Staff Paper

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A Framework for Estimating the Economic Damages of Groundwater Contamination: An Application to Nitrates

ABSTRACT

This paper develops a conceptual framework for estimating the economic damages imposed on residential users when groundwater becomes contaminated. The damage framework is based upon the economic concepts of water demand and supply. Previous research and engineering data are used to empirically implement the framework in the form of an economic damage model. The model is applied to estimating the economic damages due to nitrate contamination of groundwater.

A Framework for Estimating the Economic Damages of Groundwater Contamination: An Application to Nitrates

Groundwater contamination has a potentially wide-ranging impact on public health and well-being. In the United States, one fourth of all the water used by people and industry comes from groundwater (Solley et al). Fifty percent of the water used for residential purposes is obtained from groundwater. In rural areas the dependence on groundwater is even greater. Over ninety-five percent of the rural residential water supply comes from groundwater (Pye et al).

Groundwater contamination is one byproduct of human activity. Residential activities contribute contaminants in the form of waste sewage, household chemicals, and fertilizers. Agricultural activities may result in pesticide and fertilizer contamination. Industrial chemicals may leach into groundwater due to improper disposal, leaky landfills, and accidental spills. Deicing salts are a problem for aquifers near roadways.

In several areas of the nation, more than 25 percent of water wells sampled fail to meet Federal drinking water standards of 10 milligrams per liter of nitrate or less (Nielson and Lee). For example, in irrigated regions of Arizona and Illinois, 112 milligrams per liter (mgl) of nitrate is common in well water (Rajagapol and Carmack). In southern Michigan, a 1984 survey revealed that 34 percent of 191 rural drinking water wells tested exceeded the Federal limit of 10 mgl of nitrate (Vitosh).

Protection of groundwater quality poses difficult tradeoffs. On one hand, maintenance of a high quality water supply has direct public health and environmental benefits. On the other hand, protection involves costs. Control may imply restrictions on numerous routine activities. A greater share of public and private budgets will be drawn away from other beneficial uses and directed to groundwater management.

Economic analysis can help to identify the costs and benefits of groundwater management. Economic methods can be used to quantify the tradeoffs that individuals are willing to make across alternative policies. By providing methods to consistently identify and quantify tradeoffs, economic analysis encourages an informed policy choice. This paper develops a framework for estimating the economic damages of groundwater contamination. The framework is applied to the case of groundwater contamination by nitrates. As an initial case study, nitrate contamination is interesting for at least three reasons. First, many rural areas face the threat of nitrate contamination from either agricultural fertilizers (Nielson and Lee) or residential wastes (Pye et al).

Second, the health effects of ingesting nitrate contaminated water is well documented (National Academy of the Sciences). Young infants are highly susceptible to contracting the disease methemoglobinemia from ingesting nitrate rich water. There is also concern that nitrate may cause certain cancers as well as mild retardation (National Academy of the Sciences).

Third, drinking water standards for nitrates are clear; faced with a water supply contaminated by nitrates, community water systems in the United States must take steps to provide water that meets legal standards (Code of Federal Regulations). This requires an investment in equipment to remove contaminants from intake water before it is delivered to consumers.

To estimate the damages of groundwater contamination, we need to select a contamination response scenario. First, consistent with the rural incidence of nitrates, we examine the economic damages caused by nitrate contamination in public water systems that serve small communities. Second, given the regulatory structure surrounding nitrates, we assume that contamination is detected and investments are made to chemically remove the contaminant from the water supply. The damages of contamination are therefore the costs incurred to remove the contaminant from the water actually used by residents.

The paper is divided into three sections. The first section develops the conceptual framework for estimating the damages of groundwater contamination. The second section applies the framework to estimating the costs of nitrate contamination of groundwater. The third section reviews the estimated economic damages caused by nitrate contamination of a groundwater supply.

A Framework for Measuring the Economic Damages of Groundwater Contamination

The framework developed for estimating residential damages is based on the economic concepts of demand and supply. Before a contamination event occurs, demand and supply of residential water determine initial water costs and water consumption benefits. After groundwater contamination occurs, additional water treatment is required and additional supply costs are incurred. These additional supply costs lead to an increase in water prices and a reduction in the net benefits of residential water consumption.

This section shows how this loss in net benefits can be measured. The section begins with a description of residential water demand. A water supply function is then described. Finally, using the concepts of demand and supply for water, the benefits of consuming and producing water and the damages resulting from groundwater contamination are identified.

Residential Water Demand

Economic demand measures a consumers' marginal willingness to pay for successive quantities of a good or service. A residential water demand function summarizes the relation between a community's willingness to pay for water and the successive quantities of water that the community is willing to purchase.

Residential water demand is a function of water, community, and climatic characteristics. This functional relation is

$$(1) \qquad p = f(q,c,y,r)$$

where p is the price that households are willing to pay for successive quantities of water, q is the quantity of water consumed per household, c is water quality delivered to households, y is average household income and r is precipitation.

The demand price, p, tends to decline with an increase in the quantity of water available to households. Demand price tends to increase with increases in water quality. For a given quantity of water, demand price also tends to increase with the average household income; higher income households are willing to pay more for a given quantity of water. Finally, demand price declines with increases in precipation since less water is needed for lawn and garden irrigation.

Residential Water Supply

The economic supply of a good is the marginal cost of a good or service. A water supply function measures a water system's cost of providing successive quantities of water.

The marginal cost of providing water arises due to the resources used in the development, treatment, and delivery of potable water. A water supply function represents these costs as

(2) $mc = g(q,k,h,w)$

where mc represents marginal costs, k is input water quality, h is the number of households that a public water system serves and w is input prices.

Marginal costs may either increase or decrease with the quantity of water provided to households. A decline in input water quality tends to increase marginal costs since additional treatment and processing are required in order to maintain a consistent output water quality. In other words, the firm is supplying some level of health safety. By increasing water quality, the firm is reducing the level of harmful health effects. Marginal costs may either increase or decrease with the number of households within a service area. Marginal costs tend to increase as input prices increase.

The Economic Benefits of Water Consumption

The interaction of water demand and supply are basic forces that guide the provision of water within a community. Households are willing to pay for additional units of water as long as their demand price is not less than the market price. Over the long run, it pays a water system to increase the quantity of water supplied until the marginal cost of the last unit of water sold is equal to the market price. Water demand and supply tend to equilibrate at a point where the price that households are willing to pay equals the price at which water is supplied.

Figure 1 illustrates one possible price and quantity equilibrium. With the supply curve S1 and demand curve D1, demand price and marginal cost are equal at point A1. At this equilibrium economic benefit accrues to consumers and producers. The economic benefit of a community water supply is the households' total willingness to pay for water quantity Q1 minus the total cost of supplying this quantity. This economic benefit, also referred to as net surplus (the summation of consumer surplus and producer surplus), is the area underneath the demand curve between points zero and Q1 minus the area underneath the supply curve between zero and Q1. The consumers gain economic benefit because they pay less for the water they consumed than they would have been willing to pay. Producers gain economic benefit because they receive a price for the water they supply which is higher than their costs of production. Total economic benefit is therefore the triangular area connecting points B, A1, and C1.[1]

The Economic Damages of Groundwater Contamination

Public water systems that provide drinking water to households are required by law to maintain nitrate concentrations below ten milligrams per liter (mgl) of water (Code of Federal Regulations). If nitrate concentrations in groundwater rise above ten mgl, the system must either find a source of uncontaminated water or add on additional treatment facilities to remove the contaminant before water is actually distributed to households. Either action increases the system's marginal costs. We focus on the latter case.

To maintain water quality level requires additional water treatment once groundwater becomes contaminated. This additional treatment results in an increase in the marginal cost of supplying water, therefore causing a shift in the supply of water provided. This shift in the supply of water provided decreases the benefits that acrue from producing and consuming water. Where contaminants are removed by treatment, this reduction in benefits represents the economic damages imposed on residential users by groundwater contamination.

Figure 1 illustrates economic damages for a representative case of groundwater contamination. As discussed above, the initial economic benefit of the community water system is the area of triangle BA1C1.

After contamination occurs, the marginal cost of providing water shifts upward from S1 to S2 due to the increased cost of supplying water to households. The increased cost of supplying water is due to the cost of removing the contaminant from the water supply. After contamination, the marginal cost of providing Q1 units of water is greater than households' marginal willingness to pay for Q1. Given marginal costs S2, households are willing to purchase no more than water quantity Q2. After the contamination event the system provides quantity Q2 and households pay a price of P2 dollars per unit of water.

Due to the increase in marginal costs, water quantity consumed is lower and the water price is higher after contamination occurs.

The economic benefit of water consumption after the contamination event is the difference between a households' total willingness to pay for water quantity Q2 minus the total cost of providing this quantity. Therefore, after the contamination event, the economic benefit of consumption is the triangular area connecting points B, A2, and C2.

The economic damage caused by groundwater contamination is the difference between the economic benefits of water consumption before and after the contamination event. This difference, the economic damage due to contamination is the quadrilateral connecting the points A2, A1, C1 and C2.

Measuring the Economic Damages Due to Nitrate Contamination

This section uses the economic damage framework to develop an empirical model for estimating the economic damages of groundwater contamination by nitrates. The model is based upon the assumption that nitrates are removed from the water supplied to households using a centralized, ion exchange treatment facility (Gumerman et al).

There are three functions that are necessary for applying the general framework: a residential water demand function, a pre-contamination supply function, and a post-contamination supply function. Once these functions are identified, they are combined in a manner analogous to Figure 1 to create an economic damage model for nitrates.

A Water Demand Function

There have been at least fifteen different studies of residential water demand in the United States during the last twenty years. All but three of these studies are specific to particular cities or regions. Of the three national studies, only a study by Foster and Beattie allows adjustments for regional variations in water demand. These regional adjustments result in a single demand function that compares very favorably with the estimates obtained in twelve regional demand studies (Libby et al). Since it accurately represents many different regions, the Foster and Beattie estimates are used to represent residential water demand in the empirical model of economic damages.

The FB water demand function is

$$(3) \quad Q = A\exp(aP)Y^{.6274}R^{-.0403}N^{.3026}$$

where Q is the quantity of water demanded per household (in thousands of cubic feet per year), A is the constant term, P is the average price of water (per thousand cubic feet in 1983 dollars), Y is median annual household income measured in 1983 dollars, R is rainfall in inches, and N is the average number of persons per water service meter.[2]

A notable aspect of the FB water demand function is that it does not include any proxy for water quality. In this regard, the FB function is not unique; there appears to be no existing estimates of the impact of quality on residential demand (Libby et al). This lack of demand information, however, does not preclude and estimate of contamination damages. Public water systems are required to maintain certain water quality levels. In this institutional environment, there is no need to know how water demand shifts with quality since quality is required to be constant. The economic damages are the damages incurred due to the higher marginal costs of water processing and treatment.

Pre-Contamination Water Supply

The pre-contamination water supply function represents the marginal cost of providing water before contamination occurs. Pre-contamination marginal cost is assumed to be constant in both the quantity of water consumed per household and service area size. Capital and input prices are also assumed to be constant. Under these assumptions, the pre-contamination supply function is

$$(4) \qquad S1 = b$$

where b is a constant. In implementing the model of economic damages, b represents the initial equilibrium price of water. This initial price may be different for different water systems.

The assumption of constant marginal cost does not fit all supply situations equally well. However, in Michigan, approximately twenty-five percent of all water systems appear to operate under the assumption of constant marginal cost (Walker).

A Post-Contamination Water Supply Function

The post-contamination water supply function represents the marginal cost of providing water after nitrate contamination of groundwater occurs. Analytically, post-contamination marginal cost is the sum of two quantities: (1) pre-contamination marginal cost S1 and (2) the additional marginal cost of removing excess nitrates.

A post-contamination supply function was estimated in three steps. First, the treatment costs of removing excess nitrates from the water supply by a centralized ion exchange treatment system is estimated using an engineering model developed by the United States Environmental Protection Agency (Gumerman et al). A treatment cost equation is estimated by running a number of contamination scenarios (baseline conditions) through the E.P.A. model and then using statistical methods to estimate the algebraic relation between the baseline conditions and the resulting treatment costs. Second, using simple differentiation, a marginal treatment cost equation is derived from the treatment cost equation. Finally, the pre-contamination supply function -- b -- is added to the marginal cost function resulting in the post-contamination supply function.

The water treatment cost equation was estimated using cost data generated by the Gumerman et al model. Three variables are entered into the Gumerman model so as to estimate the treatment costs of removing nitrate from public water supplies. The three variables include the nitrate concentration in the intake water supply, the quantity of water treated, and the evaporation rate. The size of the three variables are allowed to vary so as to represent different nitrate contamination scenarios. Treatment costs are regressed on the three variables.

The estimated treatment cost equation is

$$(5)\quad \ln TC = 9.8377 + \underset{(.0142)}{0.6280\ln(q)} + \underset{(.0267)}{0.1265\ln(k)} - \underset{(.0217)}{0.3062\ln(v)}$$

where ln is the natural log, TC is treatment costs in 1983 dollars, q is the amount of water treated in thousands of cubic feet per day, k is water quality or nitrate concentration (milligrams per liter of water), and v is the evaporation rate in inches per year.[3] Standard errors of the regression coefficients are in parentheses. The equation estimates the cost of treating water given the quantity of water treated per day, the concentration of nitrate in the water supply and the annual evaporation rate.

The positive elasticity coefficient on q implies that as the quantity of water treated increases, the costs of treatment increase. A 10 percent increase in the quantity of water treated increases treatment costs by 6.28 percent.

The positive elasiticity coefficient on k implies that as the nitrate concentration increases in the water supply, the cost of treatment increases. If nitrate concentrations increase by 10 percent then treatment costs increases by 1.26 percent.

The negative sign on the elasticity coefficient on the evaporation rate v implies that as the evaporation rate increases the cost of treatment decreases. If the evaporation rate increases by 10 percent, the costs of treatment decrease by 3.06 percent.

The derivative of treatment cost is marginal treatment cost. Therefore, differentiating the antilog of equation (5) with respect to q, the marginal treatment cost of removing nitrate is

$$(6) \quad MC = .6280e^{9.8377}q^{-.3720}k^{.1265}v^{-.3062}$$

where MC is the marginal cost of removing nitrate from water supply. This equation estimates the marginal costs of removing nitrate from water given the quantity of water treated per day, the concentration of nitrates in the water supply, and the annual evaporation rate. Notice that as the quantity of water treated increases the marginal cost of treating each additional unit of water decreases.

The post-contamination supply function is the sum of the pre-contamination supply function (equation 4) and the marginal costs of removing nitrates (equation 6). This sum is

$$(7) \qquad S2 = b + .6280e^{9.8377}q^{-.3720}k^{.1265}v^{-.3062}$$

where S2 represents the post-contamination supply function, b is the pre-contamination price of water, and the other variables are the same as in equation 5.

Economic Damage Estimates

To estimate economic damages with centralized treatment, a computerized algorithm was developed to carry out the calculations implied by Figure 1 and the economic damage estimation framework. Equations (3), (4) and (7) are the demand and supply functions used in the algorithm for estimating economic damages. To produce a set of damage estimates using the algorithm, one first describes a set of baseline conditions. Baseline conditions allow for six community-specific characteristics; nitrate concentration in the system intake water, average household income of the population served by the water system, the water system's service area size, initial water price, annual precipitation, and annual evaporation.

An Economic Damage Model

The damage model was set up to estimate the economic damages associated with a contamination event that requires the removal of ten milligrams of nitrate per liter. It was assumed that contamination results in an intake concentration of fifteen milligrams per liter and the system management invests in equipment to bring the output water quality down to five milligrams of nitrate per liter. Five milligrams per liter allows a margin of safety below the Federal standard of ten milligrams per liter.

Other baseline conditions included the following. The initial water price was set at 7.5 dollars per thousand cubic feet (one dollar per thousand gallons). Average annual household income in the community was $14,000. The number of households served by the water system was 1,000. Annual precipitation was 20 inches and annual evaporation was 15 inches. There was assumed to be 2.7 persons per household.

Table 1 reviews the output of the economic damage model. After contamination occurs, the price of water within the community doubles from 7.5 dollars to 15 dollars per thousand cubic feet (one dollar to two dollars per thousand gallons of water). Given the increase in water prices, average household water consumption drops from 18 cubic feet per day to 15 cubic feet per day (135 gallons per day (gpd) to 112 gpd).

Annual economic benefits of water consumption are initially $275 per household but drop to only $175 per household after contamination. Nitrate contamination of groundwater at a concentration of fifteen milligrams per liter therefore imposes an annual economic damage of $100 per household or $100,000 across the community as a whole.

A change in baseline conditions changes the level of economic damages. To illustrate this, the damage model was run for two communities. The first community has an average household income of $15,000 per year and the second an average household income of $35,000 per year. In each community, the initial water price was assumed to be 15 dollars per thousand cubic feet (two dollars per thousand gallons), the number of households serviced was 500, annual precipitation was 20 inches, and annual evaporation was 15 inches. Both communities remove ten milligrams of nitrate per liter from the system intake water.

Table 2 gives results for both communities. Though initial prices are the same in both communities, the higher income community consumes more water. After the contamination event, the increase in water price in the higher income community is actually smaller than for the lower income community. This result is due to the decreasing marginal costs of treatment. The price increase causes higher income households to cut back on water consumption by 4.5 cubic feet per day (thirty five gallons per day). The lower income community cuts back on water consumption by 3.5 cubic feet per day (twenty-five gallons per day). Even though the higher income community had a smaller price increase, the higher income community could decrease their consumption of water to a greater extent. Since the lower income community was initially consuming much less than the higher income community, they had less leeway to cut back on consumption than the higher income community. For example, the high income community could reduce the quantity of water used for lawn irrigation but lower income communities would decrease water consumption for less water intensive activities.

After the contamination event, the annual benefits per household decreases to 120 dollars for the lower income community and to 220 dollars for the higher income community. Therefore, the annual economic damages of groundwater contamination by nitrate is 105 dollars and 150 dollars per household for the low and high income communitites respectively.

In Table 3 two different size communities are compared. The first community has a population of 500 households while the second community has a population of 2,000 households. Both communities have an average income of $15,000, the initial price of water is assumed to be 15.0 dollars per thousand cubic feet, annual precipitation is 20 inches and annual evaporation is 15 inches. Both communities remove ten milligrams of nitrate per liter from the system intake water. The larger community has a much lower increase in their price of water resulting in much lower decreases in water consumption. In fact, water consumption in the smaller community decreases by almost twice that of the larger community. Therefore the loss in benefits is only 65 dollars per household per year for the 2000 household community but is 105 dollars per household per year for the 500 household community. These results stem from the fact that the marginal cost of treating water decreases as the quantity of water treated increases.

The effect of baseline conditions is clearly evident in the structure of the summary damage equation.[4] The summary damage equation is

$$(8)\qquad \ln ED = 3.5 + \underset{(.0091)}{.118\ln(k)} - \underset{(.0057)}{.152\ln(p)} + \underset{(.0138)}{.383\ln(y)} - \underset{(.0056)}{.340\ln(h)} - \underset{(.0112)}{.016\ln(r)} - \underset{(.0078)}{.092\ln(v)}$$

where ED is economic damages sustained per household. The standard errors of the regression coefficients are in parentheses. The adjusted R-square of the equation is 0.987. The positive exponents on nitrate concentration, k, and average household income, y, indicate that economic damages increase with increases in either of these variables. The negative exponents on initial price, p, service area size, h, precipitation, r, and evaporation rate, v, indicate that economic damages decrease with increases in these variables.

Point-of-Use Treatment

Table 4 lists estimated costs for a community that chooses point-of-use treatment for the removal of nitrate. It is assumed that households only treat water that is used for drinking and cooking.

There are currently two POU devices available for removing nitrate. One is an ion exchange device and the other is a reverse osmosis system. The cost of the reverse osmosis will be used for comparison to the costs of using a centralized treatment system. A point of use ion exchange system is better suited to removing nitrates at the point of entry. A reverse osmosis system is desirable over the ion exchange system when nitrate is to be removed at the point of use, such as the kitchen sink (Gumerman).

Annualized costs were obtained by amortizing capital costs over a ten year time horizon at a real interest rate of five percent and then adding these amortized capital costs to operating and monitoring costs. Given the discussion of the previous section, these annualized costs represent the annual economic damages of groundwater contamination when POU treatment is used.

As seen in Table 4 the costs estimated by Gumerman et al are somewhat higher than those calculated by Bellen and Anderson. There are two reasons for this difference. Part of the difference in costs is the way data was used to calculate costs. Gumerman et al apparently used average retail prices for reverse osmosis systems. The Bellen and Anderson data are drawn from actual installation and maintenance costs as experienced by a single community in Illinois. The Illinois community organized to install POU devices and obtained a volume discount from the manufacturer. The Gumerman et al and Bellen and Anderson estimates indicate that community organization may result in significant cost savings.

A second reason for the difference in costs estimates is the monitoring and testing component. Gumerman et al were conservative and assumed that the POU device would be tested four times a year to guarantee system performance. Bellen and Anderson suggest a testing regime closer to manufacturer's recommendation of testing once a year.

The damage estimates associated with POU scenario are substantially higher than the damage estimates for the centralized treatment scenarios detailed in Tables 1, 2 and 3. This may appear to indicate that centralized treatment is a less damaging alternative when a community is faced with the nitrate contamination of groundwater. Such a conclusion, however, would not be warranted.

Figure 2 compares the economic damages associated with both the centralized and POU treatment alternatives. Damage estimates are plotted for service area sizes ranging up to 1000 households. POU damage estimates per household are constant across all service area sizes. The upper dashed line represents the POU damage estimates derived from Gumerman et al. The lower dotted line represents POU damages derived from Bellen and Anderson.

The downward sloping solid line in Figure 2 plots the per household damages estimated using the summary damage equation for centralized treatment. The plot of economic damages with centralized treatment assumes a nitrate concentration of fifteen milligrams per liter, an average household income of $25,000, precipitation at 20 inches per year, an evaporation rate of 15 inches per year and an initial price of water set at 15 dollars per thousand cubic feet.

Figure 2 shows that the choice of treatment approaches depends on the baseline conditions in a community. In particular, the size of a community dominates the treatment choice. For communities smaller than approximately forty households, POU treatment results in lower economic damages than does centralized treatment. For communities larger than 270 households, the situation is reversed; centralized treatment results in lower economic damages.

For communities ranging in size from 40 to 270 households, the choice of POU versus centralized treatment is less conclusive. For communities in this intermediate range, the choice of POU versus centralized treatment depends on specifics such as the availability of manufacturer discounts and the level of monitoring and testing that is thought to be adequate.

Conclusions

This paper has described a framework for estimating the economic damages of groundwater contamination. Damages are incurred when the marginal costs of supplying water increases due to the firm adding on new treatment facilities for removing the contaminant from the water supply. With increased marginal costs of supplying water, the price of water rises resulting in decreased water consumption. This results in decreased benefits from the consumption of a given quantity of water. The decrease in benefits is the measure of the economic damages of groundwater contamination.

The framework was applied to guide the design of an empirical economic damage model. It was shown that as the income level of a community increases the economic damages associated with groundwater contamination is greater. Also it was shown that as the service area size increases the economic damages per household decreases holding other factors constant.

Finally, it was shown that the economic damages is lower for a firm serving 40 households if they use POU treatment rather than centralized treatment. For firms serving more than 270 households, centralized treatment results in lower economic damages per household than a POU system. This implies that economic damages can be reduced when POU systems are bought in bulk by the public water system rather than being bought by the individual household.

The results indicate that the economic damages associated with groundwater contamination may be substantial and that the level of damages can vary depending on certain community characteristics. These results imply that a policy response to a contamination event needs to take account of factors such as income and population in estimating the impact of the chosen response.

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Footnotes

1. The Marshallian benefit - cost measures used in this research should be viewed as approximations to the ideal welfare measures (Just, Heuth and Schmitz). In the case considered, this approximation should be very close to the ideal (Willig).
2. A water service meter measures the quantity of water used by the occupants of a home, apartment complex, nursing home and etc. The coefficient a, on price P varies depending on region. The appendix contains Foster and Beattie's estimates for coefficient a for regions within the United States. This study used the Midwest region.
3. The adjusted R-square of the equation was 0.978 and the regression F-statistic was 729.99.
4. The summary damage equation was derived to fit the following conditions: nitrate concentrations ranging from zero to 100 milligrams per liter; services areas of up to 5000 households; evaporation rates from 5 to 100 inches per year. Dollar terms are at the 1983 price level.

Appendix

Foster and Beattie's Estimated Parameters[a]

Region	A	a	By	Br	Bn
1. New England and Northern Atlantic	.04307	-.1180	.6274	-.0403	.3026
2. Midwest	.03558	-.0804	.6274	-.0403	.3026
3. South	.04303	-.0928	.6274	-.0403	.3026
4. Plains and Rocky mountains	.08858	-.2261	.6274	-.0403	.3026
5. Southwest	.08121	-.1223	.6274	-.0403	.3026
6. Northern California and Pacific North-West	.09416	-.2686	.6274	-.0403	.3026

[a] From Foster and Beattie, 1979

FIGURE 1: BENEFITS OF WATER CONSUMPTION

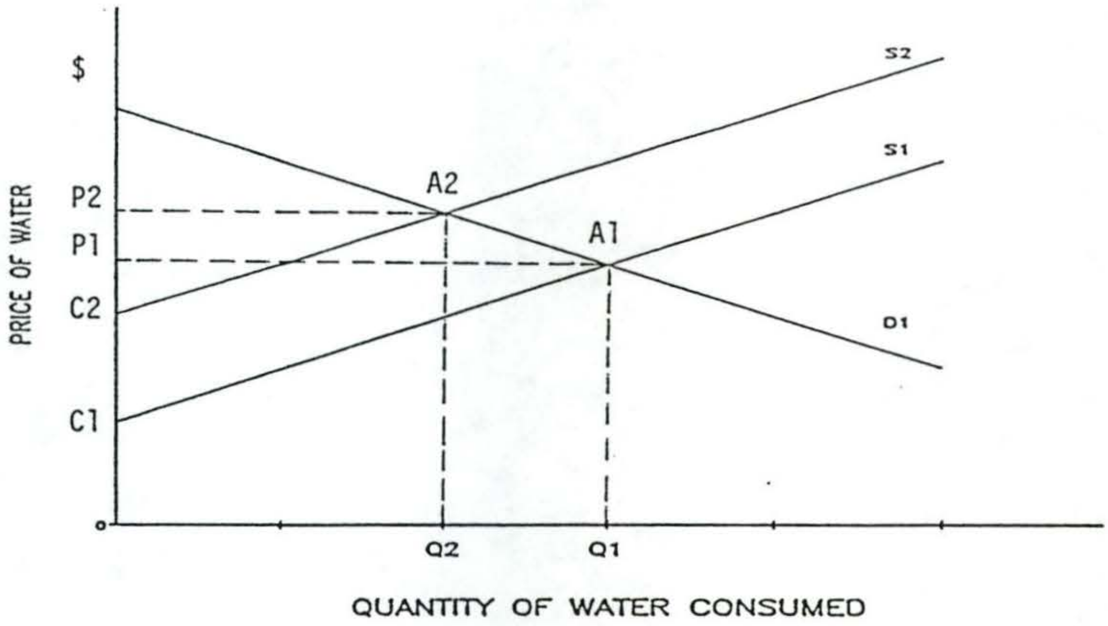

FIGURE 2: CENTRALIZED VERSUS POU

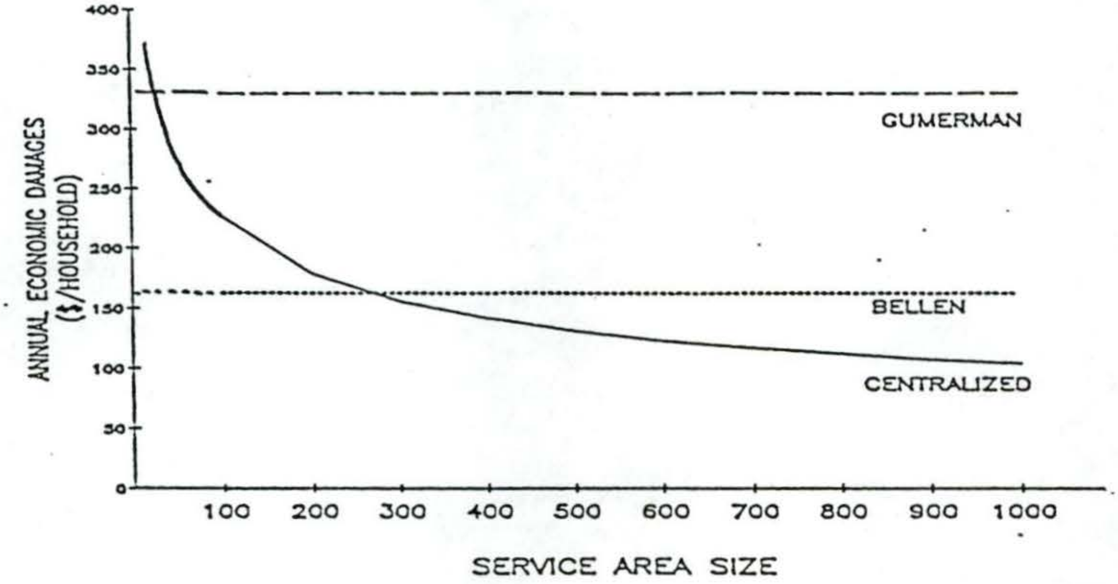

Table 1. Annual Economic Damages Due to Nitrate Contamination

Variable	Initial Situation	10 MGL Removed
Price of Water[a]	$7.5	$15.0
Household Water Consumption[b]	18.0	15.0
Annual Benefits per Household	$275	$175
Annual Net Damages per Household	-	$100

[a] 1983 dollars per thousand cubic feet of water.
[b] Cubic feet per day.

Table 2. Annual Economic Damages by Income

Variable	Income = $15,000		Income =$35,000	
	Initial	Post-Event	Initial	Post-Event
Price of Water[a]	$15.0	$25.5	$15.0	$23.6
Water Consumption[b]	15.0	11.5	24.0	19.5
Annual Benefits per Household	$225	$120	$370	$220
Annual Damages per Household	-	$105	-	$150

[a] 1983 dollars per thousand cubic feet of water.
[b] Cubic feet per day.

Table 3. Annual Economic Damages by Community Size

Variable	Community Size = 500		Community Size = 2000	
	Initial	Post-Event	Initial	Post-Event
Price of Water[a]	$15.0	$25.5	$15.0	$21.0
Water Consumption[b]	15.0	11.5	15.0	13.0
Annual Benefits per Household	$225	$120	$225	$160
Annual Damages per Household	-	$105	-	$65

[a] 1983 dollars per thousand cubic feet of water.
[b] Cubic feet per day

Table 4. Annual Costs of Point of Use Nitrate Removal

Source	Gummerman et al ($)	Bellin et al ($)
Capital Costs[a]	58	45
Operating Costs	148	87
Monitoring and Testing	124	31
Total Annualized Costs	330	163

[a] These are amortized capital costs. Amortization is over a ten year time horizon at a five percent real rate of interest.