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UNCERTAINTY IN WATER RESOURCE PLANNING: AN ECONOMIC EVALUATION OF A WATER USE REDUCTION ALTERNATIVE

Bruce E. Lindsay
University of New Hampshire, Bruce.Lindsay@unh.edu

John R. Powell
University of New Hampshire

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TECHNICAL COMPLETION REPORT

Water Resource Research Center
University of New Hampshire
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ABSTRACT

Traditionally, engineers and planners have considered shortage costs to be unacceptable, financially and politically, and designed water supply systems to acommodate demand at all times. Studies of geographic areas that have suffered some form of unanticipated shortage (usually drought) have revealed that the costs are not as large as previously imagined.

While it is realized that economic losses due to planned and anticipated shortages will vary geographically and by sectoral use (industrial, domestic,...), little work has been done to evaluate the effect of duration, size, and seasonal timing of shortage on monetary loss. With more and more communities facing future water deficits and fiscal budgetary constraints affecting capacity expansion decisions, an alternative water management strategy of planned water cutbacks may be attractive.

This report focuses upon a methodology that measures the consumer surplus loss associated with various levels of water shortage (ten, twenty-five, forty, and sixty percent cutbacks) for the domestic sector of a New Hampshire community. Community water resource personnel can evaluate the effects of conservation measures and seasonal variations upon monetary losses within this framework.

ACKNOWLEDGEMENTS

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INTRODUCTION

It is well recognized that municipal water investments contribute to a sizable portion of the capital budget expended by local governments. In adjusting water supply to meet projected demand, it is commonplace to overbuild facility capacity so as to minimize the possibility of inadequate supply. This approach often results in diseconomies of size and unnecessary disruptions in land use patterns that relate to particular water investment sites. Also, additional tax revenues required to finance project construction are imposed on the public at a time when budget levels are being closely scrutinized.

It is common in water resource planning to assume a deterministic "water use over time" or demand curve. Based on this fixed demand curve, the typical capacity expansion problem seeks to determine the optimal sequence of available projects that will minimize present value cost for a defined planning horizon. As suggested by Butcher et al. (1969), the optimum sequence of implementation of these projects is affected by the shape and magnitude level of the projected water demand curve. To assume such a curve to be stationary, approaches the water planning process very naively and simplistically and implicitly assumes predicted water demand as a certainty. Project sequencing over time that is considered optimal may in fact be "suboptimal" because of the lack of consideration for stochastic water demands.

For example, Lindsay and Dunn (1982) developed a mixed integer programming model for the selection of a water investment schedule that will minimize total discounted cost over four time periods for three New Hampshire towns of the construction, operation, and maintenance of new reservoirs and pumping stations, new pipeline systems, existing wells, and currently existing pipelines. The model consists of 296 variables and 235 constraints. An initial model (scenario 1) using three town forecasted demand requirements was formulated and a minimum total discounted cost value was found. To evaluate the sensitivity of the initial model to deviations from projected water use for each town, the original demand requirements were first increased by 10 percent for each time period (scenario 2) and a new objective function value calculated. This procedure was repeated for a 10 percent decrease (scenario 4), 20 percent increase (scenario 3), and finally scenario 5, a 20 percent decrease. Table 1 contains the minimized total discounted costs associated with each scenario in terms of 1980 dollars. Deviations from scenario 1 range from an approximate +22 percent to -18.4 percent. This sensitivity of optimal solutions to levels of water demand requirements illustrates the importance that "demand" plays in water management decisions. Such divergency may on one hand result in overbuilding, which ties up valuable monetary resources, while underbuilding threatens system inadequacy. More specifically, overplanning or overestimating demand contributes to an excessive use of money and underestimating demand causes water shortage. It is the latter situation which will mainly serve as the focus for this study.

Table 1. Comparison of Discounted Total Costs for Demand Scenarios Associated with Multi-Period, Water Management Programming Model De-Regionalized.

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
	(---)	(10%↑)	(20%↑)	(10%↓)	(20%↓)
Discounted	$3,709,823	$4,201,027	$4,525,488	$3,367,974	$3,026,452

A limited number of researchers have explored the implications of demand uncertainty for decision-making involving water resource investment. Young _et al_. (1972) verified that of all uncertainty aspects associated with water supply planning, demand uncertainty contributed the largest part. Grossman and Marks (1977) looked at four demand models for a capacity expansion problem depicting the following situations: (1) certain demand, no shortages; (2) certain demand, shortage; (3) uncertain demand, shortages with decision-maker not utilizing demand information as realized; and (4) uncertain demand, shortages with decision-maker utilizing demand information as realized. According to Grossman and Marks, a shortage penalty cost is incurred if the demand exceeds available capacity. Uncertainty in demand enters the decision-making process only insofar as it induces uncertainty in the shortage costs that are actually realized. Since the water planning process is marked by demand uncertainty, it is logical to translate this feature into penalties associated with imperfect planning.

If water resource planners translate a water shortage situation as an intentional act, artifically contrived, under the guise of a water conservation program, a shortage penalty cost results that can be compared with long-run and short-run capacity expansion costs that would normally be derived from a particular system expansion. These shortage costs, expressed in monetary terms, would be directly influenced by the quantity of cutback from the level of customary use and the duration or length of the imposed cutback. It would seem desirable under conditions of uncertainty attached to a particular demand curve to ascertain the tradeoffs that occur between water shortage and monetary savings at various points of time for a designated planning horizon. The opposite situation of water surplus and monetary loss (overbuilding)could also be investigated. It is one aspect of the former situation that will be the emphasis of this study; that being, the measurement of water shortage costs for a water supply system. Such shortages can be looked at as being both unintentional and intentional. The former situation would refer to a drought, while the latter being a planned shortage or an institutionally designated water conservation program.

Measuring the costs of a water demand cutback in a supply system can thus be considered a part of the capacity expansion planning problem. It is desirable to find the optimum solution to the problem as there are penalties involved in overbuilding (excess capacity), which ties up valuable resources, and in underbuilding, which implies shortage cost. The cost of overbuilding are well known. The costs of shortage are largely unknown. By investigating the costs of a planned water shortage, water resource managers can compare the costs of such an institutional practice with less demand uncertainty to the additional costs of capacity expansion under greater demand uncertainty.

This study examines water consumption in the residential sector for a New Hampshire community. The study illustrates when and where monetary costs accrued to water cutbacks occur in the residential sector, the effect of seasonal demand on shortage costs is shown, and time is included as a penalty factor in assessing the costs of shortages of varying quantity amounts.

LITERATURE OVERVIEW

Water conservation, as a viable alternative to capacity expansion planning, is largely an unknown area when evaluating the resulting monetary loss. Although numerous studies have focused on capacity expansion planning, water cutback costs have been mainly considered theoretically and their magnitude and nature have not been studied. However, work by Manne (1961) and Grossman (1977) has suggested that there are important gains to be made in capacity expansion planning by considering the existence of water conservation measures.

Russell _et al_. (1970) attempt to measure shortage costs. They measured costs of the 1963-66 Massachusetts drought during its third year. The level of drought was defined as the ratio of potential demand to safe yield of supply. A mathematical equation was developed to measure the expected losses associated with varying levels of inadequate supply. Two models to measure drought losses were developed; a theoretical construct which estimated what the losses should be (which tended to give much higher levels of loss) and an empirical model derived from data collected during the drought. Using different discount rates, a range of four values was chosen to illustrate the effects of changes in the level of shortage costs on capacity expansion planning. Their study revealed that drought costs were not as large as anticipated. Russell _et al_. have measured shortage costs relative to a drought, with costs including the use of emergency sources of supply. What is required for the capacity expansion problem is the costs of an artifically generated shortage, which by its very nature, will not include the costs of emergency supply. This implicity assumes that the costs of a planned shortage will be lower than those of a drought of comparable size and duration.

Young et al. (1972) studied a drought in York, Pennsylvania in 1966 and measured the risks involved in keeping varying levels of safe yield in supply. Losses to various consumption sectors were measured at the local and regional levels. Losses were measured from the viewpoint of each sector of demand. Local losses represented transactions between sectors, and regional losses represented dollar flows out of the region. The authors concluded that though the drought may be of overriding importance locally, its effects do not spread out far beyond the immediate zone of impact. Furthermore, they concluded that the domestic and municipal sectors have losses far above those of the industrial and commercial sectors, revealing the importance of these sectors when studying drought-related costs and losses.

Both of the above-mentioned studies measure shortage costs resulting from a drought, during its duration and/or after the fact. Both of the cases evaluate water shortage costs, not from an institutionally imposed cutback (conservation program), but rather from a natural phenomenon. Implementation of a program that mandatorily calls for water restrictions allows for the size, duration, and timing of the conservation practice to be controlled.

Hanke (1980) presented a method for evaluating the costs and benefits of adopting water conservation practices. His method was applied to institutional water use restrictions for Perth, Western Australia. A conservation policy was favorably pursued whenever marginal benefits exceed marginal costs of implementing a particular water restriction. Whenever marginal costs exceed marginal benefits, a disfavorable attitude towards a conservation policy should prevail. For comparative purposes, calculations were made of the change in total benefits and the change in total costs to be derived from water conservation policies. No consideration was given to duration as a factor influencing the level of benefits and costs.

METHODOLOGY

For the residential sector, monetary loss estimations related to a given level of water restriction were measured by the use of consumer surplus loss. Water, as a commodity, has a certain utility value to the consumer. Whenever water restrictions are imposed, the individual suffers a loss in total utility. Since the residential demand for water tends to be highly inelastic, decreases in the level of water consumption would lead to a high disutility value to the consumer.

The concept of consumer surplus is viewed as the difference between the maximum amount consumers would be prepared to pay and what is actually paid. For our purposes, measurement of monetary losses attributed to induced reductions in residential water demand levels is based upon the loss in consumer surplus from one quantity demanded level to a lower quantity level. In other words, consumer surplus loss for the individual is calculated when his or her level of water demand is decreased below the normal usage level. Figure 1 illustrates the concept being discussed.

The figure shows the individual's demand curve for a period of time for water (AEBC); Q_{nr} is his normal level of demand before water restrictions and Q_r is his actual consumption level after restrictions are imposed. The total value of Q_{nr} quantity of water is $OQ_{nr}BA$ and for the restricted quantity of water, total value is OQ_rEA. The amount of water reduction is represented by Q_{nr} less Q_r. The level of reduction in total value of water by imposing a reduction of $(Q_{nr}-Q_r)$ is the area $Q_rQ_{nr}BE$. The level of consumer surplus for quantity Q_{nr} is FBA and for the quantity Q_r consumer surplus is GEA. The consumer surplus loss in reducing water consumption from a level of Q_{nr} to Q_r is the area represented by DBE. This measurement will be used as a proxy for monetary

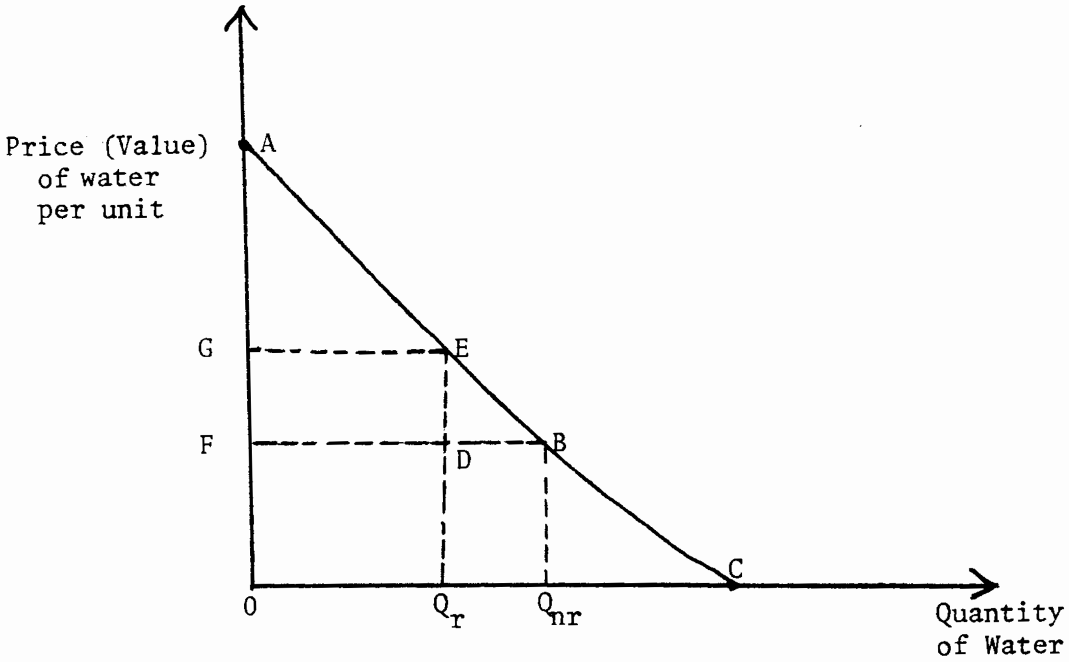


Figure 1: Illustration of Consumer Surplus Loss.

loss attributed to water restrictions for a defined time period for an individual resident. The area FDEG represents a distributional effect, which takes a former portion of consumer surplus area FBA and redistributes the area into total expenditures for water quantity level Q_r. The area FDEG is not actually lost, but redistributed.

Water consumption figures were collected for Rollinsford, New Hampshire. This community was selected because of its total water use, 90-95 percent of the total use is classified as residential. It was important that a town be selected that had a very high level of residential consumption because the methodology developed is more applicable to that particular category of use. To evaluate the impact of shortages or conservation measures on industrial, municipal, or commercial uses, would involve the development of impact multipliers and sales/payroll losses. This data were not available.

Data were collected for a total of 11 quarters from June 1978 to December 1980 for an average of 466 residential units per quarter. The average residential consumption per day was 158.45 gallons for all seasons. For the fall, winter, spring, and summer seasons, the averages were 147.8, 146.1, 159.2, and 176.4 respectively.

The pricing structure was based on 15,000 gallons per residential unit per quarter at a rate of fifteen dollars. The charge above this level is $0.46 per 1000 gallons.

Shortage losses were measured for three seasons: fall/winter, spring and summer. Data for the fall was also considered a proxy for the winter season, since there was no signigicant difference between the two consumption levels. In other words, since the consumption levels were very similiar, calculations were made for only one of the seasons. Demand was split into domestic (in house) and sprinkling (outside) uses of water. Equations, developed by Howe and Linaweaver (1967), were utilized to estimate changes in the value of water as demand was cut back. The equation sets were derived from cross sectional data from 21 cities from the United States. The following equations and data were used to find the individual residential unit demand for water:

Domestic demand;

(1) $Q_{a,d*} = c + 0.352v* - 0.142a* - 0.034dp* - 0.146k* - 0.214p*$

where:

$Q_{a,d}$ is the quantity demanded per unit per day, c refers to the coefficient to fit the area, v equals average household value (for Rollinsford: $45,508), dp denotes average number of people per household (dp = 3.1), a depicts the average age of dwelling units (a=85), k refers to water pressure (k=60), p is the price per 1000 gallons or the average price per average consumption, and * refers to logarithmic values.

Sprinkling demand;

(2) $Q_{s,s*} = c + 2.07\ (W_s - 0.6r_s)* - 1.12p* + 0.662v*$

where:

$Q_{s,s}$ denotes average summer sprinkling demand, c and v are defined previously, W_s refers to potential evaportranspiration (summer = 9.08; summer + 10.32), r_s is average precipitation level (spring = 12.6; summer = 9.74), and p is defined previously.

Consumer surplus loss was measured for 10%, 25%, 40%, and 60% cuts in the average daily demand for each of the three seasons. A 100% cut in sprinkling supply (total ban on outside water use) was also measured for the spring and summer seasons. The procedure that was followed when simulating a percentage cut in demand was to reduce sprinkling consumption of water first, followed by a reduction in domestic use. This approach was based on the usual procedure of reducing outside use of water first whenever communities face water shortages.

The procedure used to measure shortage losses for the residential sector consisted of first calculating the average daily water consumption levels per dwelling unit for the residential sector for each season. Using the Howe-Linaweaver equations (1) and (2), the consumer surplus loss for the various sizes of water cutback percentages was computed. This yielded the consumer surplus loss per dwelling unit for a one day water cutback. Monetary savings were calculated whenever consumption above 15000 gallons per quarter are reduced to levels above and below 15000. The resulting savings, if any, were subtracted from consumer surplus levels previously derived. No monetary savings accrue when consumption levels below 15000 gallons per quarter are reduced, because of the water pricing structure existing for Rollinsford, New Hampshire. Loss levels (corrected for savings) are multiplied by the number of residential dwelling units to give total one day losses for water cutback percentages for the residential sector.

EMPIRICAL RESULTS WITHOUT CONSIDERATION OF DURATION

One Day Consumer Loss Values for the Residential Dwelling

Table 2 contains the consumer surplus loss values for the residential sector by percentage cutback and season as well as for the residential sector disaggregated (households and apartments). The table shows that as the percentage cutback increases, the one day consumer surplus loss monetary value also increases for each season. For example, during the winter season, a twenty-five percent cut in water demand results in a consumer surplus loss of four cents per residential dwelling. In the spring, a twenty-five percent cut in water usage results in a consumer surplus loss of twelve cents per residential dwelling. Of the twelve cents, ten cents of this loss is attributed to one hundred percent reduction in lawn sprinkling. The one day loss figures increase at an increasing rate as the percentage cutback increases for all seasons. Comparing the winter season to the summer season at a sixty percent cutback, the one day loss figure is greater for the winter than the summer. The reason is that a reduction at such a high percent during the winter season lies solely with inhouse use and a greater loss of utility, than reductions in the summer which first reduce outside use before inhouse consumption.

When disaggregating the residential sector into households and apartments, comparisons can be made between the two subsectors. Sprinkling is not accounted for in figuring losses for the apartment categories, because of the lack of this type of activity for apartment dwellers. Different loss values for households occur between seasons when sprinkling water demand must be accounted for. Sprinkling demand results in losses to be calculated at a less elastic portion of the

Table 2: One Day Consumer Surplus Loss Per Dwelling Unit: Domestic and Sprinkling.

(In $ Units)

% Cut In Supply	WINTER % Cutback				SPRING % Cutback					SUMMER % Cutback				
Consumer Group	10	25	40	60	10	25	40	60	100 Sprink.	10	25	40	60	100 Sprink.
Residential Sector	.004	.04	.18	1.15	.10	.12	.21	.86	.10	.007	.23	.28	.69	.23
Households Only	.004	.04	.18	1.15	.02	.17	.25	.86	.16	.005	.32	.35	.67	.32
Apartments Only	.004	.04	.18	1.15	.004	.04	.18	1.15	---	.004	.04	.18	1.15	---

domestic water demand curve and thus resulting in lower computed values.

Figure 2 illustrates the one day consumer losses for each season for the aggregated residential sector.

One Day Consumer Loss Values for all Residential Dwellings

The consumer surplus loss values, given in Table 1, were aggregated by multiplying each by the average number of dwelling units (466 units) typically in existence in the town. These values are contained in Table 3. The population of Rollinsford has stayed relatively stable, as well as, the number of residential dwelling units.

It is interesting to note how the shortage losses vary depending on the size of cutback and the season. The widest variation in costs occurs for ten and twenty-five percent cutbacks. The ten percent cut has highest costs in spring and lowest in summer and the twenty-five percent cut has steadily increasing costs, winter to summer. There is little difference in costs between a ten percent cutback and a twenty-five percent cutback for the spring season. Looking at the summer season, there is very little difference between a twenty-five and forty percent cut. A water systems manager could to a certain extent regulate the level of consumer surplus loss by strategically adjusting when and where to institute a cutback in water use by the consumer.

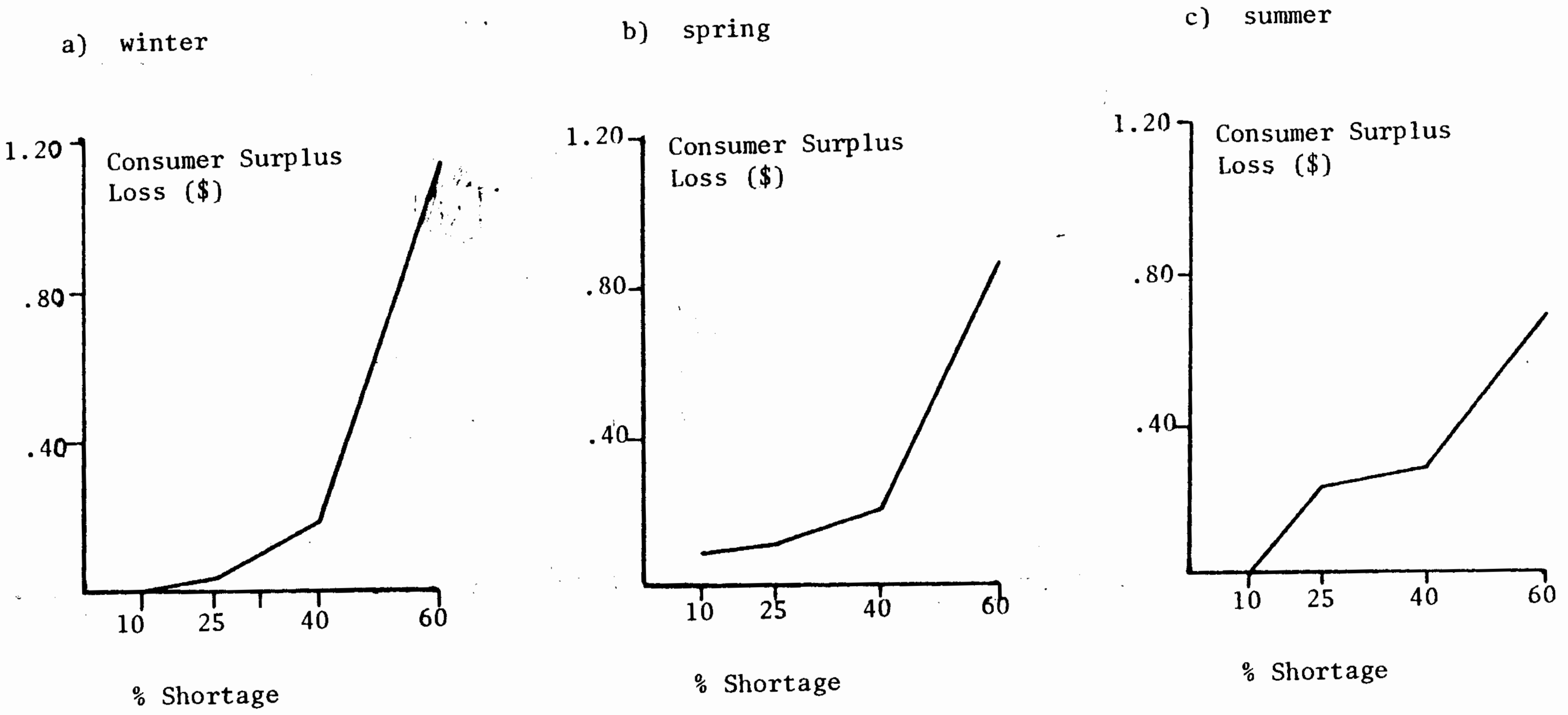


Figure 2: One Day Consumer Surplus Loss Measurements In The Residential Sector.

Table 3: Total One Day Shortage Costs for the Aggregated and Disaggregated Residential Sector.

WINTER	10	25	40	60
Residential Sector	1.86	18.64	83.88	536.00[1]
Households & Apts.	1.86	18.64	83.88	536.00

SPRING	10	25	40	60	100 Sprink.
Residential Sector	46.60	55.92	97.86	401.00	46.60
Households & Apts.	4.38	49.44	95.08	443.00	42.56

SUMMER	10	25	40	60	100 Sprink.
Residential Sector	0.00	97.86	116.00	298.00	103.00
Households & Apts.	+0.38[2]	91.00	123.00	387.00	85.40

[1] Figures over $100 are rounded to the nearest dollar.

[2] Plus sign implies a monetary savings and not a loss.

EMPIRICAL RESULTS WITH CONSIDERATION OF DURATION

Duration Effects Upon Costs of Water Use Reduction

The previous calculated costs have been for instantaneous, one-day only shortages. The Howe-Linaweaver equations that were utilized do not take into account the effect of time upon overall total costs to the consumer. Water cutbacks that endure for time periods longer than one day are not readily obtained from these equations.

Russell *et al*. (1970) and Young *et al*. (1972) overcame this problem by assuming linearity between number of days and total shortage costs. For example, their method involves taking the values of one-day consumer surplus losses and multiplying these figures by the number of days of water use reduction. This particular approach assumes that costs as a function of time will increase at a constant rate. This may be totally unrealistic, because linearity more than likely would be a special case with a nonlinearity relationship being realistic or typical.

The procedure for determining the relationship between total costs and time (duration) was to hypothesize how duration of a cutback in water supply potentially impacts costs. The hypotheses were based on two points. First, studies by Howe and Vaughn (1972) and Flack (1981) have shown when and where water use takes place in the home. Home in-house use takes on fairly stable quantities of use. Therefore, any disruption of these use levels will result in the water user to suffer. The larger the magnitude of cut and the longer it lasts the greater will be the hardship suffered by the consumer. For short durations of water reduction, the consumer will be able to conserve by putting off certain uses. Tradeoffs will eventually result between particular water uses so as to stay within the allowable consumption level and often particular uses will be curtailed. This first point lends support to a nonlinear relationship between costs and duration.

Secondly, our initial measurements of shortage costs, using the Howe-Linaweaver equations, have shown that costs increase steeply in a nonlinear fashion with larger and larger cutbacks in supply. Although the shape and steepness of these costs curves is caused by the nature of the equations themselves; they do serve to illustrate that the less water a consumer has, the more highly valued it is. Obviously, the effect of duration on costs will be proportional to the magnitude of cutback in supply.

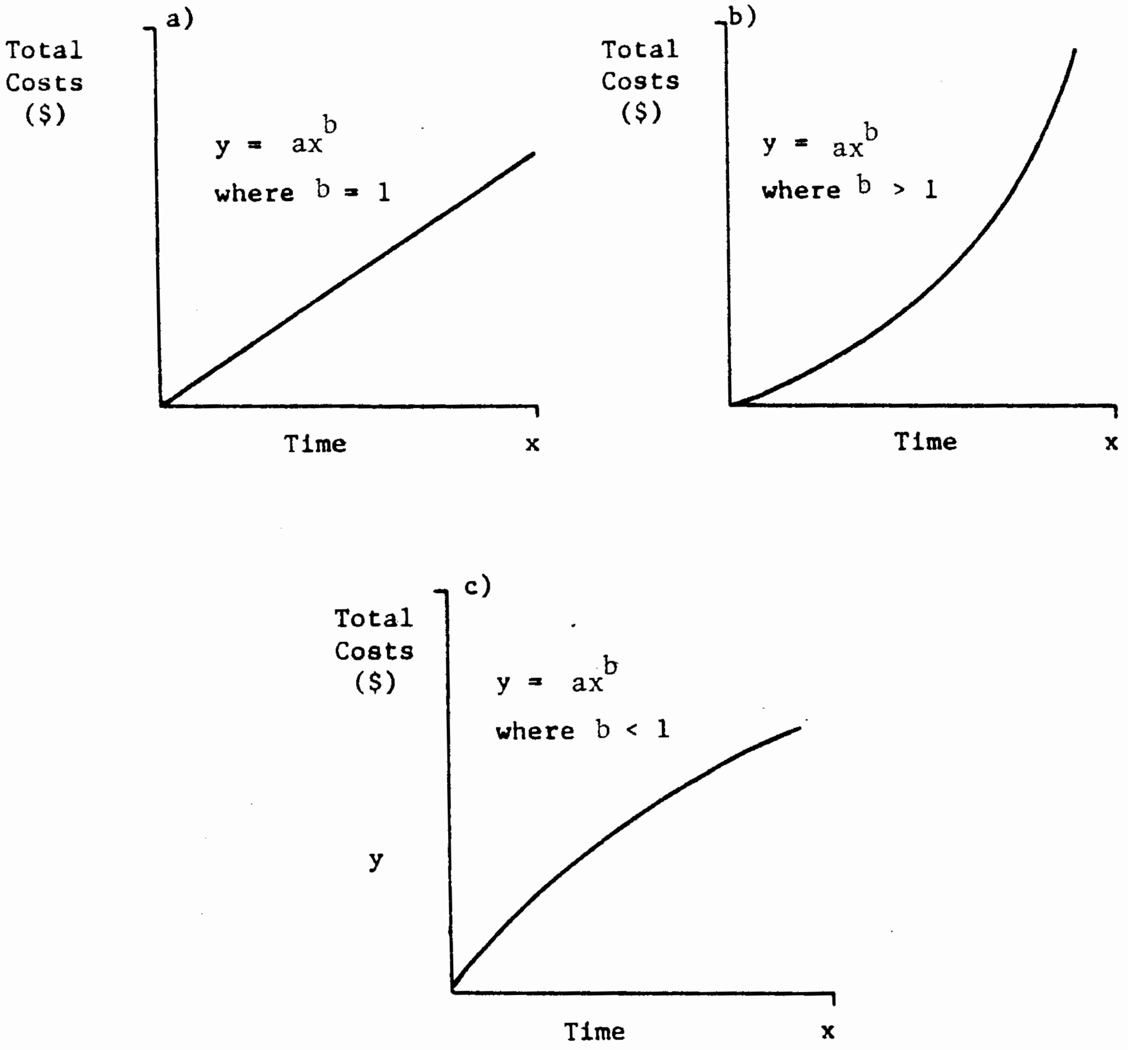
The above two points suggest a nonlinear relationship between costs and duration, but do not lend any evidence to the particular nonlinear form. How and at what rate duration will cause costs to be altered can only be conceptualized or hypothesized and three scenarios were investigated.

Figure 3 illustrates three scenarios that were hypothesized between water shortage costs and duration of water reduction. The three scenarios relate to costs increasing at a constant rate over time, costs increasing at an increasing rate over time, and costs increasing at a decreasing rate over time.

The general form of the equation used was as follows:

(3) $y = ax^b$

where, y represents total costs to the residential sector, a is the one day consumer surplus loss value, x is the number of duration days of water reduction, and b is a fixed parameter value. The value of b determines the shape of the resulting curve. If $b > 1$, than it is assumed that costs increase at an increasing rate with duration. When $b = 1$, costs increase at a constant rate with duration and with $b < 1$ costs increase at a decreasing rate. The values of b selected for this



Where: y = total costs x = days duration of shortage
a = one day shortage costs

Figure 3: Hypothesized Changes in Costs Over Duration of Shortage.

study were 0.95, 1.0, and 1.05. These particular values were selected for comparative purposes and because they covered the three scenarios relating to curve shape. Any other values could have been easily selected.

Shortage Costs Increasing at a Constant Rate

This is the situation in which the one day consumer surplus loss values are multiplied by the number of days duration of water shortage. Costs for the residential sector are given in Table 4 for various durations of shortage for the three seasons: winter, spring, and summer. These values show a steady, linear increase in costs with time.

The tables reveal that losses for 10% cuts in domestic water use tend to be highest in spring and lowest in summer. For the 25% and 40% cuts, losses tend to increase from winter to summer, and for the 60% cut, decrease towards the summer. The loss patterns follow those exhibited in the examination of the one day consumer surplus losses between seasons. For a 91 day shortage, losses range from $69.90 for a 10% cut in summer to $48,767 for a 60% cut in winter.

If this is contrasted with $4,421 for a 91 day, 10% cutback in spring and $29,036 for a 91 day, 60% shortage in summer, there is the potential for significant savings depending on when a community chooses to implement water conservation practices. In the summer, for instance, it is even possible to incur some savings for 7 day to 60 day, 10% cuts in residential water use. This is due to the low level of consumer surplus loss from sprinkling demand and the fact that decreased consumption means monetary savings to the consumer.

Shortage Costs Increasing at an Increasing Rate

In order to observe what happens to total costs with time under costs

Table 4: Total Costs for the Residential Sector Where b = 1.

a) WINTER

% Cut in Supply	DURATION-DAYS								
	1	3	7	14	28	45	60	75	91
10	1.86	5.58	13.02	26.04	52.08	83.70	112	139	169
25	18.64	55.92	130	261	522	839	118	1,398	1,696
40	83.88	251.6	587	1,174	2,349	3,775	5,033	6,291	7,633
60	535	1,608	3,751	7,503	15,005	24,116	32,154	40,192	48,767
100% Sprinkling	---	---	---	---	---	---	---	---	----

b) SPRING

% Cut in Supply	DURATION-DAYS								
	1	3	7	14	28	45	60	75	91
10	46.60	140	326	652	1,304	2,097	2,796	3,495	4,241
25	55.92	168	391	783	1,566	2,516	3,355	4,194	5,089
40	97.86	294	685	1,370	2,740	4,403	5,871	7,329	8,905
60	401	1,202	2,805	5,610	11,221	18,034	24,045	30,057	36,469
100% Sprinkling	46.60	140	326	652	1,304	2,097	2,796	3,495	4,241

c) SUMMER

% Cut in Supply	DURATION-DAYS								
	1	3	7	14	28	45	60	75	91
10	0.00	0.00	+0.46[1]	+9.32	+18.64	+23.30	+27.96	18.64	69.90
25	97.86	294	690	1,370	2,777	4,599	6,207	7,815	9,530
40	116	349	811	1,617	3,430	5,648	7,605	9,562	11,650
60	298	899	2,092	4,278	8,799	14,245	19,068	23,892	29,036
100% Sprinkling	102	303	708	1,417	2,763	4,599	6,207	7,815	9,530

[1] Plus signs refer to monetary savings,not costs.

increasing at an increasing rate, b was set equal to 1.05. Table 5 contains the results for the three seasons. In general, the calculated values show that the longer the duration of shortage, the higher are the costs. In a case, where duration has the effect of increasing costs of a water cutback, it would be more beneficial to have shorter duration cutbacks in water use. This is due to the fact that the longer the duration, the higher the penalty attached to the costs and the less effect any monetary savings will have on the overall costs to the consumer. This suggests that there may exist the possibility of tradeoffs between duration of shortage and intensity (i.e., size of percentage cut) of shortage. It is thought that at low levels of percentage cuts the possibilities for tradeoffs between decreasing duration and increasing intensity of cutback exist. This area of interest will be presented in the latter portion of this report.

Shortage Costs Increasing at a Decreasing Rate

Table 6 gives the results for b = 0.95 for the three seasons. It is more beneficial to have low intensity, long duration cutbacks as the costs per day decrease with time. For instance, a 91 day, 10% shortage in winter, results in losses of only $135 as compared to $169 for losses measured when b - 1. Also, it should be noted that more savings result. In the summer season for a 10% cut, there are either zero costs or savings for durations of 1 to 75 days.

Duration Versus Intensity of Shortage

Up to this point, the results have shown that the effect of increasing the intensity of shortage greatly increases losses to the consumer. As has been the case in previous studies of assuming shortage costs increase in a linear fashion over time (b = 1), low intensity, lengthy duration

Table 5: Total Costs for the Residential Sector Where b = 1.05.

a) WINTER

% Cut in	DURATION-DAYS								
Supply	1	3	7	14	28	45	60	75	91
10	1.86	5.87	14.34	29.70	61.51	101	136	173	212
25	18.64	58.90	144	297	616	1,014	1,368	1,735	2,125
40	83.88	265	646	1,339	2,774	4,565	6,159	7,806	9,564
60	536	1,693	4,132	8,558	17,722	29,169	39,351	49,876	61,103
100% Sprinkling									

b) SPRING

% Cut in	DURATION-DAYS								
Supply	1	3	7	14	28	45	60	75	91
10	46.60	144	359	741	1,538	2,535	3,430	4,334	5,312
25	55.92	172	429	890	1,845	3,043	4,115	5,201	6,375
40	97.86	308	750	1,561	3,234	5,326	7,204	9,106	11,156
60	401	1,263	3,090	6,398	13,253	21,507	29,507	32,299	45,691
100% Sprinkling	46.60	144	359	741	1,538	2,535	3,430	4,334	5,312

c) SUMMER

% Cut in	DURATION-DAYS								
Supply	1	3	7	14	28	45	60	75	91
10	0.00	0.00	0.00	0.00	4.66	9.32	13.98	79.22	144
25	97.86	307	764	1,580	3,369	5,606	7,666	9,748	11,995
40	116.50	368	899	1,873	3,318	6,878	9,381	11,916	14,651
60	298	951	2,316	4,907	10,406	17,275	23,449	29,880	36,437
100% Sprinkling	103	317	783	1,626	3,369	5,606	7,666	9,749	11,995

Table 6: Total Costs for the Residential Sector Where b = 0.95.

a) WINTER

% Cut in Supply	DURATION-DAYS 1	3	7	14	28	45	60	75	91
10	1.86	4.66	9.32	22.80	41.94	65.24	88.54	112	135
25	18.64	51.26	116	228	438	690	909	1,123	1,351
40	83.88	233	1,025	1,025	1,985	3,118	4,101	5.065	6,091
60	536	1,514	3,402	6,566	12,698	19,935	26,199	32,382	38,916
100% Sprinkling	---	---	---	---	---	---	---	---	---

b) SPRING

% Cut in Supply	DURATION-DAYS 1	3	7	14	28	45	60	75	91
10	46.60	130	294	569	1,104	1,734	2,274	2,815	3,383
25	55.92	154	354	685	1,323	2,078	2,726	3,374	4,059
40	97.86	275	620	1,198	2,316	3,639	4,772	5,909	7,102
60	401	1,132	2,544	4,912	9,497	14,907	19,553	24,204	29,092
100% Sprinkling	46.60	130	394	569	1,104	1,734	2,274	2,815	3,383

C) SUMMER

% Cut in Supply	DURATION-DAYS 1	3	7	14	28	45	60	75	91
10	0.00	0.00	+4.66[1]	+13.98	+27.96	+46.60	+65.24	+27.96	9.32
25	97.86	274	620	1,179	2,316	3,761	5,005	6,249	7,554
40	116	326	620	1,389	2,865	4,627	6,142	7,656	9,245
60	298	843	722	3,714	7,395	11,734	15,467	19,195	23,118
100% Sprinkling	102.52	284	638	1,226	2,316	3,761	5,005	6,249	7,554

[1] Plus signs refer to monetary savings, not costs.

shortages will always result in lower costs to the consumer than high intensity, lesser duration cuts for the same quantity of water lost. Figure 4 illustrates this point. Each linear line represents cost increasing at a constant rate various levels of percentage cutbacks in water supply. For higher percentage cutbacks, the resulting linear lines will be steeper sloped than those lines far lower percentage cutbacks. The curve Q represents the costs of a set quantity of water as it is spread over different time durations. The shorter the time period, the higher are costs as larger percentage cuts are required in order to make up this quantity of water.

It would seem that there would come a point where the costs of a long duration, low intensity shortage might be greater than that of a shorter duration, high intensity shortage for the same quantity of water. Potentially, this could result if there was a penalty associated with duration of a water shortage.

Figure 5 depicts this situation. Assuming $b > 1$ in equation (3) there is a penalty factor associated with time which causes costs to rise at an increasing rate with duration of shortage. A tradeoff results between intensity and duration of shortage. For example, the ten percent shortage of duration T_3 has higher costs than the twenty-five percent shortage duration T_2. Tradeoffs (resulting in lower costs can be made anywhere along the curve Q between T_1 and T_3.

Table 7 illustrates areas where potential savings exist for ten, twenty-five, forty and sixty percent shortages in the residential sector for b values of .95, 1.0, and 1.05. The quantity of water Q given for each season corresponds to the amount of water not supplied to the residential sector over a 91 day, ten percent cutback for that season. Any percentage cutback and length of time could have been chosen as a

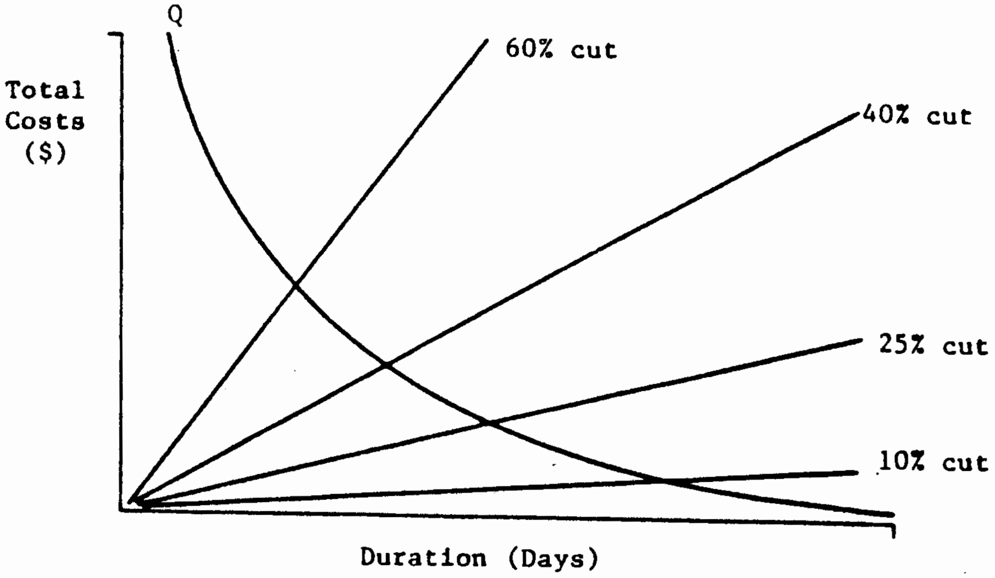


Figure 4: Changes In Total Costs Associated With A Specific Volume of Water Shortage (Q) With Changes In Intensity And Duration of Shortage Where Costs Are Assumed to Remain Equal Over Time (b = 1).

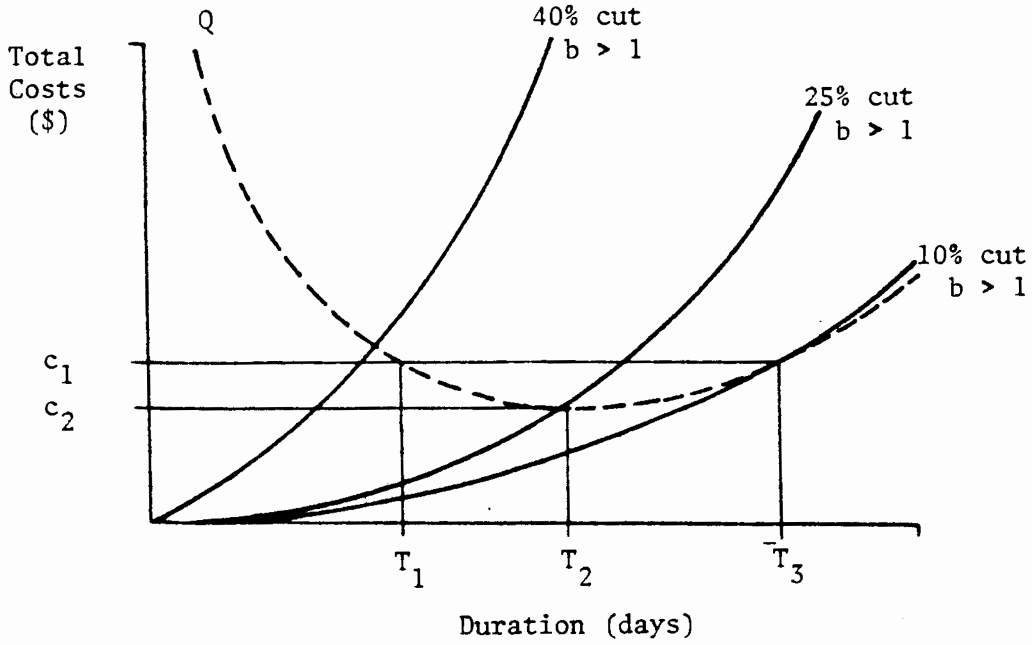


Figure 5: Changes In Total Costs Associated With A Specific Volume Of Water (Q) Where Costs Assumed To Increase With Time (b > 1).

Table 7: Variations in Costs Associated with a Set Quantity of Water Shortage (Q) with Changes in Intensity and Duration of Shortage for the Residential Sector.

	% Cut	Duration Days	Shortage Costs ($)		
			b = 0.95	b = 1.0	b = 1.05
Winter Season (Q=621,637 gallons)	10	91	135	169	212
	25	36	560	671	802
	40	23	1,649	1,929	2,257
	60	15	7,022	8,036	9,204
Spring Season (Q=679,316 gallons)	10	91	3,383*[1]	4,240*	5,312*
	25	36	1,683*	2,013*	2,408*
	40	23	1,924	2,250	2,632
	60	15	5,253	6,011	6,881
Summer Season (Q=746,660 gallons)	10	91	0.32	69.90	144.46
	25	36	2,944*	3,522*	4,213*
	40	23	2,290*	2,679*	3,133*
	60	15	3,907	4,473	5,121

[1] Denotes where savings possible from trade-offs between duration and intensity of water reduction.

numeraire or benchmark. When intensity of shortage is increased to twenty-five, forty, and sixty percent cutbacks, the same quantity of water is found over thirty-six, twenty-three, and fifteen days.

This table depicts trade offs in the Spring season between the ten and twenty-five percent cutbacks in water supply for the three values of b. For b equal to 1.0, savings of $2,227 can be made between a 91 day, 10 percent cut in supply and a 36 day, 25 percent cut. For the b value greater than 1.0, savings are greater and for the b value lower than 1.0, savings are less.

For the summer season, this table shows that the costs of a ten percent water cutback are very low. There are trade offs possible between twenty-five and forty percent cutback levels. When b = 1, savings of $843 can be made between a 36 day, 25 percent cut and a 23 day, 40 percent cut. Again savings increase with the b value greater than 1.0 and decrease with b less than 1.0.

The winter season does not have a trade off range. This is because the shape of the Q curve is negatively sloped through its entire range.

CONCLUSIONS

This research into the impact of a water conservation program with respect to different percentage cutbacks in water demand was undertaken to put into perspective this type of institutional program with that of the usual capacity expansion approach. This investigation has found that total costs attributed to water cutbacks to the community vary greatly and much money can be saved by careful planning.

Traditionally, the institutional practice of imposition of water demand cutbacks has been viewed very emotionally. Water consumers often take the view that more water (creating additional supplies of water) is better than less water. Given the distressful financial and budgetary climate that many communities are currently facing, investment in capacity expansion is often viewed as an untimely activity, especially under conditions of demand uncertainty. This study illustrates an alternative to capital water investment which results in levels of monetary losses (in some instances, monetary savings) that seemingly lessen the intensity of emotional argument. This is not to say that toleration of community induced water cutbacks is the best water policy for all communities. But communities that have low industrial and commercial usage, may find this alternative economically feasible.

The methodology developed here gives a community an individually tailored range of costs and losses for varying sizes of percentage cuts in water demand over varying time periods. Rather than tie shortage penalty costs to size of shortage in linear fashion, or develop a shortage penalty cost function that is based on three different levels of shortage in three different towns (Russell _et al_. (1970), the individualism of the community is emphasized. If a town is planning to increase its water supply capacity, it can develop its own shortage cost function based on the range of losses that can be expected, along with including duration. These can be measured for each year into the future for which it is expected there will be a water shortage or artificially generated water cutbacks and compared to the costs of increasing supply.

This study shows that the costs of a water cutback (shortage) are influenced by the time of year, the level of consumption, and the size and length of the water cutback. This investigation is very site specific with respect to consumption levels, rate structure, and the predominance of water use in the residential sector. However, this methodology can be utilized in any community that has a high residential water use level by planning for the timing, the size, and length of cutbacks in demand.

For Rollinsford the greatest variability in shortage costs exists for cuts in demand below forty percent. The greatest variability exists during the spring and summer months and is caused by the existence of sprinkling demand. For these two months, it is possible to lessen the cutback costs by focusing upon those households that have a sprinkling demand.

This study shows that losses for similar sized shortages are not fixed, but vary depending upon the season in which they occur. It was also found that there are savings that can be made from trade offs between duration and the intensity of cutbacks in demand.

This methodology also seems possible for implementation purposes under conditions of water demand uncertainty when contemplating water supply expansion. Direct control of water usage can lessen the degree of demand uncertainty and lead to a rationale alternative posture to expansion.

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