is not known, the similarity of the values provides confidence in using the benefit transfer values for estimating the ecosystem services of the George W. Shannon Wetlands Water Reuse Project.

As expected, the replacement cost method provides a larger value for the George W. Shannon Wetlands Water Reuse Project CWs than any of the meta-analysis approach. Providing a larger value supports previous contentions that the replacement cost approach may provide upper bound estimates (Anderson and Rockel, 1991). Specifically, the value for the CW obtained from Woodward and Wui (2001) meta-analysis is approximately one-half of the value obtained from the replacement cost approach. The value obtained using Brander et al. (2006) estimated function is approximately 60% of the replacement cost approach value, whereas, using Ghermandi et al. (2009)'s function the value obtained is approximately 70%.

Although not explicitly modeled, one could postulate the more a wetland's functions can be controlled, the potentially higher the ecosystem service values assigned to the wetlands. Support for this postulate is provided by this analysis. From replacement costs analysis where the CWs functions are highly controlled to Ghermandi et al. (2009)'s analysis with some controlled CWs, to the natural wetlands investigated by Brander et al. (2006) and Woodward and Wui (2001), wetland ecosystem service values seem to decline as control over the wetlands decreases. Hence, values between natural wetlands and CWs may differ; the more water flows are controlled the more likely the CWs to be valued more than natural wetlands everything else held constant. This is a researchable issue that deserves further attention.

With the development of more CWs and additional studies, it will become easier to compare natural wetlands versus CWs in terms of costs, ecosystem services values and societal welfare. Caution should be exercised in interpreting the differences in the values presented strictly as values for natural vs. constructed wetlands. Many CWs are a form of rehabilitation for already damaged natural wetlands. How this impacts the value to society is another important extension. All indications are that wetlands provide large ecosystem services values. Further, the range of estimated values provides additional evidence of the large uncertainty associated with estimating ecosystem services. Additional studies into the cause of the large variation are warranted. Are the large differences caused by methodological issues, differences in wetland values that cannot be controlled for, or a more fundamental human valuation issue?

ACKNOWLEDGEMENTS

The authors wish to acknowledge use of a meta-analysis program used for this research from Dr. Richard Woodward to whom we are very grateful. Thanks also go to the American Farmland Trust for funding and Dr. Neil Wilkins for the support of part of this research. To Mr. Darrel Andrews, thank you for your time and expertise, we would not have done it timely without your help. We also wish to thank Dr. Bill Batchelor, Dr. Jim Cathey, Mr. Jeff Gunnels, Dr. Edward Rister, and Dr. Brad Wilcox, for their insights and advice during the course of this research. Views and opinions expressed remain the sole responsibility of the authors.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

Alan Plummer Associates, Inc. (2008). Tarrant regional water district field-scale constructed wetland phase 1 operations June 3, 2003 –Jan. 9, 2007. Final Report, Tarrant Regional Water District, Denton, TX.

Anderson, R., Rockel, M. (1991).Economic valuation of wetlands. Discussion Paper No. 065. American Petroleum Institute, Washington, DC.

Bergstrom, J.C., Stoll, J.R. (1993). Value estimator models for wetlands-based recreational use values. Land Economics, 69, 132-37.

Brander, L.M., Florax, R.J.G.M., Vermaat, J.E. (2006). The Empirics of Wetland Valuation: a Comprehensive Summary and a Meta-analysis of Literature. Environmental and Resource Economics, 33, 223-250.

Brix, H. (1999). How ‘green’ are aquaculture, constructed wetlands and conventional wastewater treatment systems? Water Science and Technology, 40, 45-50.

Cardoch, L., Day, J.W. Jr., Rybczyk, J.M., Kemp, G.P. (2000). An economic analysis of using wetlands for treatment of shrimp processing wastewater – a case study in Dulac, LA. Ecological Economics, 33, 93-101.

Carlsson, F., Frykblom, P., Liljenstolpe, C. (2003). Valuing wetland attributes: an application of choice experiments. Ecological Economics, 47, 95-103.

Cronk, J.K. (1996). Constructed wetlands to treat wastewater from dairy and swine operations: a review. Agriculture, Ecosystems and Environment, 58, 97-114.

Day, J.W., Rybczyk, J.W., Cardoch, L., Conner, W.H., Delgado-Sanchez, P., Pratt, R.I., Westphal, A. (2004). A review of recent studies of the ecological and economic aspects of the application of secondary treated municipal effluent to wetlands in southern Louisiana. In: Rozas, L.P., Nyman, J.A., Proffitt, C.E, Rabalais, N., Reed, D.J., Turner, R.E. (eds) Recent research in coastal Louisiana: natural system function and response to human influence. Louisiana Sea Grant College Program.

Frossard, W., Andrews, D., Plummer, A.H., Mokry, L. (2006).Over the river and through the plants to Richland Chambers we go. Water Environment Federation Technical Exhibit and Conference. http://www.environmentalexpert.com/Files%5C5306%5Carticles%5C12640%5C376.pdf. Accessed on 20 Sept 2007

Ghermandi, A., Van den Bergh, J.C.J.M., Brander, L.M., De Groot, H.L., Henri, L.F., Nunes, P.A.L.D. (2009). The values of natural and constructed wetlands: a meta-analysis. Tinbergen Institute 2009-080/3. http://ssrn.com/abstract=1474751. Accessed 10 Jan 2010.

Gustavson, K., Kennedy, E. (2010).Approaching wetland valuation in Canada. Wetlands, 30, 065-1076.

Hydromantis, Inc. (2008). CAPDETWorks. http://www.hydromantis.com/CapdetWorks.html. Accessed on 25 June 2008.

Knight, R.L. (1997). Wildlife habitat and public use benefits of treatment wetlands. Water Science and Technology, 35, 35-43.

Knowlton, M.F., Cuvellier, C., Jones, J.R. (2002) Initial performance of a high capacity surface-flow treatment wetland. Wetlands22, 522-527.

Locke, S.L., Frentress, C., Cathey, J.C., Mason, C., Hirsch, R., Wagner, M.W. (2007).Techniques for wetland construction and management. Texas A&M University Agr. Exp. Sta. Res. Bull. No. SP-316.

Machingambi, M. (2010). Essays on the impact of development on agricultural land amenities and values in Texas.Ph.D. Dissertation, Texas A&M University, College Station, TX.

PlaceNames.com. (2008). Richland-Chambers Reservoirhttp://www.placenames.com/us/p1385472/. Accessed on 15 March 2010.

Rister, M.E. (2008). Professor, Department of Agricultural Economics. Texas A&M University. College Station, TX. Personal Communication of Preliminary Data published in Rister, M.E., Sturdivant A.W., Lee, T., Waidler, D., Seawright, E.K., Lacewell, R.D., Leidner, A.J., Srinivasan, R., Narasimhan, B., Wolfe, C., Andrews, D., Ernst, M., Owens, J., Lesikar, B., Adams, R.F., Berthold, A., Jones, C.A., Harris, B.L. NCTXWQ project: evaluating the economics of best management practices for Tarrant Regional Water District's Cedar Creek Reservoir. Texas Water Resources Institute. TR-357. College Station, TX.

Rousseau, D.P.L., Lesage, E., Story, A., Vanrolleghem, P.A., De Pauw, N. (2008). Constructed wetlands for water reclamation. Desalination, 218, 181-89.

Steer, D., Aseltyne, T. Fraser, L. (2003). Life-cycle economic model of small treatment wetlands for domestic wastewater disposal. Ecological Economics, 44, 359-69.

Tarrant Regional Water District (TRWD) (2010).Tarrant Regional Water District: Overview of Wetlands. http://www.trwd.com/wetlandsoverview.aspx. Accessed on 25 Sept 2008; 15 Oct 2010.

Texas Parks and Wildlife Department. (TPWD). (2008a). Richland Creek WMA. http://www.tpwd.state.tx.us/huntwild/hunt/wma/find_a_wma/list/?id=23. Accessed on 20 Oct 2008.

United Nations Environment Program (UNEP). (2008). Water quality improvement technologies in alternative technologies for freshwater augmentation in Africa. New York. www.unep.or.jp/ietc/publications/TechPublications/TechPub-8a/artificial.asp Accessed on 1 Nov 2008.

U.S. Department of Commerce, Bureau of the Census. (2008). American Fact Finder. Washington DC. http://factfinder.census.gov/. Accessed on 10 Nov 2008.

U.S. Department Labor, Bureau of Labor Statistics. (2008). Washington DC. http://www.bls.gov/data/inflation_calculator.htm. Accessed on 13 Oct 2008.

U.S. Environmental Protection Agency (U.S. EPA). (1993).Constructed wetlands for wastewater treatment and wildlife habitat: 17 case studies. Report No. 832-R-93-005. Washington DC, May.

U.S. Environmental Protection Agency (U.S. EPA). (2007).Wetlands and water quality trading: review of current science and economic practices with selected case studies. Report No. 600-R-06-155. Oklahoma, June.

Weitzman, M.L. (2001).Gamma discounting. The American Economic Review, 91, 260-271.

Wetlands Reserve Program. (WRP). (1999). Examples of performance standards for wetland creation and restoration in section 404 permits and an approach to developing performance standards. WRP Technical Note WG-RS-3.3. Available at: http://el.erdc.usace.army.mil/wrtc/wrp/tnotes/wgrs3-3.pdf. Accessed on January 23, 2008.

Woodward, R.T., Wui, Y.S. (2001). The economic value of wetland services: a meta-analysis. Ecological Economics, 37, 257-270.

© 2012 Machingambi & Mjelde; This is an Open Access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/3.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.