9. Valuing Groundwater

This chapter provides an overview of the NRDA economic valuation approaches to be used to quantify damages to groundwater.

Section 9.1 provides an overview of damage assessment concepts and definitions. Section 9.2 presents a market-based approach to estimating damages resulting from loss of groundwater use services. Section 9.3 describes a restoration-based approach, and Section 9.4 then presents a total value equivalency (TVE)/restoration scaling approach, including a description of the foundations of the approach; the steps and data necessary for implementing this non-market method; and future work that may be conducted as part of this assessment.

9.1 Damage Assessment Concepts and Definitions

As noted in Chapter 8, the purpose of the damage determination phase is to establish the amount of money to be sought in compensation for injuries to natural resources resulting from a release of hazardous substances, including the *cost of restoration* and, at the discretion of the authorized official, the *compensable value* of all or a portion of the interim loss [43 CFR § 11.80(a)(2)(b)]. Compensable values include "the value of lost public use of the services provided by the injured resources, plus lost non-use values such as existence and bequest values" [43 CFR § 11.83(c)(1)].

These terms are defined in the regulations as follows:

- *Compensable value* is the amount of money required to compensate the public for the loss in services provided by the injured resources between the time of the release and the time the resources and the services those resources provided are fully returned to their baseline conditions [43 CFR 11.83(c)(1)]

- *Use value* is the value of the resources to the public attributable to the direct use of the resources [43 CFR 11.83(c)(1)(i)]

- *Direct use values* are generally associated with well-identified, active, and often on-site, uses such as recreational and commercial activities

- *Non-use value* is the difference between compensable value and use value [43 CFR 11.83(c)(1)(ii)]. Non-use values (or passive use values) arise from the values individuals place on resources apart from their own readily identified and measured direct or active use. Non-use values may include bequest values, which are the values individuals place

on the availability of resources for future generations, existence values, which are those values individuals place on a resource even if they never use it [56 FR 19760], or option values, which are values held by individuals who wish to preserve the resources for their own potential use.

Service flow losses and selection of economic assessment methods

Economic methods are used to identify, characterize, quantify, and value human use service losses. Based on the potential groundwater service losses, the Trustees anticipate using both market price methods and restoration-based approaches for estimating damages. Specifically,

- **Market price methods.** Market prices can be used to establish the diminished value of the injured groundwater.
- **Resource equivalency analysis**. REA can be used to develop the cost of restoring, replacing, or acquiring the equivalent groundwater and aquifer resources and services, including interim losses.
- **Total value/restoration scaling methods.** Methods such as conjoint or stated choice methods can be used to establish the type and amount of restoration actions that provide value to the public equivalent to the value held for the injured resource.

9.2 Market Price Approaches

For water resources, including groundwater, that are traded in reasonably competitive markets, one of the valuation methods available to the Trustees is the market price method [43 CFR §11.83 (c) (2)(i)]. This section describes how market prices for the direct consumption of water in municipal and industrial activities, or for its use as an input to other commodities such as irrigated agriculture, reflect the value of water in the Front Range region of Colorado.

Water that could have been available from the Arsenal absent the contamination can be valued using market data that are readily available, comprehensive, and consistent. Initial evaluation of data indicates that sufficient information is available to form an accurate representation of the willingness to pay for water over the past 15 years in the Front Range area of Colorado. This can provide a basis on which to calculate contaminated groundwater damages from the Arsenal site.

9.2.1 Water market literature overview

Over the past 15 years, natural resource agencies in the western United States have gradually accepted water markets as a way to encourage the efficient allocation of water among competing

uses. In this period, the 14 contiguous western states have enacted legislation that clarify water rights, and in particular the conditions under which water is transferred by a temporary lease or permanent sale. Economists have recognized differences in the value of water depending on the geographic regions and sectors of the economy using the water. They have advocated water markets as a method to allow for the increased benefits that can be realized by allowing water to move between sectors of the economy and across geographic regions. Potential gains in efficiency have been shown by Hartman and Seastone (1970), Vaux and Howitt (1984), and Hearne and Easter (1997). These gains from trade have led to active water markets in many parts of the western United States including Colorado.

The wide range of transferable water rights in western states breaks down into two broad classes commonly termed leases and sales. Leases of water are generally for a single year and for a known quantity of water. Some lease contracts are for longer periods of time and can be contingent on hydrologic conditions. Such contingent leases are a way of sharing the supply risk between the buyer and seller. Sales of water rights, on the other hand, usually entitle the purchaser to a permanent share of a water supply system that may yield varying amounts of water depending on weather and other factors. The seniority of the rights affects their expected yield and their sale price.

Table 9.1. Cumulative volume and volume-weighted prices for reported water transactions in Western states, 1990–2005[a]

	Volume				
	Lease	Sale	Total	Lease/sale ratio	Transactions as % of total use
State	(thousand acre-feet)				
AZ	10,869	1,958	12,826		
CA	18,407	2,557	20,965	7.20	3.13
CO	516	2,977	3,494	0.17	1.52
ID	4,338	408	4,746	10.64	1.42
MT	52	9	62	5.56	0.04
NM	837	258	1,095	3.24	1.82
NV	236	960	1,196	0.25	2.38
OR	1,070	2,406	3,476	0.44	2.61
TX	5,351	3,907	9,258	1.37	2.17
UT	262	190	452	1.38	0.55
WA	128	298	427	0.43	0.37
WY	234	207	441	1.13	0.42
Average				2.62	2.35
Total	42,302	16,135	58,437		

a. Water transferred under sale or long-term lease is counted each year for which the transfer occurs.

Source: Data from the *Water Strategist* (1990–2006).

9.2.2 Market value of groundwater: Conceptual approach

Using the market price approach, damages will be estimated based on observed market trades for water in the Front Range region to ascertain a market value (i.e., water users' willingness to pay) for the groundwater that, in the absence of contamination, would have been available.

Many of the Front Range water utilities that purchase surface water supplies also use groundwater that is blended with surface water for consumption, thus creating a single commodity with a shared market price. In addition, the cost of obtaining the rights to use shallow, tributary groundwater is often related to the cost of obtaining sufficient augmentation water. Augmentation water can be other sources of groundwater, including bedrock supplies, but more often is obtained by purchasing and retiring senior surface water rights. Thus, the Trustees will consider both groundwater and surface water transactions in determining appropriate market prices.

As with any market price valuation, the ultimate estimate of appropriate value will depend upon an analysis of variables affecting the price for each transaction. Such variables may include quality, location, reliability of supply, quantity of water transacted, seniority of rights, and consumptive use percentage of the water right. Transactions for sales of permanent rights as well as temporary leases will be analyzed.

To develop market prices for groundwater in the Arsenal region, the Trustees will use observed market data, including associated variables, to establish appropriate prices that water would sell for in the Front Range region at a given date. The sale price of water would then be used to calculate the annual diminished value of injured resources. Market prices for dates after those available in the collected transactions would be based on statistical forecasts using projections of variables that help explain changes in water prices, such as urbanization and development in the region. Values may also be based on differences in water quality and any use restrictions or other constraints not related to the injury.

9.2.3 Illustration of market price approach

To demonstrate the applicability of the market price method, the Trustees identified 1,118 observations of water rights sales in Colorado from 3,696 transactions compiled from the *Water Strategist* (Hansen et al., 2007). The *Water Strategist* reports permanent transfers and leases (including price, quantity, buyer and seller identification, buyer and seller use, and some additional contract terms) in 14 western states on a monthly basis.[1] The details of transactions

1. The implicit assumption is that the *Water Strategist* data are, if not comprehensive, at least representative of trades taking place in western states.

that occurred in Colorado over 16 years allow estimates of the economic, hydrological, and institutional factors that determine the price of water in Colorado, and thus allow direct estimates of water values in monetary terms. Table 9.2 provides information on transactions for the Colorado water market.

Table 9.2. Water purchasers in the Denver area, with number of transactions (1990–2005)

Buyer	Number of permanent transfers	Buyer	Number of permanent transfers
Arkins WA	2	Kersey	6
Arvada	1	LaSalle	20
Ault	6	Left Hand WD	36
Aurora	2	Little Thompson WD	81
Berthoud	4	Longmont	4
Boulder	41	Longs Peak WD	16
Brighton	1	Louisville	25
Broomfield	47	Loveland	3
Central Weld County WD	38	Lower Latham Reservoir Co.	8
Dacono	22	Lyons	5
East Larimer County WD	13	Mead	5
Erie	42	Milliken	19
Estes Park	5	North Weld County WD	28
Evans	29	Northglenn	3
Firestone	44	Nunn	11
Fort Collins-Loveland WD	86	Pierce	10
Fort Lupton	32	Platteville	22
Fort Morgan	17	Severance	1
Frederick	36	St. Vrain and Left Hand WCD	14
Gilcrest	13	Superior Metro District No. 1	5
Golden	1	West Fort Collins WD	1
Greeley	24	Westminster	8
Hudson	6	Windsor	19
Johnstown	6		

WD = water district.

Buyers were included in this list if they made at least one trade through the Colorado Big Thompson (CBT) over the study period or if they are located within the Denver Metropolitan Statistical Area.

Water in Colorado is traded in the form of three different property rights: a short-term lease of a quantity of water (lease), a permanent sale of a water right (sale), and a permanent sale of a share in large water projects (e.g., share in a ditch company or in the CBT project). Shares vary in their yield of water from year to year. In Colorado, like many western states, leases of water are common. However, as shown in Table 9.1, when considering the total volume of water transacted, the ratio of leases to actual sales is relatively low in Colorado. (Colby et al., 1993). On the other hand, Table 9.3 shows the average quantities and prices of transfers by type of water and year. All types of water are traded, but clearly, the number of trades in leases and shares greatly exceeds the number of permanent sales of water rights.

Table 9.3. Water transfers in Colorado by year (1990–2005)

	Total quantity (acre-feet)			Average price		
Year	**Lease**	**Sale**	**Share**	**Lease**	**Sale**	**Share**
1990	14,000		3,626	$70		$2,991
1991	10,000	250	12,579	$93	$5,851	$2,890
1992	2,000		4,492	$27		$2,734
1993	14,300		2,019	$25		$2,334
1994	37,558	200	2,509	$18	$5,338	$2,234
1995	23,312		2,128	$34		$2,935
1996	62,534		2,841	$489		$3,806
1997	7,000		8,254	$83		$3,916
1998	38,857		3,569	$539		$4,620
1999	35,256	5,800	7,352	$8	$3,666	$6,839
2000	15,674		4,055	$10		$16,800
2001	25,603		2,861	$73		$15,850
2002	1,221	450	2,513	$170	$9,468	$20,687
2003	14,946	7,596	2,087	$159	$4,845	$15,862
2004	15,640		3,367	$347		$18,365
2005	22,478	873	2,279	$212	$948	$15,797

To demonstrate how water market data are used to estimate a time series of representative prices for the Colorado Front Range water market, a statistical regression analysis was developed to measure those factors that are associated with changes in the price of water rights. The regression results presented here are intended to be illustrative, as the effect of different explanatory variables will be investigated further during the assessment. However, this illustration demonstrates how regression analysis can be used to reveal the factors associated with changes

in prevailing water market prices. The ability to measure these factors enables estimation of a market clearing price. Table 9.4 shows the results of an initial regression applied to 1,118 observations of prices and quantities of water rights sales from 1990 to 2005. In this illustrative example, the data available on annual prices are in constant 2004 dollars, and sale price was related to five variables to explain changes in price through time: the annual quantity of water rights sold in Colorado, a variable that accounts for sales originating from shares in the CBT (see below), a time trend, the number of acre-feet in the particular contract, and an index of the relative level of drought in a given year called the Palmer Drought Index.[2] Water rights based in the CBT are hypothesized to be more valuable than other sources, as they are for transmountain diversions and have fewer augmentation requirements than many other sources.

Table 9.4. Regression of Colorado water rights sales, 1990–2005

Water price (2004 dollars)	Annual volume traded (1,000 acre-feet)	Transaction volume (acre-feet)	CBT (= 1 if trade occurs within CBT)	Annual Palmer Drought Index (larger numbers = higher precipitation)	Time trend	Constant
	-52.0497	-1.3741	815.7813	-996.6406	1,033.028	738.5783
	(3.02)[a]	(2.08)[b]	(0.38)	(7.26)[a]	(7.77)[a]	(0.53)

Observations: 1,118.
R-squared: 0.24.
Robust t-statistics in parentheses.

a. Significant at 1% level.
b. Significant at 5% level.

The regression equation from Table 9.4 for calculating water price in 2004 dollars is:

> Water Price = 738.57 – 52.05 × (Annual Volume Traded/1,000) – 1.374 Transaction Volume + 815.78 CBT – 996.64 Drought Index + 1,033.03 Year Index.

This illustrative regression equation has some explanatory power, with an R^2 of 0.24. Three of the six variables are highly statistically significant in explaining changes in the observed water prices: the total quantity of rights sold, time, and drought severity. The total annual quantity of water rights sold in a year is negatively related to the prevailing market price, as would be

2. The Palmer Index was developed by Wayne Palmer in the 1960s and uses temperature and rainfall information in a formula to determine dryness. The Palmer Index uses 0 as normal, and drought is shown in terms of minus numbers; for example, minus 2 is moderate drought, minus 3 is severe drought, and minus 4 is extreme drought. The Index can also reflect excess rain using a corresponding level reflected by plus figures, e.g., 0 is normal, plus 2 is moderate rainfall.

expected from basic demand theory. The time trend of prices is increasing, as expected given the increased water demand from residential development and economic growth in the Front Range region over the 16-year time period. In addition, water prices increased with the severity of drought conditions, as measured by the Palmer Drought Index. The quantity of the water traded has a moderately significant effect on the price, with smaller quantities requiring a higher unit price.

Using regression results such as those in Table 9.4, the resulting average price of water can be calculated under different conditions and times. Figure 9.1 shows a plot of actual and estimated average prices over the 16 years in the sample. The illustrative regression annual price predictions fit the actual average price quite well, except in the extreme drought years of 2002–2003. Figure 9.1 also shows a pronounced increase in average water prices after 2000, when the current drought cycle began. Average sale prices after 2000 have fluctuated around $15,000 per acre-foot (in 2004 dollars), providing a reliable estimate of the current value of groundwater rights.

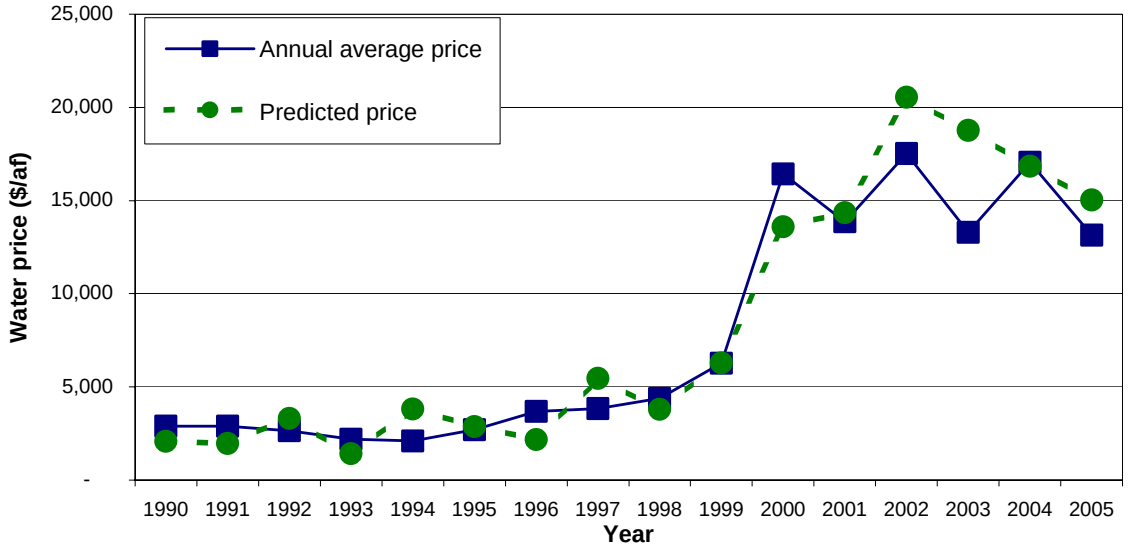

Figure 9.1. Observed and predicted price of permanent water transfers in Colorado over time (2004 dollars).

Water Strategist sales data and other information will be used to measure the actual valuation of water rights in terms of real monetary transactions. Damage recoveries based upon this market price approach would be used for implementing restoration actions. Restoration planning to identify appropriate restoration actions will be undertaken as described in Chapter 8.

9.2.4 Anticipated assessment activities

In the assessment, determination of damages through the market price valuation of groundwater will be pursued. Detailed market price valuation activities will include:

- Updating and refining a water transactions database to allow for more detailed comparisons to groundwater values in the region
- Incorporation of regional water demand conditions
- Refinement of statistical analysis of water market prices
- Forecasting to future water prices
- Application of water valuation to estimation of groundwater damages resulting from contamination and institutional controls.

9.3 Restoration-Based Equivalency Approaches

As discussed in Chapter 8, equivalency approaches such as REA can be used to determine the appropriate amount of restoration required to adequately compensate the public for its loss of natural resources and services.

The State will use the selection criteria discussed in Chapter 8 to identify potential restoration projects that would provide compensation for injuries to groundwater. These projects would provide benefits to groundwater systems, aquifers, groundwater-surface water interactions, or water users. Specific types of projects may include:

- *Water quality protection and improvement programs.* The State may choose to implement projects that protect water quality by reducing urban or agricultural runoff or that improve water quality.
- *Water reuse programs.* The State may choose to work with municipalities to implement non-potable water reuse programs that would result in measurable savings of potable groundwater. Such a project might involve construction of facilities to transport, store, and apply non-potable irrigation water to public parks, recreational areas, roadway medians, and landscaping around public buildings.
- *Water conservation programs.* The State may choose to work with municipalities and other appropriate entities to implement water conservation programs that would result in measurable savings of groundwater with no reductions in groundwater services.

- *Water recharge programs.* The State may choose to create wetlands or detention basins to contain high water flows and allow slower infiltration to groundwater, thereby reducing evaporative losses, increasing the quantity of available groundwater, and restoring groundwater-surface water interaction.

- *Water salvage programs*. The State may undertake to salvage water lost to invasive species such as tamarisk.

After quantifying reductions in services from injured groundwater resources, the Trustees will determine the appropriate scale of restoration projects. As discussed previously in Chapter 8, reductions in services provided by groundwater may include:

- Loss of human active-use services such as drinking water
- Loss of human passive-use services
- Loss of clean water for recharging surface water
- Loss of aquifers for recharge, storage and transportation of groundwater.

The Trustees will then determine the required size ("scale") and timing of implementation for the preferred groundwater restoration projects such that increases in services from restoration would be equal to the loss of services from injured resources at the Arsenal, with both losses and gains adjusted to present-value equivalents. This scaling could compensate for both interim losses and restoration that is required to return injured resources to baseline conditions. Once the required size of each proposed groundwater restoration project is established, the State will estimate the cost to implement these projects. Where the size of the project can vary, unit costs may be developed to enable the Trustees to scale up or down.

9.4 Total Value/Restoration Scaling Method

As discussed previously, when groundwater is injured by releases of hazardous substances, both use and non-use values are lost. Market price approaches, as described in Section 9.2, can measure use values, which make up a portion of total economic value. To estimate total damages for the groundwater injury, however, an alternative to the market price approach is necessary. This alternative approach will identify and quantify the amount and type of restoration that would provide value to the public equivalent to the value of the groundwater that has been injured. These values are ascertained by:

1. Obtaining public preferences for the types and mix of restoration alternatives
2. Providing value-based methods to scale resource restoration projects to provide services of equivalent societal value to the total value of the injured groundwater.

The results of the survey and analysis would determine the restoration plan selected by the Trustees; the cost of the plan would become the amount of damages sought by the Trustees.

A TVE study would support groundwater restoration planning in two ways. First, the study would explicitly obtain the public's input regarding the preferences and values for alternative types of restoration projects. This would aid the Trustees in evaluating the benefits of alternatives [43 CFR § 11.82(d)(2)] and provide additional input into the selection of alternatives [43 CFR § 11.90]. Second, the study provides value-based, as opposed to service-based, methods to determine the appropriate scale of potential restoration actions.

As described in Chapter 8, scaling restoration projects that provide similar services is referred to as *service-to-service* scaling, where the amount of restored services are scaled to be equal to the amount of lost services now and through time. For a large share of the service flow losses in the assessment area, providing restoration with similar groundwater services may not be technically feasible, may be undesirable, or may be too expensive. Thus, it may be preferable to select restoration actions that provide resources and services with similarly held value to those injured in determining the appropriate restoration. *Value-to-value* equivalency analysis ensures that the societal value of the services gained through restoration equals the societal value of losses. Value reflects the benefits or satisfaction that people derive from all active and passive uses of the resources lost due to contamination and gained through restoration.

9.4.1 Conceptual approach

At least since the mid-1960s, environmental economists have argued that people may hold both use (active use) and non-use (passive use) values for environmental resources (Krutilla, 1967). These use and non-use values make up what economists call total value. Passive use values are typically described as values that people hold for goods independent of any direct or active use of the goods. For example, they may gain satisfaction from knowing that an environmental resource will be preserved for others to enjoy, including others alive today and members of future generations. In the case of the Arsenal, even though citizens do not personally use the groundwater from a specific aquifer or area, they might still hold values for it because they would like it to be available to future generations or for other reasons. As the National Research Council (NRC, 1997, p. 2) has stated, "A fundamental step in valuing a ground water resource is recognizing and quantifying the resource's total economic value. Knowing the resource's total economic value is crucial for determining the net benefits of policies and management actions."

Passive values are routinely measured in benefit-cost analysis and have been used in the courts. The D.C. Circuit Court of Appeals confirmed the legitimacy of passive use values in damage assessments in *Ohio v. U.S. Department of the Interior* [880 F.2d 432 (1989)] and these values have been recognized in other cases as well (Freeman, 2003).

Damages for injured groundwater at the Arsenal will be measured using TVE, which considers both active use and passive use values. People's values will be measured by asking them appropriately crafted survey questions. The survey-based approach that is best suited to restoration planning involves stated-choice questions, where members of the public are presented with two or more restoration alternatives with different combinations of environmental resources and services. They are then asked to either choose their preferred alternative or to rank the alternatives. Typically, a cost is also associated with each alternative.

The history of applications of stated-choice questions is presented by Holmes and Adamowicz (2003). Stated-choice questions are now routinely used in nonmarket valuation studies, routinely conducted by state and federal agencies, and the results are accepted in benefit-cost analysis by federal agencies (OMB, 2003). An example of this approach, used on behalf of the USFWS and co-Trustees as part of the Lower Fox River/Green Bay NRDA, is discussed in the Fox River RCDP for the Lower Fox River/Green Bay NRDA (Stratus Consulting, 2000).

9.4.2 Anticipated assessment activities

An approach similar to that undertaken at the Fox River will be applied to determine the types and amount of restoration necessary to compensate for groundwater injuries at the Arsenal. The goal of the TVE approach for the Arsenal assessment will be to develop a variety of restoration projects that provides the public with value equivalent to that lost as a result of groundwater injuries.

Development of restoration options

To identify the potential of restoration options for a TVE study, the Trustees anticipate soliciting projects from a number of sources, including ongoing restoration planning efforts by local resource managers (e.g., Northwest Greenway Corridor); direct solicitation from the public at large through public comment; and focused discussions with identified stakeholder groups and State agencies. Restoration options would then be evaluated for possible inclusion in the TVE survey instrument.

Qualitative survey research

Qualitative survey research such as focus groups and structured individual interviews would be used in the initial stages of TVE survey development. These activities would allow the Trustees to investigate the public's understanding of the injury and its associated value, to identify aspects of greatest concern to the public, to confirm that the exercise is likely to be successful in soliciting the requisite feedback, and to identify types of restoration actions seen as appropriate for compensation.

Development of a survey instrument

Based on findings from the qualitative research phase, and in coordination with the ongoing injury studies, a TVE survey instrument would be designed to measure the public's value for the restoration options in relation to the value of the lost groundwater resources and services due to contamination at the site. Survey development will include peer review of the survey and overall implementation process.

Implementation of survey

The survey would be administered to a representative sample of the relevant population of Colorado. The relevant population would be determined during the qualitative survey research efforts. The survey would be administered in a format (e.g., mail, in-person) determined to obtain reliable results.

Data analysis and reporting

Data collected through the administration of the survey would be evaluated and statistically analyzed to estimate the damages to the public based on a TVE approach.

References

Colby, B., K. Crandall, and D. Bush. 1993. Water rights transactions: Market values and price dispersion. *Water Resources Research* 29:1565–1572.

Freeman III, A.M. 2003. The Measurement of Environmental and Resource Values. Resources for the Future, Washington, DC.

Hansen K, R.E. Howitt, and J. Williams. 2007. An Econometric Test of the Endogeneity of Market Structure: Water Markets in the Western United States. Working paper: Department of Agricultural & Resource Economics, University of California, Davis.

Hartman, L.M. and D. Seastone. 1970. *Water Transfers: Economic Efficiency and Alternative Institutions*. Resources for the Future, Johns Hopkins Press, Baltimore, MD.

Hearne, R. and K. Easter. 1997. The economic and financial gains from water markets in Chile. *American Journal of Agricultural Economics* 15:187–199.

Holmes, T.P. and W.L. Adamowicz. 2003. Attribute-based methods. Chapter 6 in *A Primer on Nonmarket Valuation*, P.A. Champ, K.J. Boyle, and T.C. Brown (eds.). Kluwer Academic Publishers, Dordrecht/Boston/London.

Krutilla, J.V. 1967. Conservation reconsidered. *American Economic Review* 57(4):777–786.

NRC. 1997. Valuing Ground Water: Economic Concepts and Approaches (Free Executive Summary). National Research Council, Committee on Groundwater Valuation. Available: http://www.nap.edu/catalog/5498.html. Accessed 8/24/2007.

OMB. 2003. Regulatory Analysis. Circular No. A-4. U.S. Office of Management and Budget. Available: http://www.whitehouse.gov/omb/inforeg/circular_a4.pdf. Accessed 8/24/2007.

Stratus Consulting. 2000. Restoration Scaling Based on Total Value Equivalency: Green Bay Natural Resource Damage Assessment. Appendix A of U.S. Fish and Wildlife Service et al. 2000. Restoration and Compensation Determination Plan: Lower Fox River/Green Bay Natural Resource Damage Assessment. Stratus Consulting, Inc., Boulder, CO. Available: http://www.fws.gov/midwest/FoxRiverNRDA/documents/RCDP-1.pdf. Accessed 8/24/2007.

Vaux Jr., H. and R.E. Howitt. 1984. Managing water scarcity: An evaluation of interregional transfers. *Water Resources Research* 20:785–792.