

Economic Benefits of Municipal and Industrial Water Supply Reliability for Metropolitan Atlanta

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1 Introduction

Benefit values for authorized purposes of federal water projects have changed over time. Benefit values for Army Corps of Engineers, Bureau of Reclamation and TVA original missions to develop the backbone infrastructure of the United States have diminished and benefit values of other agency missions aimed at sustaining developed economies and enhancing society's quality of life have grown more important. Changing societal preferences mean that the best use of established water resource infrastructure in the 21st century may differ from the authorized uses of these resources for the last 70 years.

Lake Lanier, a large federal multipurpose reservoir located in the upper Chattahoochee River Basin in northern Georgia, is the principal source of drinking water for the Metropolitan Atlanta area, is one of the most visited Corps recreation spots nationwide, and is vital to maintaining adequate streamflow quantity and quality in the Chattahoochee River above Atlanta. No economic alternatives have been identified for meeting these demands. The consequences of inadequate water supply to meet projected demand growth would be disastrous to Atlanta's future. The Apalachicola-Chattahoochee-Flint (ACF) Basin Water Control Plan (WCP) gives priority to hydropower and navigation objectives in release decisionmaking.

In 1989, the Corps of Engineers recommended that the best alternative to provide long-term water supply for the Atlanta Region and Lake Lanier communities was to "reallocate" or change a portion of the water storage in Lake Lanier from hydropower use to water supply use. Georgia seeks to reallocate a portion of Lake Lanier's conservation storage from hydropower and navigation releases to water supply as its best alternative to assure reliable water supplies. (See Apalachicola-Chattahoochee-Flint River Basin Compact, January 16, 2002.)

This article is based on research conducted for Atlanta Regional Commission (ARC). (Mahon, Wade, Roach, et al, 2001.) That research was aimed at evaluating the water supply, recreation and hydropower NED and RED benefits of operating Lake Lanier. This article answers one important question to understand the values at stake for a reliable water supply for Metro Atlanta: What would be the reduction in National

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Economic Development Benefits (NED Benefits) if water supplies to Metro Atlanta were capped at 2000 water withdrawal levels and no new supply alternatives existed. While the article provides an estimate of the value of a long term supply of water to Atlanta, the presentation emphasizes methods to evaluate the values of water supply reliability. Resolution of the ongoing ACF/ACT dispute among Florida, Georgia and Alabama may entail water supply reallocations less draconian than assumed within this article. The model and methods developed in this article can be used to evaluate any alternative.

2 NED Benefit Values

The research for ARC began with an examination of NED benefits and estimation methods. Economists and water professionals have debated methods to estimate municipal and industrial (M&I) water NED Benefits (shortage costs) since the original Principals and Standards (1973) was published and more recently, since 1987, when California began the Bay Delta Hearing Process to allocate water among competing urban, agricultural and environmental needs.

Few resources are more important to the economic and social well-being of Metropolitan Atlanta than a reliable water supply. The approach established in the Water Resource Council's Principals & Guidelines is followed to translate this need to economic values. NED Benefits are estimated based on methods consistent with those discussed in the Greeley-Polhemus Group, Inc. National Economic Development Procedures Manual, 1991.

The economic analysis of NED benefits broadly hinges on:

- Cost of water; i.e., costs alternative water supplies or programs that may reduce the need for alternative water supplies; and
- Cost of shortages; i.e., drought management program costs, lost profits, and reduced consumer surplus.

We assume away the cost of an alternative physical supply source because none is known to be available; this analysis is confined to the estimation of shortage costs. The conceptual elements of relevant shortage costs are as follows:

- Costs of shortage management including conservation and reclamation;
- Agency revenues lost from reduced water sales;
- Lost consumer surplus due to shortages;
- Economic losses to the region as a result of water shortages or water supply capacity limitations.

The first three of the costs listed above are direct measures of NED benefits foregone by failing to reallocate. The last relates to Regional Economic Development (RED) benefits and are not included in this analysis. The RED losses are not known but would be large and detrimental to Atlanta's multibillion dollar economy, substantially affecting the State's and the South's employment and economic activity. When impacts are severe and likely to have national repercussions, as may be the case with inadequate water supply for the huge Atlanta economy, the RED effects are pertinent to the federal

interest in water resource development and management of multipurpose reservoirs built at taxpayer expense. RED benefits could be additive to NED benefits estimated within this section of the report.

3 Alternative Methods to Estimate NED Benefits

The Corps of Engineers mandates NED Benefits as the benchmark for the valuation of water projects. In the absence of a physical supply alternative, willingness to pay measures serve to estimate values for water supplies. Economists measure a person's total willingness to pay for a good with reference to the demand curve. The demand curve can be referred to as the willingness to pay curve because it measures how much people are willing to pay for each additional unit of the good or service. NED Benefits can be estimated as the area under the demand curve for water. This is an approximation of the total benefit a person derives from being able to consume a certain amount of a good.

Typically in water project analysis, NED benefits are capped at the supply price of the next alternative. In the case of Metro Atlanta, with no supply alternatives other than reallocating Lake Lanier storage, consumer surplus is estimated as a component of NED benefit values. Consumers pay a *charge* for water that can be seen as a lower bound estimate of their willingness to pay. We know that consumers are willing to pay at least that much because they *do* pay that much. However, they may be willing to pay considerably more than this—particularly if the alternative were water shortages. The difference between what they are *willing to pay* and what they are charged is the *consumer surplus*. The charge for the water plus the consumer surplus is the total value of the water to the consumer. In the language of NED Benefits, this is the total benefit value of water supply.

Four potential approaches to estimate benefit values have been used in various settings:

- Alternative costs;
- Contingent values;
- Marginal loss function;
- Consumer surplus (Willingness to Pay) based on observed water price, demand elasticity and use levels.

3.1 Cost of Alternatives

NED benefits typically are limited to the replacement cost of the most likely alternative. The traditional cost approach assumes that water users faced with shortage have identifiable alternatives. Typically, this implies building the next most economic dam and impoundment option.² The ACF/ACT watershed is capacity-limited and no politically, environmentally or economically feasible alternative watershed impoundment exists. All potential alternative sources of supply to meet demand growth in Metro Atlanta are fraught with economic and environmental consequences far worse than those resulting

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² The alternative cost approaches and methods are well established under Principals and Guidelines (1983).

from increased withdrawals from Lake Lanier. Proposals to import water from the Savannah or Tennessee River Basins, for example, encounter numerous obstacles in laws enacted in Tennessee, South Carolina, and even in Georgia. The private and public costs of interbasin transfers would greatly exceed those of simply making the additional withdrawals from Lanier.

3.2 Contingent Valuation

Stated preference approaches have been used to ascertain people's values for reliable water supplies. Contingent valuation methods use surveys to query consumers about the value of goods--in this case, reliable water supply. These values are expressed as willingness to pay (WTP). Carson and Mitchell (1987) surveyed California residents about their willingness to vote for a hypothetical initiative that would increase water supply reliability at a given cost. Results of this pioneering study support estimates of median annual willingness to pay (WTP) per household to avoid specified water shortages. Results are unique to California and are not transferable.

Barakat and Chamberlin (B&C, 1994) used similar contingent value methods to estimate WTP to avoid shortages of varying frequency and magnitude in nine California urban water districts. Dollar-denominated results in terms of annual WTP per household were similar to results from the Carson-Mitchell study. Griffin (2000) applied the B&C methods to Texas in relation to issues tied to the Edwards Aquifer. The Griffin WTP to secure improved future reliability asks a question in the form of what would you pay to improve reliability from 20% shortage every ten years for 14 days to 20% shortage every 15 years for 14 days, varying the amounts of shortage, frequency and duration. Other research suggests that respondents cannot adequately imagine the differences between frequencies of ten or 15 years. Nor can it be assumed that all respondents hold the same exact notions in mind when answering the WTP questions.

B&C and Griffin have another identical fatal problem; each shows a high so-called threshold effect and declining marginal shortage costs related to the extent of shortage and duration of shortage. The marginal shortage values do not conform to economic theory. For example, B&C report a monthly WTP to avoid a 10% shortage once in ten years as \$12. The WTP to avoid a 40% shortage is \$16. Griffin reports \$25 as the one time payment to avoid a 10% shortfall of 14 days, \$30 as WTP to avoid a 30% shortfall for 14 days. The marginal cost of the first 10% is \$25; but the marginal cost of the next 20% is \$5. The threshold effect can be explained by a common finding in contingent value studies known as embedding: "the value placed on a resource is virtually independent of the scale of the resource." (McFadden, 1994.)

The marginal loss curves of each study have the wrong shape and don't pass that commonsense test. This curve shape was rejected in California policy applications because of people's observed rising penalty costs to use water in droughts and agency observed contingency programs with rising costs.

3.3 Observed Demand Functions

Price is an indicator of a good's value because it tells us the minimum amount buyers are willing to give up to have the good. Normally, an individual consuming a good is willing to pay more than the good's price. How much more can be inferred from the individual's demand curve. The difference between maximum willingness to pay and the good's market price is called consumer surplus. Consumer surplus is defined as the area below the demand curve and above the price line. Consumer surplus is a component of NED Benefit.

Estimating consumer surplus requires a demand curve. Baseline water price and quantities can be combined with information on water demand elasticity to estimate demand curves. The approach to M&I water valuation used in this analysis relies on verifiable water price and quantity combinations and secondary studies on elasticity of demand for residential water. The Central Valley Project Improvement Act PEIS used this approach to achieve allocations of water among urban, agricultural and environmental requirements. (USBR, 1995)

3.3.1 Demand Elasticity

Elasticities of demand combined with price and quantity combinations can be used to develop water demand functions and values for various levels of shortage. Planning and Management Consultants, Ltd. (PMCL) estimated ACF/ACT demand elasticities within their Comprehensive Study (PMCL, 1996, Volume II). Their elasticity estimates are in the range of -0.2, which is typical for water, a good with no close substitute and small income elasticity. Renwick and Green, 2000, report a long run -0.16 price elasticity in recent and careful research done in California over retail water rates that ranged from \$0.50 to \$4.50 per 1000 gallons. California Department of Water Resources adopted Renwick's research as the basis for assuming single-family residential price elasticities of -0.1 for winter months and -0.2 for summer months. We assume the -0.16 as a single-point demand elasticity estimate. More water is used outdoors in California than in the Southeast in the summer because it seldom rains in the California summer. Arguably, the selected elasticity should be closer to the -0.1 in the Southeast based on Renwick and Green.

Industrial water users are thought to have low price elasticities where water is an input in the production process. Survey research in California revealed that many water critical manufacturing plants installed reuse and recycling programs that cost as much as \$3,000 - \$5,000 per acre foot. Value of the marginal product of water as an input of the production process was discovered to be as much as hundreds of thousands of dollars per acre foot. The high values of input water explain the high costs of recycling programs. Industrial and manufacturing water demands typically are assumed to be intolerant of shortages because water is partly a direct input in the production process. (Wade, 1991.)

Typically, in water use studies Industrial and selected Commercial water users are protected from shortages. Metro Atlanta houses little manufacturing. No demands are assumed protected. The shortage applies across the region and with the -0.16 elasticity measure applied to all demand functions. This imparts no unreasonable bias to

estimated NED Benefit values. In the Atlanta Region ARC shows that water demand components mostly are Residential and Commercial.

Use	Percent
Residential	54%
Commercial	23%
Government	6%
Industrial	4%
Other	14%
Total	100%

4 Water demand forecasts

The review of alternative estimation methods directed our research to the econometric estimation of consumer surplus as the area under the Atlanta demand curve. A model is predicated based on M&I demand functions and supply withdrawals from the ACF watershed. Water demand forecasts through 2050 are based on population, employment and per-capita water consumption data compiled by the Atlanta Regional Commission from water and wastewater master planning and permitting information provided by county, municipal, and regional water utilities withdrawing water from Lake Lanier or from the Chattahoochee River downstream. These data apply to the Lanier through Whitesburg portion of the watershed. **Table 1** lists total reservoir and river water demand projections through 2050 and projected shortfall capped by supply at year 2000 levels. Projected shortfalls in Table 1 are assumed to occur without reallocation of Lake Lanier's storage. With reallocation, supplies are assumed to grow to meet demands with no shortfalls. Without reallocation, substantial conservation would be required to offset supply shortfalls.

Table 1: Metro Atlanta Projected Water Supply Shortfall Without-reallocation, 2000–2050

Year	Forecast demand (mg/year)	Projected shortfall (mg/year)	% demand shortfall
2000 (baseline)	160,466	-	-
2010	192,446	31,980	17
2020	227,837	67,371	30
2030	247,208	86,742	35
2040	275,162	114,696	42
2050	303,570	143,104	47

Source: ARC

5 Agency Revenue Losses

Water supply limitations impose costs and reduced revenues on water providers. Reduced profits of water agencies are a component of NED Benefits. The cost of

conservation programs and policies needed to reduce Metro Atlanta water usage to match supplies plus agencies' lost revenues associated with reduced water sales are calculated as two components of shortage costs. Retail prices are raised to cover these costs and losses because in the long run, which this article describes, agencies must be assumed to cover their extensive fixed costs and bond obligations.

Regulated utilities would set a price under conditions of long term limited water supplies to cover the average cost for water supplies. Prices under shortage conditions rise only to hold operating revenues at pre-shortage conditions. This is a price lower than the market-clearing price (P_c) that would be necessary to eliminate excess demand..

5.1 Water and Sewer Rates

The cost of water to residential users includes both the water cost and sewage cost for a proportion of water inflow estimates. The split depends on the percentage of water used outside and not returned as sewage. Atlanta agencies set returned water at 80 percent. Prices used in this study are based on actual 2001 retail residential water prices in Metro Atlanta. A survey of Metro Atlanta existing water and sewer prices reveals a bimodal distribution of volumetric water prices—near \$2.00 and near \$3.50 per 1,000 gallons. Only the variable water and sewer prices matter to this calculation. These two prices are used to bound the calculations.

The volumetric sewer rates are also bimodal, near \$4.00 and near \$2.00. Dekalb and Clayton Counties, with rates near \$2.00, built most of their sewage treatment plants with federal construction grants. That program has ended. We assume that the \$4.00 charge represents the marginal rate for future sewer service.

Prolonged water shortage would cause water and sewage rates to increase. The price before shortage (P_o) is based on existing volumetric water and sewer prices for M&I residential customers in Atlanta. The price after shortage (P_1) would rise sufficiently to offset reduced water withdrawals and sales plus added costs related to conservation. This method shifts all costs to consumers by fixing a price that makes up for reduced sales and pays for agency conservation programs. The new price, P_1 , needed to cover the change in costs in Atlanta's water-shortage case, is calculated by solving for P_1 from Equation (1):

$$P_1 Q_1 = [Q_o P_o - (Q_o - Q_1) (T + D + R) + C_c (Q_o - Q_1)] \quad (1)$$

where:

- Q_o = forecast quantity of demand before the shortage.
- Q_1 = water withdrawals limited by shortage
- P_o = retail price before the shortage .
- T, D, R = treatment, distribution and other costs per 1000 gal water saved because of the shortage.
- $Q_o - Q_1$ = shortage before purchase of other make-up supplies, which are assumed zero.
- C_c = cost of conservation programs and devices to achieve user reductions equal to the shortage.

The equation states that new revenue required to maintain profitability equals the old revenue minus variable cost savings from the shortage plus out of pocket cost of conservation programs and advertising. P_1 is obtained by dividing both sides of the Equation by Q_1 , the reduced supply of water.

This equation represents a long run concept because in the long run water and sewer utilities cannot be assumed to lose money. The approach keeps utility profits constant. Treatment, distribution, and other variable costs for intake water are estimated at \$0.69 per 1000 gallons based on information provided by Cobb County and Gwinnett County public water providers. Sewer collection and treatment variable costs are estimated at \$1.40 for standard treatment. These cost elements are meant to include only variable costs incurred from pumping, treatment and distribution.

5.2 Cost of Conservation Programs

Metro Atlanta utilities' costs of conservation programs are unknown because programs to achieve significant conservation savings are not in place. Conservation is defined as long-term programs that require investments in structural elements such as ultra-low-flush toilets, low-flow showerheads, or water efficient landscape irrigation technology — coupled with ongoing public education and information campaigns. This differs from short-term behavioral conservation such as rationing or penalty pricing used during droughts.

Conservation alternatives evaluated within a regional water plan involve the implementation of cost-effective long-term programs, referred to as Best Management Practices (BMPs) that have long-lasting water savings. California water agencies have done extensive research and have implemented conservation BMPs. The BMPs are conservation programs designed to be cost-effective over the long-term. The agreed upon water savings that result from the implementation of the BMPs are based on the best available data and are subject to revision as the state of knowledge improves. These efforts will serve as the basis for understanding what Atlanta agencies must surmount.

Metropolitan Water District of Southern California (MWD) serves a semi-arid region about the size of Metropolitan Atlanta. MWD projected its M&I demands including the effects of conservation BMPs. These are shown in [Table 2](#). BMPs are expected to save about 740,000 acre-feet per year (or 15 percent) by 2010 and 880,000 acre-feet per year (or 16 percent) by 2020. [740,000 AF = 241,018 million gallons; 880,000 AF = 286,616 million gallons]

Table 2 Projected Water Demands and Conservation (Million Acre-Feet)				
	Observed	Projected		
	1990	2000	2010	2020
Water Demands with conservation:				
M&I Demands	3.6	3.66	4.168	4.644
Water Conservation (BMPs) Savings:				
1980 to 1990 Programs	0.25	0.25	0.25	0.25
1990 Plumbing Codes and Ordinances		0.089	0.157	0.235
Plumbing Retrofit Programs		0.080	0.185	0.203
Landscaping Programs		0.050	0.076	0.097
Commercial/Industrial Programs		0.014	0.027	0.045
Leak Detection/Repair		0.017	0.043	0.052
Total Savings	0.25	0.500	0.738	0.882
Conservation % of Demand	6.5%	12%	15%	16%

Source: MWD IRP Table 2.5

These conservation savings are associated with costs for various elements of the conservation strategy shown on [Table 3](#) in both costs per acre-foot (AF) and per 1000 gallons of water.

Table 3 Estimated Costs for California Implementation of Conservation BMPs		
Type of Program Conserved	Range of Costs per AF	
	(\$/AF)	(\$/1000 Gal)
		(midpoint)
<u>Low-flow showerhead replacement</u>	<u>\$150-250</u>	<u>\$0.65</u>
<u>Ultra-low-flush toilet replacement</u>	<u>\$300-400</u>	<u>\$1.07</u>
Residential water surveys and audits	\$300-500	\$1.25
Large turf area audits	\$350-600	\$1.45
Distribution leak detection/repair	\$250-350	\$0.92
Commercial/industrial conservation	\$300-650	\$1.45

Source: MWD IRP

Reclamation with expensive treatment would apply if water supplies were as limited as assumed for this analysis. These costs in the out years will be greatly more than the values shown on **Table 3**. Beyond the water supply from conventional conservation, MWD found that it could possibly reclaim up to 750,000 AF, or nearly 15 percent of its 2020 demand at under \$1,000 per AF in a rising curve from \$50 to \$1,000. The California Department of Water Resources' least-cost analysis suggests that costs of conservation and recycling to achieve savings above those identified in MWD's IRP could cost between \$500-\$1,500 per acre-foot of water saved or recycled. (CALFED, PEIS, 2000)

Based on the extensive research from California on conservation and reclamation costs, we postulate that long term conservation and reclamation programs would have a rising cost schedule akin to that shown on **Table 4**. Again, we emphasize that these are reasonable costs but not supported by BMP cost estimates in Atlanta. Neither is it certain that conservation and reclamation could mitigate shortages beyond 35 percent of demand. Hence, our analysis of the large outyear shortages is conservative.

Table 4 Conservation Costs			
Year	Shortage	Cost per 1000 Gal	Cost per Acre Foot (325,732 gal)
2010	17%	\$0.50	\$165
2020	30%	\$1.00	\$325
2030	35%	\$1.50	\$490
2040	42%	\$2.00	\$650
2050	47%	\$3.00	\$977

Source: CUWCC and MWD IRP

Long-term conservation measures that are adopted by water users can have a demand “hardening” effect. This occurs because conservation tends to reduce the “slack” in the system; that is, reduce or eliminate the least valuable water uses and/or the least efficient water use methods. This means that water use efficiencies already in place make users more vulnerable when shortages happen. Demand hardening increases the size of the economic losses associated with specific shortage events. In California, the hardening factor is assumed to adjust the effect of outyear shortage events by 50%; that is, if conservation decreases demand by 10%, the economic effect of a subsequent shortage of a specified size is computed as if the shortage were actually 5% greater. Until better understanding is achieved of Metro Atlanta’s ability to reduce current water use, no premium for demand hardening is included in the model.

6 Consumer Surplus Methods and Measures

Both linear and CES demand curves are used to derive consumer surplus estimates at ten year intervals. The linear estimates are shown for analytic simplicity but not relied on because linear water demand models have been generally rejected in the literature. (Nieswiadomy and Molina, 1991.)

CES estimates are reported as the basis for lost NED Benefits for reasons that are explained.

6.1 Linear Demand Function

The general equation for the point elasticity of a linear demand function over a range of prices from P_0 to P_1 is given as:

$$e = [(Q_1 - Q_0) / Q_0] / [(P_1 - P_0) / P_0] \quad (2)$$

This formula can be used to solve for the point where the shortage quantity, Q_1 , crosses the demand curve at P_1 . This can be used to calculate the lost consumer surplus under competitive market conditions by the formula:

$$\text{Consumer surplus} = ((P_1 - P_0) * Q_1 + (P_1 - P_0) * (Q_0 - Q_1) * .5) \quad (3)$$

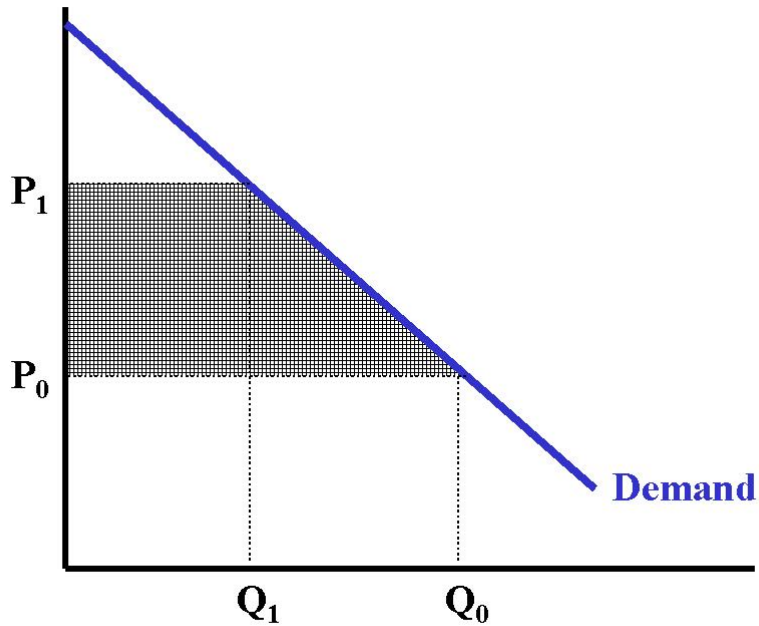
One problem with Equation (2) is that the elasticity depends on the starting point; i.e., the elasticity differs along the curve depending on whether you assume that P_0 or P_1 is the starting point. Consequently, more than one consumer surplus value may be found between two quantities, Q_i . This problem becomes more serious the larger the magnitude of the price change. One way to avoid any ambiguity in measuring elasticities is to use the arc convention. This approach uses the average price and quantities as the denominators. With the arc convention Equation (2) can be revised to:

$$e = [(Q_1 - Q_0) / ((Q_1 + Q_0) / 2)] / [(P_1 - P_0) / ((P_1 + P_0) / 2)] \quad (4)$$

The arc convention yields the same elasticity whether we assume a price increase or a price decrease. A consumer surplus equation could be derived akin to Equation (3). Knowing as we do starting prices and forecast quantities of water usage, and applying either elasticity estimate, we can estimate the change in consumer surplus under the linear demand curve in such a way as to yield that component of legitimate NED benefits. The other component of the change in NED benefit values is the amount actually paid for the reduced water, $P_0 * (Q_0 - Q_1)$.

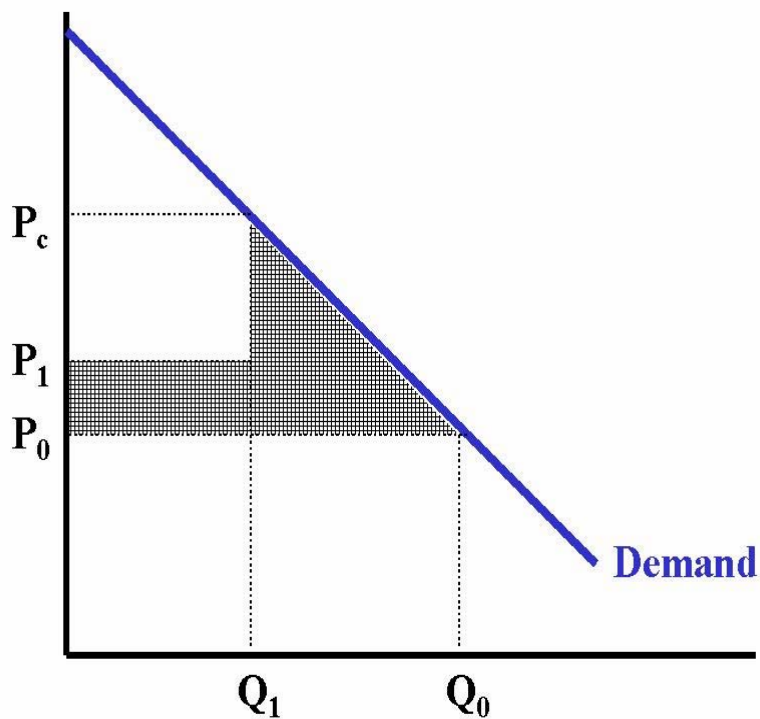
A second problem is that Equation (3) calculates the welfare loss assuming a market equilibrium solution such as implicit in a competitive market. Figure 1 shows the shaded area under the linear demand curve between the before and after price and quantity changes as the loss in consumer surplus measured within the NED Benefit, assuming a market equilibrium solution. (The shaded area is exactly equivalent to the NED measure that could be measured as lost revenue plus lost consumer surplus; i.e., the rectangle $(P_1 - P_0) * Q_1$ exactly equals the rectangle $(Q_0 - Q_1) * P_0$, everything else equal.)

Figure 1. Linear Demand Function – Market-Clearing Solution



A regulated water utility will not raise prices during a supply shortage to reach a market equilibrium. Price ceilings will result in excess demand during a shortage. Hence, prices will not be allowed to increase to P_1 during a shortage as implied in Figure 1. In Figure 2, the market clearing price is P_c . The regulated price will increase only to P_1 . The lost consumer surplus area in Figure 2 is noticeably smaller than in Figure 1. This is the conceptual value that we have measured as NED Benefit.

Figure 2. Linear Demand Function – Regulated Monopoly Solution



Ignoring the arc elasticity convention, the corrected equation to estimate the monopoly linear consumer surplus is

$$\text{Consumer surplus} = ((P_1 - P_0) * Q_1 + (P_c - P_0) * (Q_0 - Q_1) * .5) \quad (5)$$

Market clearing prices (P_c) must be computed to estimate the lost welfare. These are calculated with Equation (6). Equation (6) combines steps that solve for the coefficient of demand for a 1 percent price change and then solves for the equilibrium price (P_c) for a move along the demand curve from Q_0 to Q_1

$$P_c = P_0 + \left(\left(\frac{Q_0 - Q_1}{Q_0 - (Q_0 * (0.01 * e) + 1)} \right) \right) * 0.01 * P_0 \quad (6)$$

Price to maintain regulated revenues is estimated with Equation (1). These prices vary with starting price, shortage and conservation costs, assuming that T,D,R costs are constant through time. Estimated prices are shown on [Table 5](#). These prices are lower than the market clearing prices; i.e., the monopoly water districts are price regulated to maintain profits.

Table 5 Revenue Satisfying Price (P_1)		
Year	$P_o = \$2.00$	$P_o = \$3.50$
2010	\$2.36	\$4.16
2020	\$2.97	\$5.10
2030	\$3.52	\$5.83
2040	\$4.37	\$6.94
2050	\$5.84	\$8.68

Source: Energy and Water Economics, March 9, 2001

Welfare losses derived from the linear demand monopoly model are estimated and shown at ten-year intervals on [Table 6](#). These annual estimates increase with the increasing shortage of water through time and vary positively with starting water price. Tests show that the estimates behave as expected by economic theory. These estimates are shown only for completeness; the NED Benefits derive from the CES welfare losses in Section 6.2.

Table 6 Linear Lost NED Benefits \$ Million		
Year	Linear Lost Consumer Surplus at $P_o = \$2.00,$ $e = -.16$	Linear Lost Consumer Surplus at $P_o = \$3.50,$ $e = -.16$
2010	\$91.1	\$164.0
2020	\$280.1	\$474.6
2030	\$434.0	\$706.7
2040	\$678.5	\$1,074.6
2050	\$1,038.4	\$1,569.3

Source: Energy and Water Economics, March 9, 2001

6.2 CES Demand Function

The CES demand curve is a typical representation of consumer behavior, which assumes that consumers make proportionate adjustments to price changes. [Figure 3](#) shows how the linear and CES demand curves compare, assuming that each passes through the original price quantity point in demand space. Note that the market-clearing price during a shortage is higher for a CES demand function than a linear demand function. The consumer surplus losses will be larger for the CES demand function.

The CES demand function is given by the equation:

$$Q = BP^e \quad (7)$$

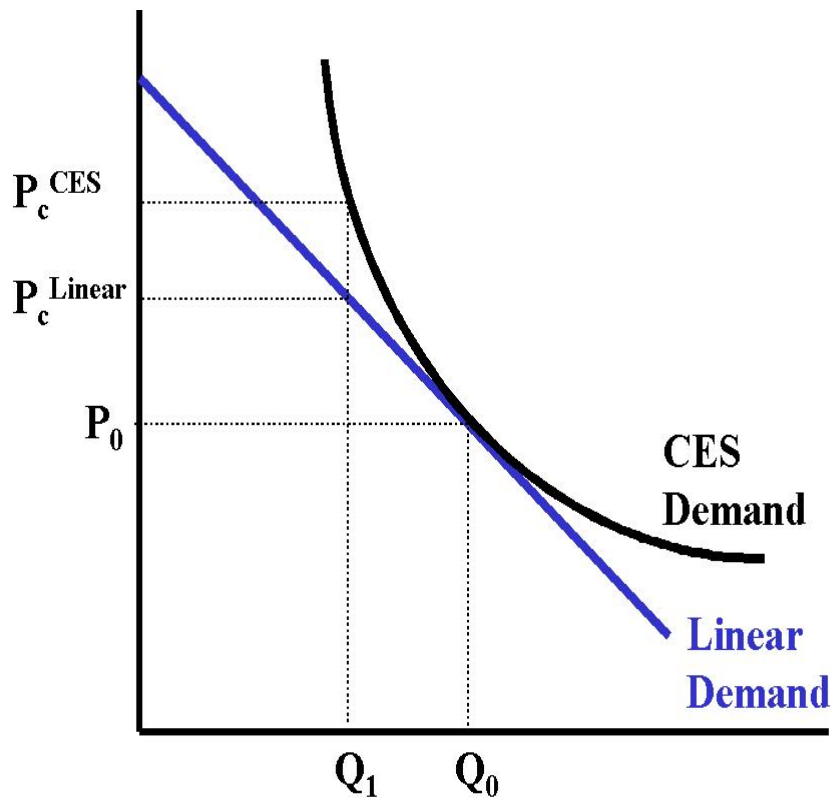
When we consider the change in consumer surplus with a shortage where we allow market-clearing prices, the CES consumer surplus loss calculation is straightforward because we are integrating between two finite points. The change in consumer surplus associated with a change in water supplies between Q_0 and Q_1 when price is not regulated can be written as:

$$CS = [((BP_c^e) * P_c) / (e+1)] - [((BP_0^e) * P_0) / (e+1)] \quad (8)$$

which can also be written as:

$$CS = [(BP_c^{e+1}) / (e + 1)] - [(BP_0^{e+1}) / (e + 1)]. \quad (9)$$

Figure 3. Comparison of Linear and CES Demand Curves



Or, because $BP^e = Q$, can be expressed as:

$$CS = [(Q_1 * P_c) / (e + 1)] - [(Q_0 * P_0) / (e + 1)]. \quad (10)$$

Again, this is the change in consumer surplus assuming a market-clearing price (P_c) after the shortage.

Figure 4 shows a CES demand curve with market clearing and regulated prices. Assuming that prices adjust to clear the market during a shortage, price would rise to P_c and the lost consumer surplus would be the area between P_c and P_0 and to the left of the demand curve. With a regulated utility we assume that price will be set at a level below P_c during a shortage (P_1 in Figure 4). To calculate the lost consumer surplus as the cross-hatched area in Figure 4, we use the formula:

$$CS = [(Q_1 * P_c) / (e + 1)] - [(Q_0 * P_0) / (e + 1)] - [(P_c - P_1) * Q_1]. \quad (11)$$

While the values of e , P_0 , Q_0 , P_1 , and Q_1 in Equation (11) are known, the value of P_c needs to be calculated. Given e , P_0 , and Q_0 , we can solve for B using Equation (7) as:

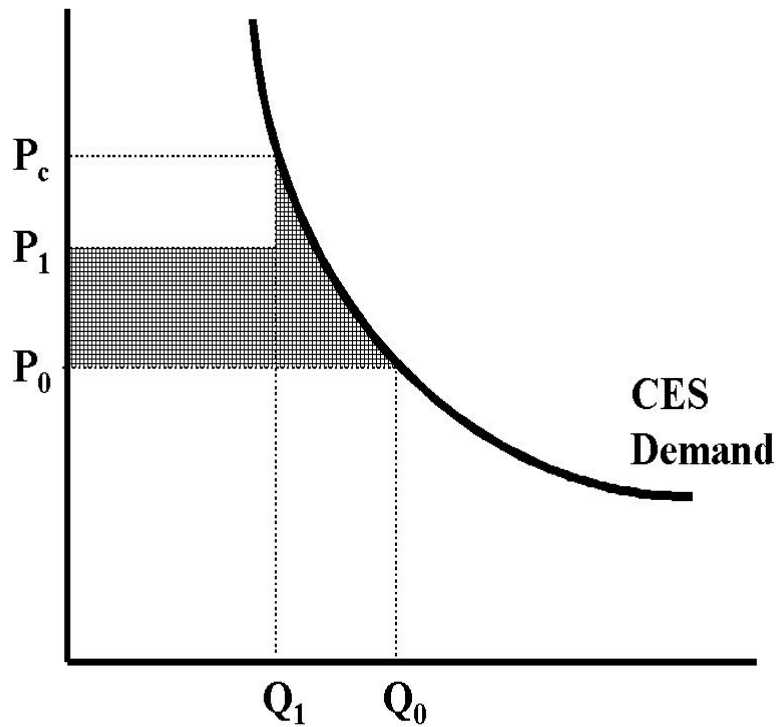
$$B = Q_0 / P_0^e. \quad (12)$$

After solving for B , we can solve for P_c as:

$$P_c = (Q_1 / B)^{1/e}. \quad (13)$$

Once we know the value of P_c , we can solve for the lost consumer surplus using Equation (11) and P_1 calculated from Equation (1) using calculated values of P_c for different assumptions about P_0 .

Figure 4. CES Demand Function



Lost consumer surplus at ten-year intervals is calculated with the above equations and shown on [Table 7](#). The range of prices bound the high and low NED Benefit losses for the existing price level range in Atlanta Metro. These estimates conform to NED Benefit values depicted on Figure 4.

Table 7 Lost CES Consumer Surplus Due to Shortage \$Million			
Year	CES Consumer Surplus	CES Consumer Surplus	
	$P_o = \$2.00$ $e = -.16$	$P_o = \$3.50$ $e = -.16$	
2010	\$111		\$199
2020	\$481		\$826
2030	\$887		\$1,499
2040	\$1,823		\$3,079
2050	\$3,501		\$5,879

Source: Energy and Water Economics, March 9, 2001

6. Wastewater NED Benefits

Metro Atlanta water bills include charges related to intake water usage and wastewater discharge. If intake water were limited as assumed, waste water prices would have to increase for the same reasons identified above. This would add to the reduction in welfare identified for water supply shortages. These welfare losses are measured with CES Equation (11) using the same approach depicted on Figure 4. **Table 8** shows the NED Benefit estimates related to the higher price, $P_o = \$4$, for the reduced throughput with shortage.

Table 8: Wastewater NED benefits foregone

Year	Net wastewater Return shortage (mgal/year)	Wastewater price P_1 (\$/1000 gallons)	Annual wastewater NED benefit foregone, regulated monopoly (\$millions)
2000 (baseline)	-	4.00	-
2010	25,585	4.52	151.4
2020	53,897	5.09	660.4
2030	69,394	5.41	1,208.9
2040	91,758	5.86	2,549.3
2050	114,484	6.32	4,913.0

Source: Energy and Water Economics, March 9, 2001

7. Sum and Present Value of NED Benefit Losses

The water and wastewater NED Benefits are summed for total shortage losses. The midpoint of the estimates on **Table 7** is added to the waste water NED values on **Table 8** represent the annual NED Benefit losses due to water shortage at ten-year intervals, shown on **Table 9**.

Table 9 Annual NED Benefits \$Million	
Year	NED Benefits $e = -.16$
2010	\$306
2020	\$1,313
2030	\$2,402
2040	\$5,000
2050	\$9,603

Source: Energy and Water Economics, March 9, 2001

Buford Dam, which controls Lake Lanier, has a remaining life of 57 years. The ten-year values are interpolated and the 2050 value is extrapolated to 2057. The ten-year estimates of NED Benefits are converted to a present value at year 2000 using the federal discount rate, 6.625 percent. Consequently, the PV NED Benefit for reallocating water behind the dam to M&I purposes in order to avoid the annual losses estimated above is \$19.1 billion, shown on Table 13. While a single value is shown to represent the midpoint value from Table 10, an implicit range surrounds this estimate that would vary with water and waste water price assumptions, conservation cost assumptions, and price elasticity.

Table 10 PV NED Benefits \$Billion 2000
\$19.1

Source: Energy and Water Economics, March 9, 2001

The estimates on Tables 7 and 9 can be converted to shortage costs per 1000 gallons or per Acre Foot (AF). While the estimates on the underlying tables are related to ten year values, the shortage values actually relate to the amount of shortage. Table 11 show that the shortage costs rise sharply with the percent of shortage. Because the underlying losses are estimates from a nonlinear CES function, the shortage costs increase in a nonlinear fashion. Two sets of estimates are shown. The first two columns include water and wastewater losses. The last two columns reflect losses for intake water only. These losses compare very well with California DWR's LCPSIM Loss Function. (CDWR, 1999, p. A-13.) The value of losses to California users was derived from the marginal cost of water to residential users and the Carson-Mitchell, 1987, residential user survey on the willingness to pay to avoid water shortages. CDWR shortage values are \$2,250 per AF at 15 percent shortage; \$3,600 per AF at 35 percent shortage. The two different methods used to derive these values both reveal that urban water users place high values on avoiding supply shortfalls.

Table 11 Unit Shortage Value Estimates \$				
Shortage	Shortage Value per 1000 Gal	Shortage Value Per AF	Intake Water Shortage Value Per 1000 Gal	Intake Water Shortage Value per AF
17%	9.58	\$3,120	\$4.84	\$1,577
30%	19.50	\$6,351	\$9.70	\$3,158
35%	27.69	\$9,018	\$13.75	\$4,478
42%	43.60	\$14,202	\$21.37	\$6,961
47%	67.11	\$21,859	\$32.78	\$10,675

8. Conclusions

The resource economics published literature has relied on contingent valuation methods to estimate values for reliable water supplies. A revealed preference method is developed to estimate NED benefit values for reliable water supplies for urban water consumers. Computed benefit values for the scenario that limits Metro Atlanta's water to 2000 Lake Lanier withdrawal rates are very high because no other politically and environmentally feasible alternative exists. At least over the range of shortages examined in California over the last 15 years, values per acre-foot are similar. These urban water supply benefit values are compared with benefit values for existing authorized purposes of the project in the project report. (McMahon, Wade & Roach) To the extent that benefits are higher for shifting purposes to water supplies for water behind Buford Dam, society would be better off by doing so.

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