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Economic Damages To Household Items From Water Supply Use

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ECONOMIC DAMAGES TO HOUSEHOLD ITEMS

FROM WATER SUPPLY USE

by

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Program Element 1HA094

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ABSTRACT

Household appliances and personal items in contact with water supply are subject to physical damages from chemical and other constituents of the water. This study translates these damages into economic losses for a typical household. Then it aggregates these losses at the national and individual state levels. To do so requires several stages of analysis. First, the types of physical damages expected and associated water quality determinants are identified. The physical effects are next translated into economic losses. Second, damage functions are formulated to predict likely impacts of water quality changes on each household unit affected. Third, a computer program based on these functions is designed to estimate total damages per typical household and to aggregate them over selected regions. Finally, the program is applied to state-by-state data on water supply sources and socioeconomic descriptors. Total damages to U.S. residents in 1970 are estimated in the range, $0.65 to $3.45 billion, with a mean of $1.75 billion. The mean translates into $8.60 per person. States contributing most to total damages are California ($230 million) and Illinois ($164 million). On a per capita basis, Arizona ($22.53) and New Mexico ($18.58) rank highest, whereas South Carolina ($1.15) and Oregon ($1.73) are at the other end of the spectrum. When per capita damages are compared by source of water supply, those from private wells are worst at an average of $12.34, treated ground water next at $11.20, and treated surface water

sources at only $5.83. The relative contribution of man-made activities to damages from all water supply sources is roughly estimated as a minimum of 15 percent. For surface water sources, the typical figure is higher at 30 percent, while it drops to 10 percent for groundwater supplies.

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PREFACE

This report was prepared as part of a more comprehensive research program on the socio-economic impacts of environmental policy, under the direction of Alan P. Carlin, Director of the Implementation Research Division, and under the immediate supervision of Fred H. Abel, Chief of the Economic Analysis Branch. It addresses an important segment of an EPA research program to estimate the relationship of improved water quality to economic damages incurred by water uses. Specifically, this study estimates the damage to household items and extra household costs resulting from use of water containing TDS and hardness. It formulates damage functions in the context of a computer program, which can be used by local planners in a regional cost/benefit analysis. It also presents annualized estimates of economic damages incurred by each state and aggregated over the nation for 1970. These estimates pertain to various levels of water quality control and alternate sources of water supply, e.g., private wells.

Much of the TDS and hardness pollution comes from natural sources, although water use and reuse and the disposal of salts by man greatly increase the level of these pollutants. Many of the high pollution levels occur in parts of the country where water reuse is high. Yet almost no attempt is currently made in municipal plants to treat wastewater or effluent to remove TDS and hardness.

This report presents basic pollutant-damage relationships that can be used in models comprehensively evaluating national water quality improvement programs. They can be used to design and implement water quality improvement plans for river basins and municipalities. The contributions of man-made versus natural sources of these pollutants are also assessed. An understanding of the relative importance and geographical distribution of these damages is necessary for national policy decisions on water quality goals and programs.

The work reported herein is part of a broader study on economic benefit assessments of environmental quality. This broader program will allow the estimation and analysis of economic impacts of environmen+al policies whose goal is the enhancement of societal welfare.

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SECTION I

CONCLUSIONS

Some of the key conclusions drawn from this household damage study are summarized in the following items. Additional insights may be obtained by surveying the list of references in Section XI.

1. In the United States, total 1970 damages to household items from water supply use were in the range, \$0.65 - \$3.45 billion, with a mean of \$1.75 billion.
2. On a per capita basis, the mean damage estimate is \$8.60 in 1970.
3. Those states with the highest mean estimate of damages include California at \$230 million and Illinois at \$164 million.
4. Per capita damages are highest for Arizona, \$22.53, and New Mexico, \$18.58.
5. Per capita damages differ significantly with respect to the source of water supply. Those consumers using surface water supplied by public systems incur damages averaging \$5.83, compared with \$12.34 for private well owners.
6. The most significant water quality parameters affecting household expenditures include hardness, total dissolved solids, chlorides and sulfates, and acidity.
7. Economic impacts of water supply use on household items are measurable in terms of increased investment and operating costs.

8. Damage functions are formulated to estimate the impact of water quality on the service life and operating levels of nearly twenty household items.

9. The household items most vulnerable to deteriorating effects of water quality parameters include piping, water heaters and other appliances, washable fabrics, water utility systems, and soap purchases.

10. The man-made portion of total U. S. damages is at least $300 million. Thus, the complete control of municipal, industrial, or agricultural discharges of mineral loads would provide this benefit.

SECTION II

RECOMMENDATIONS

Several recommendations on treatment strategies and research priorities are listed below as implied by this household damage study.

1. Economic tradeoffs of controlling water quality parameters, such as hardness and total dissolved solids, in a central plant vs. residential homes should be analyzed on a regional basis.
2. Household damage functions from water supply use should be derived from local conditions. Although communities with water supply containing excessive amounts of certain constituents have been observed to some degree, other communities within "recommended standards" should not be ignored. The latter group must also contend with significant damages in the residential sector.
3. More information about water quality data and water use patterns should be collected on private water distribution systems.
4. More research should focus on household damages incurred by the use of water with very low concentrations of constituents. Synergistic effects of constituents at these quality levels should also be explored.

SECTION III

INTRODUCTION

The primary objective of water supply control is to protect the public health and welfare in the use and enjoyment of water resources. The health aspect of water quality criteria has been under investigation for many years, while aesthetic properties have also influenced the development of water treatment technologies. Obviously, the protection of human health and aesthetic factors are of paramount concern (e.g., CDC, 1971; J. Lackner, 1973), but other welfare aspects also relate to drinking water characteristics. Beyond its direct consumption, water is used in household activities, such as dish washing. Household appliances and plumbing, which come into daily contact with water supply, are subject to abrasive, corrosive, and other damaging effects of certain constituents in water.

This study focuses on household damages while recognizing the importance of other welfare aspects. Economic impacts of water supply use affect household costs in both the long and the short run. The service life of household items increases from contact with improved water quality. In addition, daily expenditures for soap and detergents as well as operating costs of appliance usage can decline. Unfortunately, these impacts are usually neglected, even in comprehensive water quality damage studies. A major study of estuarine pollution problems (FWPCA, 1966), for example, concludes that the benefits of more stringent control are probably not large given the existence of treatment plants which are necessary in any case.

The misconception underlying this rationale is that treatment supposedly removes all objectionable pollutants prior to household water distribution. Such is not the case, however, in normal treatment plants. Total dissolved solids (TDS) and hardness are among those elements not treated extensively in public systems. It is well documented that these and other constituents can inflict severe damages on households. Although there are suggested limits of concentration for these parameters, standards have not yet been promulgated. According to some economists, "... little rigorous evidence is available on which to base a limiting standard for drinking water with respect to total dissolved solids" (Kneese and Bower, 1968).

This study demonstrates that the economic damages from domestic water supply use are substantial and should thus be considered in defining water quality standards. Empirical evidence is reviewed from the literature and cast into a model framework to predict total damages in a specific region. The first section of the paper identifies major pollutants and their physical impacts on household items. The next section presents a method of translating these damages into economic equivalents. Following this, a predictive model is derived, after which total damage estimates are calculated by state. These values are based on complete removal of objectionable wastes. Moreover, they include all residents served by either public or private water distribution systems. Finally, partial damages are estimated in meeting recommended standards of water supply rather than complete removal.

SECTION IV

PHYSICAL IMPAIRMENT OF HOUSEHOLD UNITS

Water supply should be of sufficient quality to be safe for direct consumption and to provide for its normal uses in household activities. Most contaminants in water supply are captured and removed at the water treatment plant. But not all constituents are removed, the most notable exceptions including the components, hardness and total dissolved solids (TDS). Plants seldom reduce hardness below 85-100 ppm (Larson, 1963). Conventional water treatment processes do not readily or economically remove a significant portion of the mineral content.

Most public water supplies are within Federal recommendations limiting total dissolved solids concentration to 500 ppm (USPHS, 1963). Only 2 percent of water distributed through these systems, serving 160 million Americans, does not meet this criterion (Patterson and Banker, 1969). Yet compliance with this criterion does not imply that economic damages from water use are avoided. Corrosion and accelerated depreciation of household appurtenances have been observed at low concentrations of the water constituents. Moreover, it is generally less costly to improve water at the plant than in the homes. Sonnen (1973) demonstrated that household and industrial damages from mineralized water supplies in a California community exceeded the cost of water and waste treatment by conventional processes. Howson (1962) reported that water softening in some Wisconsin towns was ten times more expensive than municipal treatment.

The costs of water supply thus extend beyond municipal treatment and distribution to include the customer's use of water. Water quality-related consumer costs are delineated into two basic categories, as defined by the Santa Ana Watershed Planning Agency (Leeds, Hill, and Jewett, Inc., 1969). Under direct control by the user is the cost of specialized treatment for the removal of objectionable water constituents. The other cost measures the penalty attributed to the use of degraded water supply. According to the Planning Agency, the latter cost occurs "as a result of using water of particular quality. Such items as increased use of soap, scaling of pipes, and rapid deterioration of plumbing fixtures and water-using appliances are examples of the penalties incurred by the domestic user ... ." These two categories are interdependent since specialized treatment reduces penalty costs. Ideally the household degree of treatment should be optimized by setting the marginal increase of treatment cost equal to the incremental decrease of penalty costs at the desired quality of water intake.*

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*For some residents, the optimal solution must be constrained by other preferences of drinking water. Although there may be significant physical damages from certain water quality characteristics, many consumers are willing to undergo these costs because of a taste preference for this water. Should these

Damaging effects of water supply result primarily from corrosion, encrustation, and despoiling of household items that come into frequent contact with poor quality water. Affected items in the home include piping systems, plumbing fixtures, water heaters and other appliances, washable clothing and fabrics, dishes, and miscellaneous goods. Specialized water treatment, i.e., water softening, extra demand for soap and detergents, and the purchase of bottled water represent additional costs. Degraded water can inhibit houseplant growth and necessitate more frequent lawn irrigation. In addition, damages are incurred by water utility systems and customer facilities. A breakdown of these items includes water tanks, meters, pumps, and municipal water distribution systems.

Water quality parameters having the greatest economic impact on household use are (Leeds, Hill and Jewett, Inc., 1970; Metcalf & Eddy, 1972) :

(1) Total dissolved solids (TDS). The useful service life of household plumbing fixtures and appliances is sensitive to the mineral content of water (Black and Veatch, 1967).

(cont'd)

constituents be removed, the water would then become objectionable. Senate Drinking Water Bill 433 in early 1973 recognized these preferences by recommending local options for secondary (aesthetic as opposed to health oriented) drinking water standards.

Corrosion of metallic surfaces and precipitation of scale are the most apparent damages linked to the presence of minerals including calcium, magnesium, iron, manganese, sodium, potassium, sulfate, and chloride. Iron and manganese, in particular, cause staining and can even clog piping and fixtures. The demand for bottled water and extensive lawn watering are strongly related to the level of mineralization. There are no legal restrictions on the TDS content of water supplies. The U.S. Public Health Service recommends that treated water not exceed 500 ppm of TDS, but this criterion is based on potability rather than physical damages in the household sector. Indeed, there are no commonly accepted criteria for any parameters that affect consumer costs.

(2) Hardness. Water softening, scale deposits in water heaters, and purchases of soap and detergents are likely to increase with the use of hard water, whose primary constituents are calcium and magnesium compounds. Although high degrees of hardness are detrimental to water systems, low concentrations can be beneficial since the resultant scaling reduces corrosion by applying a "uniform deposit that completely covers the metallic surfaces" (Black and Veatch, 1967). The U.S. Geological Survey (1964) classifies water hardness in

terms of the concentration of calcium carbonates:

0 - 60 ppm	soft
60 - 120	moderately soft
120 - 180	hard
180 +	very hard.

Generally, household users become irritated with hardness exceeding 150 ppm while that above 300 ppm is considered excessive (FWPCA, 1968).*

(3) Chlorides and sulfates. Corrosion and scaling are caused by chemical action involving these anions. Alone they do not cause corrosion, but they lower the p^H of water and thus hasten deterioration. Chlorides are statistically shown (Patterson and Banker, 1968) to decrease the service period of water heaters, while sulfates in conjunction with magnesium ions, due to

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*The effects of hardness on human health are not addressed here, although they are frequently debated in the literature. For example, many researchers found strong associations between heart ailments and water softness (e.g., Shroeder, 1960; Morris, et al, 1961), while others claimed that these results were spurious since all causal factors were not considered, (Dingle, et al, 1964).

their laxative effect, promote bottled water consumption (Metcalf & Eddy, 1972).

(4) Acidity. Reduced service life of customer facilities may be expected from contact with highly acidic water. Acidity is corrosive at levels below 5.0. But it is not a factor of concern in most treated water, where the pH level falls between 6.5 and 8.5 (McKee and Wolf, 1971).

Other important water quality parameters include sodium, potassium, phosphates, silicates, and dissolved gases. But the above four categories are most often recognized as damaging to household items.

In estimating household damages in economic terms, this study proposes to use only two water quality measures, total dissolved solids and hardness, for several reasons. First, most empirical results reported in the literature are based on these parameters. Second, there is ample data on these descriptors of water supply throughout the United States. It must be recognized, however, that these agents are not solely responsible for gross damages. For example, without an adequate supply of dissolved oxygen in water, corrosion is seriously retarded. And warmer water tends to hasten corrosive or scaling actions. Synergistic effects of water quality conditions must therefore be recognized, but for the sake of computational simplicity, the most fundamental parameters are used in estimating damages.

SECTION V

ECONOMIC COSTS TO THE CONSUMER

The literature contains numerous estimates, by household item, of the economic impacts of degraded water supply. Some of these results are useful in calculating state and national benefits of water pollution control. Cost impacts are generally separated into investment outlays for the replacement or disposal of damaged household units and daily operation and repair expenses. The most comprehensive estimate of consumer costs is reported by Black and Veatch (1967). Annualized capital costs (discounted at 6 percent interest) and annual operating costs are estimated for a number of household or household-related units, ranging from water piping and clothing to water meters and distribution storage systems. Even expenses for soap, bottled water, and lawn over-irrigation are itemized. Curves are plotted to predict the average useful life of facilities over various qualities of water supply.

The Black and Veatch report restricts its water quality data base to total dissolved solids. Damages primarily attributed to hardness are omitted from discussion, although later estimates in this study show that hardness has greater economic effects than TDS. Moreover, total damage estimates are provided for only two extreme water quality cases with TDS concentrations of 250 and 1,750 ppm. Intermediate cases are not easily interpreted from these results because some of the damage functions per household unit are nonlinear while others are linear over the water quality range. The extreme case estimates are based on interviews in thirty-eight western municipalities, most of which are quite small. To extrapolate these results to other regions would require adjustments for household expenditures and water consumption. Yet the report distinguishes average vs. modern urban residential costs of using the same quality water. For these resident groups, the difference in per capita damages for the extreme water quality cases is $46.70 and $60.55, respectively.* But these estimates include bottled water and lawn over-irrigation costs, which are specific to an area and to a small percentage of all families. Without these items the respective damages are lowered to $17.22 and $28.97.

Two other estimates (Hamner, 1964; AWWA, 1961), both reported by the American Water Works Association, relate average TDS effects on household facilities only (excluding soap, fabrics, bottled water, irrigation, and water utility systems). These figures are $12.95 and $12.63-$18.96, respectively, which compare favorably with a

*The urban residential family consumes, on the average, 130,000 gallons of water per year compared to 100,000 gallons in the typical home. The per capita figures pertain to a typical household with 3.8 persons.

corresponding value of $13.13 by Black and Veatch. Their estimates of bottled water purchases, however, are somewhat lower than Black and Veatch figures by roughly 20 percent. Patterson and Banker (1968) use data in the Black and Veatch report to estimate effects of TDS on appliances and plumbing facilities. Their conclusions are thus similar to the latter study, although they contend that due to the subjective nature of some estimates, "the results ... should be looked upon as an initial investigation, certainly subject to more complete survey investigation and analysis."

Leeds, Hill and Jewett, Inc. (1969) estimate specialized treatment and penalty costs associated with household facilities, using both TDS and hardness parameters. Damages are assumed directly proportional to the water quality level. For the Santa Ana River Basin, per capita damages for 1970 are assessed at $18.85, with hardness contributing about two-thirds of the total. This figure is probably higher than the national average since water quality is relatively low and household expenditures high in this area.

Metcalf and Eddy (1972) conducted on-site interviews for damage estimates mainly from Southwestern communities with supplemental data from industry. Unlike most other studies that simply aggregate damages over each household unit, this report statistically verifies the significance of water quality effects. The most important relations are found to be bottled water purchases vs. TDS, softening costs and soap demand vs. hardness, and frequency of water heater replacement vs. chlorides. No significant effects of water quality are identified with lawn watering, clothing expenses, and plumbing repairs. Other studies, on the other hand, reach opposite conclusions. Certain minerals are found to have detrimental effects on dishes, glassware, and appliances (Syracuse Chine Corp., 1971; Anchor Hocking Glass Corp., 1971; Frigidaire Div., 1971). Dissolved solids can stain, discolor, and shorten fabric life (Loeb, 1963; Olson, 1939; Hein, 1970; Aultman, 1958). Metcalf and Eddy derive two exponential curves for total household costs vs. hardness with and without softening devices. For excessive water hardness of 400 ppm, per capita damages are $22.33. A serious problem with this study is that it derives total household costs only in terms of hardness levels. The interviews are conducted primarily with housewives, most of whom lack awareness of damaging minerals other than hardness, since the latter affects soap costs. As a result, cost estimates are biased in favor of hardness and omit other important water quality factors (Bovet, 1972).

An Orange County Study (1972) estimates the average per capita economic damage resulting from use of Colorado River water. Household items include water softeners, bottled water, water heaters, plumbing, water-using appliances, and swimming pools. Linear damage relations are assumed. Annual costs from both dissolved solids and hardness are quite high at $39.84, since water quality (average TDS load of 746 ppm; hardness, 349 ppm) of the riverwater supplied to households is quite poor.

Several studies examine damages for specific household items. Every 100 ppm rise in water hardness increases soap consumption. For example, the annual per capita cost of cleaning products varies considerably by study, i.e., $1.55 in an Illinois study (DeBoer and Larson, 1961), $2.52 in a Purdue University study (Aultman, 1958), $5.85 in a Southern California study (Metropolitan Water District, 1970), $8.21 for upper middle income residents in an Orange County survey (1970), and $3.32 for all respondents in this survey.* In a report on the Ohio River Valley (Bramer, 1960), hardness-related costs of soap are based on the Purdue University data. However, when total basin costs are derived, only customers using publicly treated surface water supplies are counted. Other residents on private wells and ground water are excluded since these sources, as the author contends, are not "primarily subject to the effects of pollution." This assumption is questionable since ground water is subject to (man-made) contamination from salts and toxic materials from surfaces and deep wells or through diffusion of soluble compounds from septic tank systems (Todd, 1970).

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*These figures are inflated by suitable price indices to base year 1970. The final estimate is based on a straight-line fitted through all data points in the Orange County survey.

Williams (1968) determined home water softening costs at $26.64 per person in Southern California. In a related study, the per capita cost of cleaning agents due to all water constituents is estimated in the range, $12.63-$15.79, for most American cities (AWWA, 1961). Another measure of benefit estimates is based on the willingness-to-pay concept. Orange County residents were asked what additional expenses they would accept for top quality water (Orange County Water District, 1972). Average yearly payments were $5.68 and $8.84 for water with respective TDS loads below and above 600 ppm.

SECTION VI

METHODOLOGY FOR ESTIMATING BENEFITS

The sequence of calculations for marginal benefits of water quality improvement is outlined in Figs. 1 and 2. In the first diagram, damages are calculated for each household item. These costs are partitioned into (1) investment and (2) operation. The former cost involves annualizing total capital cost over its period of usefulness. The reduced service life of unit i, resulting from contact with low vs. high quality water, is estimated by damage function $F_i(\cdot\cdot)$. The appropriate water quality index--TDS or hardness level--is an independent variable in this function. A standard capital recovery factor is defined in terms of the service life n and discount rate r, as follows:

$$\alpha(r,\ n) = \frac{r^n(1+r)^n}{(1+r)^n - 1} . \qquad (1)$$

This value, multiplied times the original value of the item, effectively amortizes the original cost into n equal yearly payments at interest r. The annualized cost decreases with improving water quality. This change represents the damage estimate for equipment corrosion or depreciation.

The other cost element arises from greater operation and maintenance of household items. This annual cost is calculated by the damage function $G_i(\cdot\cdot)$. After total costs are estimated for the two

Damage Impact	Description of unit u	Water Quality Level: Actual (W_o)	Water Quality Level: Improved (W_i)
Investment	Useful service life	$n_{uo} = F_u\ (W_o)$	$n_{ui} = F_u\ (W_i)$
	Capital recovery factor	$\alpha(r,n_{uo})$	$\alpha(r,n_{ui})$
	Base year value	V_u	V_u
	Annualized value	$\alpha(r,n_{uo})\cdot V_u$	$\alpha(r,n_{ui})\cdot V_u$
	Incremental damage	$D_u^{(1)} = [\alpha(r,n_{ui}) - \alpha(r,n_{uo})]\cdot V_u$	
Operation	Base year cost	$G_u\ (W_o)$	$G_u\ (W_i)$
	Incremental damage	$D_u^{(2)} = G_u\ (W_i) - G_u\ (W_o)$	
Total Unit	Incremental damage	$D_u = D_u^{(1)} + D_u^{(2)}$	
Total Household	Incremental damage	$D_u = \sum_u D_u$	

*Note: Water supply source, j, is implicit in these symbols i.e., $D \simeq D_j$.

Fig. 1. SCHEMATIC DIAGRAM OF WATER QUALITY DAMAGE CALCULATIONS FOR EACH HOUSEHOLD UNIT.

Land Area	Description of Region	Water Supply Source		
		Public: Surface	Public: Ground	Private: Well
State	Household Damages			
	Typical	D_1	D_2	D_3
	Adjusted for State	D_{1s}	D_{2s}	D_{3s}
	Number of Households	f_{1s}	f_{2s}	f_{3s}
	Total Damages by Source	$f_{1s}D_{1s}$	$f_{2s}D_{2s}$	$f_{3s}D_{3s}$
	Total Damages		$T_s = \sum_j f_{js}D_{js}$	
	Total Population		g_s	
	Per Capita Damages		$P_s = T_s/g_s$	
Nation	Total Damages by Source	$\sum_s f_{1s}D_{1s}$	$\sum_s f_{2s}D_{2s}$	$\sum_s f_{3s}D_{3s}$
	Total Damages		$T = \sum_s T_s$	
	Total Population		$g = \sum_s g_s$	
	Per Capita Damages		$P = T/g$	

Fig. 2. AGGREGATION SCHEME FOR REGIONAL WATER QUALITY BENEFIT CALCULATIONS.

water quality conditions, they are subtracted to yield incremental damages.

Unit damage functions and input data for these calculations are extracted from the literature. For most units, damage curves have been formulated from manufacturers' data and personal interviews. Otherwise, curves must be fitted through available data points. If only two (extreme water quality) observations are available, a linear segment is drawn through these points. In those cases where several data sources are available, averages are taken. There are also household items owned by a portion of all households, i.e., water softeners. This portion is assumed to be linearly related to the level of water quality (Orange County Water District, 1972). As a result, the average damage is a product of item cost and percent ownership, both functions of water quality. Price indices (Census, 1971) of household items are multiplied times original cost to adjust damages to base year 1970.

Table 1 presents a list of household units included in this study. Corresponding (uninflated) damage functions are formulated for capital and operating costs in a typical residence. Functional dependence on specific water quality conditions is also identified. (Note that soap and detergent costs are apportioned between TDS and hardness.) Each function is assumed valid over the observed range of water quality, although some studies caution the use of extrapolated results.* Not all household units are considered in estimating

Table 1
TYPICAL DAMAGE FUNCTIONS FOR HOUSEHOLD UNITS

UNIT	INVESTMENT/FAMILY * ORIGINAL COST ($)	LIFE SPAN (YR)	OPERATION AND MAINTENANCE * ($/YR)	WATER QUALITY VARIABLE (W) TDS	HARDNESS
Bottled Water	0	0	$\exp(-3.7)\cdot W^{.8}$	●	
Cooking Utensils	20	$10.2 - 7.0^{-4}W$	0	●	
Faucets	165	$11.5 - 2.7^{-4}W$	$7.0^{-4}W + 1.6$	●	
Garbage Grinder	8	$5.0 + \exp(1.6-1.2^{-3}W)$	$5.0^{-4}W + 1.1^{-1}$	●	
Sewage Facilities	90	$30.8 - 3.3^{-3}W$	$2.3^{-4}W + 3.4$	●	
Soap & Detergents (1)	0	0	$2.7^{-3}W + 11.7$	●	
Soap & Detergents (2)**	0	0	$1.6^{-1}W\cdot(1-X) + 11.7$, $X = 7.0^{-4}W$		●
Toilet Facilities	20	$2.0 + \exp(2.4-1.5^{-3}W)$	$1.6^{-3}W + 6.1^{-1}$	●	
Washable Fabrics	1,080	$4.6 - 1.3^{-4}W$	0	●	
Washing Appliances	120	$5.0 + \exp(1.8-7.9^{-4}N)$	$1.0^{-3}W + 3.3$	●	
Wastewater Piping	450	$10.0 + \exp(3.8-6.4^{-4}N)$	$7.0^{-4}W + 1.6$	●	
Water Heater	110	$5.0 + \exp(2.4-1.4^{-3}W)$	$1.3^{-3}W + 16.8$	●	

Table 1 (continued).

UNIT	INVESTMENT/FAMILY * ORIGINAL COST ($)	LIFE SPAN (YR)	OPERATION AND MAINTENANCE * ($/YR)	WATER QUALITY VARIABLE (W) TDS	HARDNESS
Water Piping	250	$12.0 + \exp(3.4 - 1.8^{-3}W)$	$1.1^{-3}W + 2.0$	●	
Water Softeners **	$2.1^{-1}W$	12.0	$1.1^{-4}W^2$		●
Water Utility Systems					
Distribution	450	$60.0 + \exp(3.9 - 9.1^{-4}W)$	$1.2^{-3}W + 3.2$	●	
Production	120	$30.8 - 3.3^{-3}W$	$3.2^{-4}W + 4.5$	●	
Service Lines	100	$46.7 - 6.7^{-3}W$	0	●	
Storage	60	$50.8 - 3.3^{-3}W$	$6.3^{-4}W + 3.4^{-1}$	●	
Water Meter	40	$30.5 - 2.0^{-3}W$	$2.3^{-4}W + 5.9^{-1}$	●	

* Any number of the form, $a.b^{-n}$, is an abbreviation of the scientific notation, $a.b \times 10^{-n}$.

** Damages for this unit are adjusted by the proportion of households owning water softeners.

damages. Only those with adequate documentation and proven dependence on water quality are summarized. Other likely items include ornamental shrubbery, swimming pools, home garden crops, and extra fertilizer demand.

After typical household damages are derived, state and national totals follow according to Figure 2. Each unit estimate is first adjusted to reflect state differences in housing expenditures. This adjustment is based on findings (Orange County Water District, 1972) of a strong correlation between damage levels and home value or rent payment. The factor used to reflect this standard of living adjustment is the ratio of average family income by state over the U.S. mean (Census, 1972).

Levels of drinking water quality for the largest U.S. cities (Durfor and Becker, 1965) are closely related to the quality of the

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*In the communities surveyed by Metcalf and Eddy (1972), for example, TDS always exceeded 31 ppm in water supplies, so that any damage estimate based on purer water is subject to greater uncertainty than interpolated results. Sonnen (1973) and others assume that damages are negligible below certain concentrations of minerals, i.e., 100 ppm for hardness, since no observations were surveyed in this range. Another survey (Aultman, 1958) refutes this assumption.

original water supply. Thus damages in each residence depend on the supply source, which is usually distinguished as publicly treated surface water, publicly treated ground water, or well water and other private sources. To estimate the number of households served by each supply source requires the integration of several data sets. The Environmental Protection Agency (Division of Water Hygiene, 1971) summarizes the percent of each state's population served in 1970 by public water supply systems. The remaining (unreported) population receives water from private systems. Of the proportion on public supply, a USGS report (Murray and Reeves, 1972) divides it by state into population served by surface, ground water, or combination thereof. For purposes of this study the "combination" group (which is relatively small) is partitioned among pure surface and ground water users according to their relative magnitudes. These estimates thus give a breakdown of state customers served by the three major water sources. The number of households on each source equals the percent served by source times total number of families (used as a proxy for households).

This analysis concerns itself not so much with the origin of damages as with the total use of water. Yet the distinction among household damages by supply source is important for several reasons. First, pollution of surface sources is more often identified with man-made activities than ground water contamination (Bramer, 1960). Water quality standards are generally designed to control anthropogenic wastes in surface water bodies. Second, water quality levels differ significantly by source. According to chemical analyses of raw water from large public supplies in the United States (U.S. Geological Survey, 1954), average hardness as $CaCO_3$ (weighted by population on each supply source) is 96 ppm from surface supplies but 200 ppm from ground supplies. If the water is treated publicly, these figures are reduced to 82 and 162 ppm. Total dissolved solids (measured as residue at 180 deg. F.) levels also vary considerably and are notably high in western and midwestern ground water aquifers. These high variations account in large measure for differential household damages.

Water quality varies enormously by geographic area. TDS levels ranging from less than 50 ppm in the South to well over 100,000 ppm in the West have been observed. Furthermore, extreme variability can even occur within the same aquifer. Near Sedgwick, Colorado, for instance, TDS and hardness were measured as 2140 and 990 ppm, respectively, in one private well but only 330 and 199 ppm in another well less than one mile away (Hurr, 1972). To obtain typical TDS or hardness values is thus meaningless for most areas of the country, especially the West and Southwest. For purposes of estimating aggregate damages, however, average values are useful inputs.

Water quality data were compiled from annual water resources reports, special state ground water reports, and information files in state agencies. Public water supply data was extracted from two USGS surveys (Durfor and Becker, 1965; Schneider, 1968) of major cities in the United States. The more recent data was selected if given the choice. Water quality observations were first separated into surface and ground sources. Then they were weighted by customers served in each municipality to yield a state average. Private well water data were more difficult to obtain. Observations were few in number and scattered in various documents. Some raw ground water records were compiled in annual surveys (U.S. Geological Survey, 1967-1970), but they covered fewer than half of all states. Other state data were taken from ground water analyses in the above mentioned USGS surveys of major cities. For another group of states, representative well samples were released by officials in USGS Water Resources District Offices. Still other information was found in special state ground water circulars. For each state a typical value of raw water quality was obtained by finding the mean of sample values. While caution must be exercised in using this as a representative value, the samples were chosen in heavily used aquifers. If water quality was found to be highly variable across the state, more than one of the above data references was used to assure better coverage.

From these data observations, water quality levels were estimated for each major supply source. In a few states, i.e., Maine and Minnesota, sample data for public ground water supplies were not readily available. A typical value was then calculated as the average of treated surface and well water quality.* By substituting water quality levels into the damage functions (Table 1), economic assessments of typical household damages from water use can be obtained.

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*Where water quality estimates for all supply sources by state are available, this averaging principle gives mixed results. For example, in Georgia and Idaho, treated ground water quality is roughly the average of values from other sources. In New York and California, this assumption yields underestimates, while the opposite occurs in Nebraska and Colorado.

SECTION VII

REGIONAL ESTIMATES OF ECONOMIC DAMAGES

A computer program was written to calculate 1970 household damages aggregated by state (including the District of Columbia). Tables 2-4 present a facsimile of the computer output. Damages are calculated for three discount rates: 5, 7.5, and 10%. In each table the first two columns estimate the annualized value (capital and operation) of all household items affected by observed (original) water quality. Next the damages are totalled over the number of households served by each supply source. Finally, these estimates are translated into per capita rankings. All damage values are based upon complete elimination of TDS and hardness prior to household use of water. This assumption results in a conservative value since household activities generally add more salts and minerals to the water supply (Bovet, 1973).

When the discount rate increases, household expenditures also rise, as expected. But the total per capita damage decreases. Intuitively, one would expect damages to change in the same ratio as expenditures. Examination of the capital recovery factor explains this discrepancy. For illustration, damages are calculated for water piping (unit 1) as affected by treated surface water in the state of Maine. With original water quality the annualized capital value increases 89% as interest goes from 5 to 10%. On the other hand, as water quality improves, this value decreases (because the service life

Table 2
HOUSEHOLD DAMAGES OF WATER SUPPLY BY STATE
FOR 1970

DISCOUNT RATE = 5%

STATE	HOUSEHLD EXPND TOTAL ($M)	HOUSEHLD EXPND PER CAPITA ($)	TOTAL DAMAGES ($1 M) BY SOURCE SURFACE	TR.GROUND	RAW WELL	TOTAL
MAINE	105.5	106.34	0.7	0.5	1.5	2.7
MASSACHUSETTS	792.6	139.32	3.7	5.3	3.8	12.8
VERMONT	51.4	115.73	0.5	0.4	0.8	1.7
NEW HAMPSHIRE	93.3	126.46	0.3	1.0	1.3	2.5
CONNECTICUT	497.4	164.05	5.8	2.9	3.5	12.2
RHODE ISLAND	121.8	128.65	1.4	0.5	0.2	2.1
NEW YORK	2753.7	150.99	39.1	61.3	15.6	115.9
NEW JERSEY	1133.7	158.16	8.9	12.9	14.7	36.5
DIST. COLUMBIA	97.9	129.39	6.3	0.0	0.3	6.6
PENNSYLVANIA	1584.6	134.36	50.2	13.0	21.0	84.2
WEST VIRGINIA	180.5	103.48	3.4	2.7	3.7	9.9
MARYLAND	583.4	148.74	13.3	1.8	2.4	17.4
VIRGINIA	588.1	126.52	11.6	2.9	11.0	25.4
DELAWARE	77.3	140.99	0.8	1.9	0.7	3.4
KENTUCKY	347.9	108.09	11.2	2.4	10.7	24.3
TENNESSEE	419.2	106.84	8.2	2.8	3.7	14.7
MISSISSIPPI	184.0	82.98	0.6	3.4	1.4	5.4
ALABAMA	350.3	101.70	6.4	3.5	3.3	13.2
GEORGIA	516.5	112.53	2.9	3.7	10.0	16.6
NORTH CAROLINA	542.6	106.77	5.2	2.4	9.8	17.3
SOUTH CAROLINA	250.0	96.51	2.0	0.4	0.6	3.0
FLORIDA	905.3	133.34	5.4	41.4	18.8	65.6
OHIO	1542.7	144.83	48.8	19.2	58.4	126.4

Table 2 (continued).

STATE	HOUSEHLD EXPND TOTAL ($M)	HOUSEHLD EXPND PER CAPITA ($)	TOTAL DAMAGES ($1 M) BY SOURCE SURFACE	TR.GROUND	RAW WELL	TOTAL
INDIANA	758.2	145.98	26.8	35.2	32.5	94.6
ILLINOIS	1750.3	157.49	51.9	62.1	57.0	171.0
MICHIGAN	1318.4	148.56	41.1	16.0	27.5	84.7
WISCONSIN	612.7	138.70	12.7	26.7	23.7	63.1
MINNESOTA	505.8	132.9-	5.8	16.1	15.4	37.3
ARKANSAS	180.5	93.86	0.7	2.3	4.9	7.9
LOUISIANA	365.4	100.35	7.2	3.8	2.6	13.6
OKLAHOMA	313.4	122.46	13.0	6.2	11.0	30.2
TEXAS	1406.2	125.59	39.5	69.2	12.4	121.0
NEW MEXICO	121.4	110.49	0.4	10.2	8.6	19.2
MISSOURI	614.3	131.36	17.7	15.4	16.2	49.4
IOWA	377.0	133.48	4.5	26.2	13.0	43.6
NEBRASKA	186.2	125.51	2.5	11.0	4.9	18.3
KANSAS	297.2	132.30	11.1	8.8	9.1	29.0
NORTH DAKOTA	69.3	112.15	1.7	2.2	3.8	7.6
SOUTH DAKOTA	77.0	115.63	0.5	3.3	7.9	11.7
MONTANA	82.1	118.25	2.4	1.3	2.4	6.1
WYOMING	73.2	129.99	1.0	1.3	1.7	3.9
UTAH	135.5	127.91	3.6	6.3	6.3	16.2
COLORADO	292.0	132.27	9.1	2.3	8.0	19.4
CALIFORNIA	3031.2	151.92	103.3	111.6	14.9	229.8
ARIZONA	250.4	141.38	9.7	21.7	8.0	39.5
NEVADA	72.7	148.64	0.6	3.4	1.1	5.1
HAWAII	107.0	139.26	0.2	3.4	1.2	4.7
WASHINGTON	469.7	137.78	3.1	9.4	2.4	14.9
OREGON	269.7	128.98	0.6	1.6	1.8	4.0
IDAHO	84.3	118.25	0.4	3.3	2.8	6.5
ALASKA	42.0	139.66	0.4	0.6	1.0	2.1

Table 2 (continued).

STATE	PER CAPITA DAMAGES ($) BY SOURCE			
	SURFACE	TR.GROUND	RAW WELL	TOTAL
MAINE	1.16	3.41	5.60	2.69
MASSACHUSETTS	0.99	3.83	6.60	2.24
VERMONT	2.91	3.95	4.96	3.90
NEW HAMPSHIRE	1.07	3.75	6.39	3.44
CONNECTICUT	3.03	4.92	6.76	4.03
RHODE ISLAND	2.14	2.33	2.45	2.21
NEW YORK	3.19	14.80	8.53	6.36
NEW JERSEY	3.61	5.87	5.87	5.10
DIST. COLUMBIA	8.72	0.0	8.72	8.72
PENNSYLVANIA	5.75	9.22	12.70	7.14
WEST VIRGINIA	3.81	6.35	8.88	5.65
MARYLAND	4.48	4.42	4.29	4.45
VIRGINIA	4.00	6.26	8.47	5.47
DELAWARE	3.75	7.93	8.03	6.29
KENTUCKY	6.05	8.05	10.04	7.56
TENNESSEE	4.58	2.50	3.66	3.75
MISSISSIPPI	2.21	2.42	2.61	2.44
ALABAMA	3.80	3.85	3.88	3.83
GEORGIA	1.48	3.13	6.80	3.61
NORTH CAROLINA	2.41	3.39	4.37	3.41
SOUTH CAROLINA	1.18	1.15	1.09	1.16
FLORIDA	9.68	9.13	11.05	9.65
OHIO	8.53	8.10	22.84	11.87
INDIANA	12.95	22.54	20.89	18.22
ILLINOIS	9.18	19.19	25.64	15.38

Table 2 (continued).

STATE	PER CAPITA DAMAGES ($) BY SOURCE			
	SURFACE	TR.GROUND	RAW WELL	TOTAL
MICHIGAN	7.23	11.36	15.49	9.54
WISCONSIN	8.15	17.43	17.86	14.29
MINNESOTA	4.51	10.34	16.20	9.81
ARKANSAS	1.11	3.96	6.84	4.11
LOUISIANA	4.82	2.70	3.52	3.74
OKLAHOMA	8.77	11.03	21.49	11.81
TEXAS	7.44	13.26	18.39	10.81
NEW MEXICO	5.61	16.56	25.67	18.88
MISSOURI	6.21	17.37	17.37	10.56
IOWA	7.99	15.45	22.93	15.45
NEBRASKA	11.02	11.40	16.53	12.37
KANSAS	12.33	9.81	20.21	12.90
NORTH DAKOTA	8.43	11.98	15.63	12.27
SOUTH DAKOTA	5.30	14.37	23.60	17.59
MONTANA	7.02	9.08	11.18	8.74
WYOMING	8.02	10.01	19.95	11.78
UTAH	10.40	16.23	19.26	15.28
COLORADO	5.40	7.36	36.42	8.77
CALIFORNIA	9.52	13.78	14.96	11.52
ARIZONA	20.76	23.84	20.49	22.29
NEVADA	3.48	14.09	13.49	10.47
HAWAII	6.18	6.18	6.18	6.18
WASHINGTON	1.67	8.32	5.84	4.36
OREGON	0.57	3.36	3.36	1.89
IDAHO	5.75	7.82	12.80	9.17
ALASKA	4.77	7.73	7.73	6.91

Table 3
HOUSEHOLD DAMAGES OF WATER SUPPLY USE BY STATE
FOR 1970

DISCOUNT RATE = 7.5%

STATE	HOUSEHLD EXPND TOTAL ($M)	HOUSEHLD EXPND PER CAPITA ($)	TOTAL DAMAGES ($1 M) BY SOURCE SURFACE	TR.GROUND	RAW WELL	TOTAL
MAINE	119.0	119.97	0.7	0.5	1.5	2.6
MASSACHUSETTS	895.1	157.33	3.6	5.2	3.7	12.5
VERMONT	58.0	130.43	0.5	0.4	0.8	1.7
NEW HAMPSHIRE	105.2	142.60	0.3	1.0	1.3	2.5
CONNECTICUT	561.1	185.06	5.7	2.9	3.4	12.0
RHODE ISLAND	137.5	145.27	1.3	0.5	0.2	2.1
NEW YORK	3099.9	169.98	38.7	60.7	15.4	114.8
NEW JERSEY	1277.7	178.25	8.8	12.8	14.5	36.0
DIST. COLUMBIA	109.8	145.20	6.2	0.0	0.3	6.5
PENNSYLVANIA	1781.4	151.04	49.6	13.0	20.9	83.4
WEST VIRGINIA	202.8	116.30	3.4	2.7	3.7	9.8
MARYLAND	657.7	167.68	13.2	1.7	2.3	17.2
VIRGINIA	662.0	142.41	11.4	2.8	11.0	25.2
DELAWARE	87.0	158.64	0.8	1.9	0.7	3.4
KENTUCKY	390.3	121.25	11.0	2.4	10.6	24.1
TENNESSEE	472.3	120.38	8.1	2.7	3.7	14.6
MISSISSIPPI	207.3	93.52	0.6	3.3	1.4	5.3
ALABAMA	394.5	114.53	6.3	3.4	3.3	13.0
GEORGIA	582.2	126.84	2.8	3.7	9.9	16.4
NORTH CAROLINA	611.5	120.33	5.1	2.3	9.6	17.0
SOUTH CAROLINA	282.5	109.03	1.9	0.4	0.5	2.9
FLORIDA	1015.1	149.51	5.3	40.8	18.6	64.7
OHIO	1728.1	162.23	48.2	19.0	58.1	125.3

Table 3 (continued).

STATE	HOUSEHLD EXPND TOTAL ($M)	HOUSEHLD EXPND PER CAPITA ($)	TOTAL DAMAGES ($1 M) BY SOURCE SURFACE	TR.GROUND	RAW WELL	TOTAL
INDIANA	845.1	162.71	26.6	35.1	32.4	94.1
ILLINOIS	1957.5	176.13	51.6	61.9	56.7	170.2
MICHIGAN	1480.4	166.80	40.8	15.9	27.4	84.1
WISCONSIN	684.9	155.03	12.6	26.7	23.6	62.9
MINNESOTA	567.2	149.07	5.8	16.0	15.4	37.1
ARKANSAS	203.1	105.61	0.7	2.3	4.8	7.8
LOUISIANA	411.2	112.94	7.1	3.6	2.5	13.1
OKLAHOMA	350.3	136.87	12.9	6.1	10.9	29.8
TEXAS	1573.3	140.51	38.8	68.0	12.1	118.8
NEW MEXICO	134.6	132.48	0.3	10.1	8.5	18.9
MISSOURI	687.9	147.09	17.3	15.2	16.0	48.6
IOWA	420.4	148.86	4.4	25.9	12.9	43.2
NEBRASKA	208.1	140.25	2.4	10.8	4.9	18.1
KANSAS	332.1	147.82	10.9	8.6	9.0	28.5
NORTH DAKOTA	77.2	124.96	1.6	2.1	3.6	7.4
SOUTH DAKOTA	85.3	128.23	0.5	3.2	7.7	11.5
MONTANA	92.0	132.48	2.3	1.3	2.3	5.9
WYOMING	48.4	145.46	0.9	1.3	1.6	3.9
UTAH	151.0	142.57	3.6	6.2	6.3	16.0
COLORADO	327.6	148.44	9.0	2.2	8.0	19.1
CALIFORNIA	3395.7	170.19	101.4	109.4	14.7	225.5
ARIZONA	277.5	156.70	9.6	21.4	7.8	38.8
NEVADA	81.5	166.76	0.6	3.4	1.1	5.1
HAWAII	120.4	156.61	0.2	3.3	1.2	4.6
WASHINGTON	529.5	155.32	3.1	9.3	2.4	14.8
OREGON	304.7	145.67	0.6	1.5	1.7	3.9
IDAHO	94.4	132.52	0.4	3.3	2.8	6.5
ALASKA	47.2	157.09	0.4	0.6	1.0	2.1

Table 3 (continued).

STATE	PER CAPITA DAMAGES ($) BY SOURCE SURFACE	TR.GROUND	RAW WELL	TOTAL
MAINE	1.15	3.37	5.56	2.67
MASSACHUSETTS	0.97	3.77	6.50	2.21
VERMONT	2.89	3.92	4.91	3.86
NEW HAMPSHIRE	1.04	3.69	6.29	3.38
CONNECTICUT	2.99	4.84	6.64	3.97
RHODE ISLAND	2.11	2.29	2.40	2.18
NEW YORK	3.15	14.67	8.44	6.29
NEW JERSEY	3.56	5.80	5.80	5.03
DIST. COLUMBIA	8.64	0.0	8.64	8.64
PENNSYLVANIA	5.68	9.15	12.64	7.07
WEST VIRGINIA	3.77	6.28	8.79	5.59
MARYLAND	4.43	4.35	4.20	4.39
VIRGINIA	3.95	6.21	8.43	5.43
DELAWARE	3.69	7.82	7.92	6.20
KENTUCKY	5.96	7.97	9.98	7.47
TENNESSEE	4.53	2.46	3.62	3.71
MISSISSIPPI	2.17	2.37	2.53	2.38
ALABAMA	3.76	3.79	3.81	3.78
GEORGIA	1.46	3.09	6.76	3.58
NORTH CAROLINA	2.38	3.33	4.29	3.35
SOUTH CAROLINA	1.15	1.11	1.04	1.12
FLORIDA	9.60	8.99	10.97	9.53
OHIO	8.42	7.99	22.73	11.76
INDIANA	12.86	22.44	20.81	18.13
ILLINOIS	9.12	19.14	25.49	15.31

Table 3 (continued).

STATE	PER CAPITA DAMAGES ($) BY SOURCE SURFACE	TR.GROUND	RAW WELL	TOTAL
MICHIGAN	7.18	11.29	15.42	9.48
WISCONSIN	8.10	17.39	17.79	14.23
MINNESOTA	4.45	10.28	16.14	9.75
ARKANSAS	1.09	3.90	6.73	4.04
LOUISIANA	4.73	2.52	3.38	3.60
OHLAHOMA	8.68	10.79	21.22	11.65
TEXAS	7.30	13.03	18.00	10.61
NEW MEXICO	5.46	16.30	25.38	18.61
MISSOURI	6.07	17.13	17.13	10.38
IOWA	7.85	16.29	22.76	15.29
NEBRASKA	10.80	11.26	16.37	12.21
KANSAS	12.12	9.61	20.02	12.70
NORTH DAKOTA	8.28	11.64	15.14	11.93
SOUTH DAKOTA	5.20	14.09	23.20	17.28
MONTANA	6.94	8.86	10.83	8.54
WYOMING	7.93	9.96	19.76	11.68
UTAH	10.34	15.95	19.09	15.11
COLORADO	5.33	7.24	36.09	8.67
CALIFORNIA	9.34	13.51	14.72	11.30
ARIZONA	20.37	23.49	20.15	21.93
NEVADA	3.41	14.03	13.39	10.40
HAWAII	6.01	6.01	6.01	6.01
WASHINGTON	1.64	8.28	5.79	4.33
OREGON	0.55	3.29	3.29	1.85
IDAHO	5.71	7.74	12.66	9.08
ALASKA	4.72	7.68	7.68	6.86

Table 4
HOUSEHOLD DAMAGES OF WATER SUPPLY BY STATE
FOR 1970

DISCOUNT RATE = 10%

STATE	HOUSEHLD EXPND TOTAL ($M)	HOUSEHLD EXPND PER CAPITA ($)	TOTAL DAMAGES ($1 M) BY SOURCE SURFACE	TR.GROUND	RAW WELL	TOTAL
MAINE	133.2	134.22	0.7	0.5	1.5	2.6
MASSACHUSETTS	1002.3	176.18	3.6	5.2	3.7	12.4
VERMONT	64.8	145.81	0.5	0.4	0.8	1.7
NEW HAMPSHIRE	117.7	159.50	0.3	0.9	1.2	2.5
CONNECTICUT	627.7	207.05	5.7	2.9	3.4	11.9
RHODE ISLAND	154.0	162.66	1.3	0.5	0.2	2.0
NEW YORK	3462.3	189.85	38.4	60.4	15.3	114.1
NEW JERSEY	1428.5	199.28	8.7	12.6	14.4	35.7
DIST. COLUMBIA	122.4	161.77	6.2	0.0	0.3	6.5
PENNSYLVANIA	1987.5	168.52	49.2	12.9	20.8	82.9
WEST VIRGINIA	226.3	129.72	3.4	2.7	3.7	9.7
MARYLAND	735.5	187.51	13.1	1.7	2.3	17.1
VIRGINIA	739.4	159.06	11.3	2.8	11.0	25.1
DELAWARE	97.1	177.13	0.8	1.9	0.4	3.4
KENTUCKY	434.7	135.04	10.9	2.4	10.6	23.9
TENNESSEE	527.9	134.55	8.1	2.7	3.7	14.5
MISSISSIPPI	231.8	104.56	0.5	3.3	1.4	5.2
ALABAMA	440.7	127.96	6.2	3.4	3.2	12.9
GEORGIA	650.9	141.82	2.8	3.6	9.9	16.3
NORTH CAROLINA	683.7	134.52	5.1	2.3	9.5	16.9
SOUTH CAROLINA	316.4	122.14	1.9	0.4	0.5	2.8
FLORIDA	1130.1	166.45	5.3	40.3	18.5	64.2
OHIO	1922.4	180.47	47.8	18.8	58.0	124.6

Table 4 (continued).

STATE	HOUSEHLD EXPND TOTAL ($M)	HOUSEHLD EXPND PER CAPITA ($)	TOTAL DAMAGES ($1 M) BY SOURCE SURFACE	TR.GROUND	RAW WELL	TOTAL
INDIANA	936.2	180.26	26.5	35.0	32.4	93.9
ILLINOIS	2174.6	195.67	51.5	61.9	56.5	169.9
MICHIGAN	1650.0	185.91	40.7	15.9	27.3	83.9
WISCONSIN	760.5	172.14	12.6	26.7	23.5	62.8
MINNESOTA	631.6	166.00	5.7	16.0	15.3	37.0
ARKANSAS	226.8	117.92	0.7	2.3	4.7	7.7
LOUISIANA	459.3	126.13	7.0	3.3	2.4	12.7
OKLAHOMA	389.0	151.99	12.8	6.0	10.7	29.5
TEXAS	1748.5	156.16	38.2	67.0	11.9	117.1
NEW MEXICO	148.5	146.12	0.3	9.9	8.4	18.7
MISSOURI	765.0	163.59	17.0	15.1	15.8	47.9
IOWA	466.0	165.00	4.4	25.7	12.8	42.9
NEBRASKA	231.0	155.72	2.4	10.8	4.8	18.0
KANSAS	368.7	164.10	10.8	8.5	8.9	28.2
NORTH DAKOTA	85.5	138.42	1.6	2.0	3.5	7.2
SOUTH DAKOTA	94.1	141.46	0.5	3.2	7.6	11.3
MONTANS	102.4	147.40	2.3	1.2	2.3	5.8
WYOMING	53.7	161.68	0.9	1.3	1.6	3.9
UTAH	167.3	157.95	3.5	6.1	6.2	15.9
COLORADO	365.0	165.37	8.9	2.2	7.9	19.0
CALIFORNIA	3778.0	189.34	99.9	107.7	14.5	222.1
ARIZONA	306.0	172.79	9.4	21.2	7.7	38.3
NEVADA	90.8	185.75	0.5	3.4	1.1	5.1
HAWAII	134.3	174.80	0.2	3.2	1.1	4.5
WASHINGTON	592.1	173.67	3.0	9.3	2.4	14.7
OREGON	341.2	163.14	0.6	1.5	1.7	3.8
IDAHO	105.1	147.48	0.4	3.3	2.8	6.4
ALASKA	52.7	175.34	0.4	0.6	1.0	2.1

Table 4 (continued).

STATE	PER CAPITA DAMAGES ($) BY SOURCE			
	SURFACE	TR.GROUND	RAW WELL	TOTAL
MAINE	1.14	3.36	5.53	2.66
MASSACHUSETTS	0.96	3.73	6.43	2.18
VERMONT	2.88	3.90	4.88	3.84
NEW HAMPSHIRE	1.02	3.64	6.22	3.34
CONNECTICUT	2.96	4.78	6.55	3.93
RHODE ISLAND	2.09	2.26	2.36	2.16
NEW YORK	3.13	14.59	8.37	6.25
NEW JERSEY	3.53	5.74	5.74	4.99
DIST. COLUMBIA	8.60	0.0	8.60	8.60
PENNSYLVANIA	5.64	9.12	12.62	7.03
WEST VIRGINIA	3.74	6.23	8.73	5.55
MARYLAND	4.40	4.30	4.13	4.35
VIRGINIA	3.92	6.19	8.43	5.41
DELAWARE	3.66	7.74	7.84	6.14
KENTUCKY	5.89	7.92	9.95	7.42
TENNESSEE	4.51	2.43	3.61	3.69
MISSISSIPPI	2.15	2.32	2.47	2.34
ALABAMA	3.73	3.75	3.76	3.74
GEORGIA	1.44	3.06	6.75	3.56
NORTH CAROLINA	2.37	3.30	4.23	3.32
SOUTH CAROLINA	1.13	1.08	1.00	1.09
FLORIDA	9.55	8.89	10.92	9.45
OHIO	8.36	7.92	22.68	11.70
INDIANA	12.81	22.40	20.78	18.09
ILLINOIS	9.10	19.15	25.41	15.29

Table 4 (continued).

STATE	PER CAPITA DAMAGES ($) BY SOURCE SURFACE	TR.GROUND	RAW WELL	TOTAL
MICHIGAN	7.15	11.27	15.40	9.45
WISCONSIN	8.08	17.39	17.77	14.22
MINNESOTA	4.41	10.25	16.13	9.73
ARKANSAS	1.08	3.85	6.64	3.99
LOUISIANA	4.66	2.37	3.26	3.49
OKLAHOMA	8.63	10.59	21.00	11.54
TEXAS	7.20	12.84	17.65	10.46
NEW MEXICO	5.35	16.09	25.13	18.40
MISSOURI	5.96	16.94	16.94	10.25
IOWA	7.74	15.17	22.64	15.18
NEBRASKA	10.63	11.17	16.26	12.10
KANSAS	11.96	9.45	19.88	12.54
NORTH DAKOTA	8.16	11.34	14.69	11.63
SOUTH DAKOTA	5.13	13.86	22.85	17.01
MONTANA	6.89	8.68	10.52	8.39
WYOMING	7.88	9.94	19.63	11.62
UTAH	10.32	15.72	18.98	14.98
COLORADO	5.29	7.16	35.84	8.60
CALIFORNIA	9.20	13.29	14.53	11.13
ARIZONA	20.03	23.21	19.86	21.63
NEVADA	3.37	14.01	13.33	10.37
HAWAII	5.88	5.88	5.88	5.88
WASHINGTON	1.63	8.28	5.77	4.32
OREGON	0.54	3.25	3.25	1.82
IDAHO	5.69	7.69	12.57	9.02
ALASKA	4.70	7.66	7.66	6.83

of the unit lengthens) by 1.31% at 5% interest but only by 0.33% at 10%. The ratio of decreases is thus 398% (=1.31/.33), which equals the ratio of changes in the capital recovery factor. Since the ratio of decreases exceeds the annualized value increase, the net result implies lower damages.

The highest per capita damages are identified with Arizona, New Mexico, Indiana, and South Dakota. In spite of the fact that South Dakotans have relatively good treated surface water, a high percentage of them own private wells whose water has high TDS loads. The other states have high concentrations of minerals from all supply sources. Because these states are not populous, their high per capita damages do not translate into the highest totals. Rather, this distinction belongs to California, Illinois, Texas, Ohio, and New York, in that order. New York has relatively clean water within this group of states, but its large population and high standard of living rank it in the top five. Figure 3 compares per capita and total damages for the most populous state in each EPA region. State abbreviations are as follows: Massachusetts-MA, New York-NY, Pennsylvania-PA, Florida-FL, Illinois-IL, Missouri-MO, Texas-TX, Colorado-CO, California-CA, and Washington-WA. Damages are consistently low in the New England and Southern states (except Florida) because of their relatively pure natural water supplies.

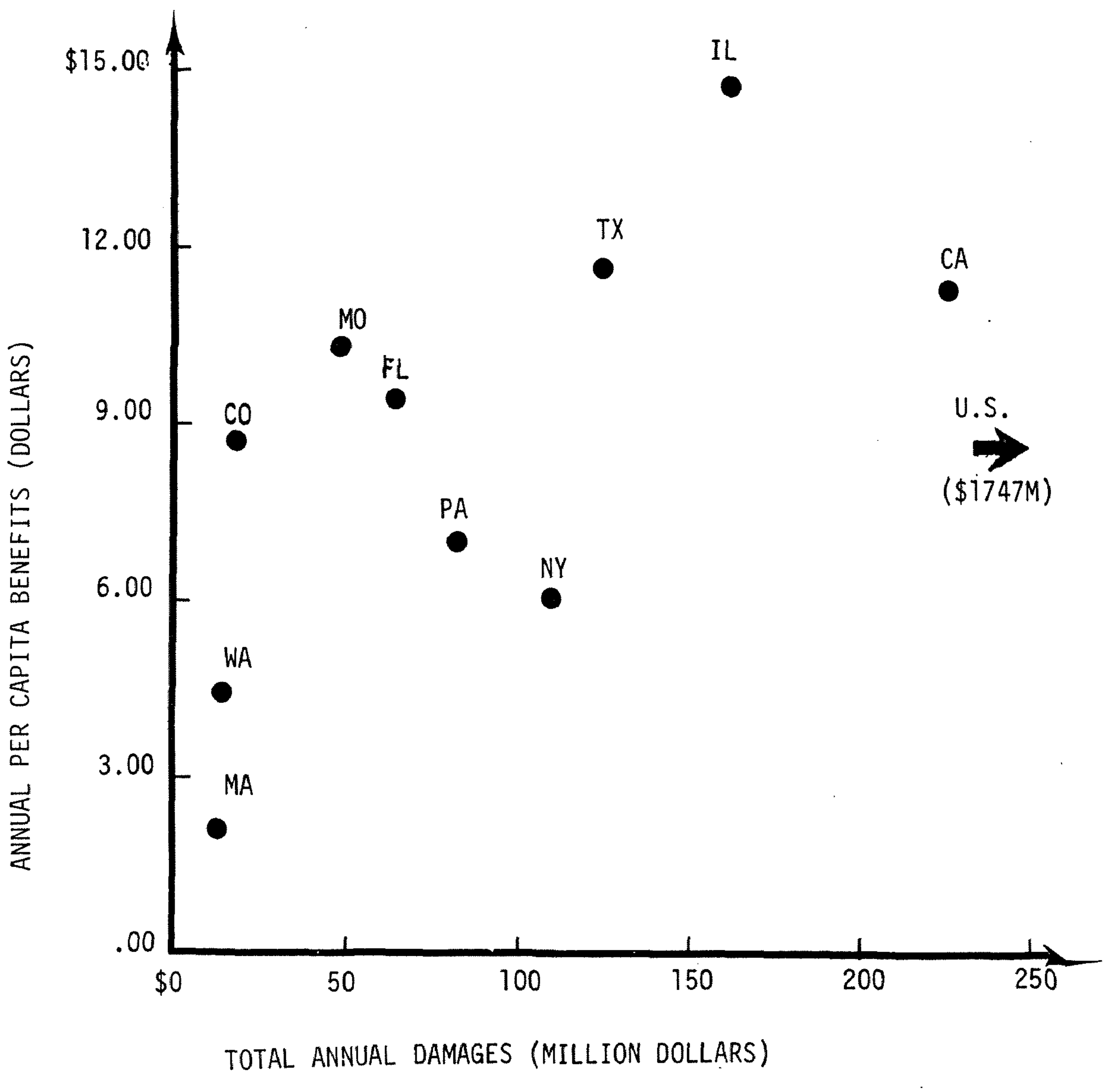


Fig. 3 1970 HOUSEHOLD DAMAGES OF WATER SUPPLY USE BY SELECTED STATE

SECTION VIII

RESULTS AT THE NATIONAL LEVEL

For the United States (see Table 3), household damages at 7.5% interest total around $1.75 billion or $8.60 per person. These estimates relate to complete removal of water constituents. Tables 5-10 list benefits of improving water quality at intermediate levels. Each pair of tables pertains to the same discount rate, comparing total and per capita benefits. The effects of TDS and hardness are separated for each source of water supply, with the latter accounting for almost two-thirds of all household expenses. Most TDS-related damages reduce investment life, whereas hardness contributes primarily to daily operating costs (soap and water softening).

Again at 7.5% interest, Figure 4 relates damages to various degrees of removal. For 10% improvement in overall water quality, total benefits increase by more than $175 million. At 50% improvement, per capita benefits are slightly less than half of potential benefits from complete removal. TDS-related damages maintain a fairly constant share of total costs, except below 40% removal. Their dominance in this range is influenced largely by the concavity of the damage curve for bottled water. The damage functions are very flat S-curves, concave in the lower water quality improvement range, convex in the upper range, with the flex point around 75% removal. In the lower range, concavity of household unit damage functions, i.e., bottled water and water softeners, is most important.

Table 5
HOUSEHOLD BENEFITS OF WATER SUPPLY TREATMENT IN THE U.S.
FOR 1970

DISCOUNT RATE = 5%

SUPPLY SOURCE	TOTAL BENEFITS ($1 M) AT VARIOUS LEVELS (PCT) OF WATER QUALITY IMPROVEMENT				
	10%	20%	30%	40%	50%
TDS AND HARDNESS					
TREATED SURFACE	60.8	121.6	182.3	242.9	303.5
TREATED GROUND	67.3	134.5	201.4	268.2	334.8
PRIVATE WELL	50.4	100.6	150.7	200.7	250.6
TOTAL	178.5	356.7	534.5	711.9	888.9
TDS ONLY					
TREATED SURFACE	22.7	45.2	67.8	90.2	112.6
TREATED GROUND	25.8	51.4	76.9	102.1	127.2
PRIVATE WELL	17.5	34.9	52.1	69.3	86.3
TOTAL	65.9	131.5	196.8	261.6	326.1
HARDNESS ONLY					
TREATED SURFACE	38.2	76.4	114.6	152.7	190.9
TREATED GROUND	41.5	83.1	124.6	166.1	207.6
PRIVATE WELL	32.9	65.7	98.6	131.4	164.3
TOTAL	112.6	225.2	337.7	450.3	562.8

Table 5 (continued).

SUPPLY SOURCE	TOTAL BENEFITS ($1 M) AT VARIOUS LEVELS (PCT) OF WATER QUALITY IMPROVEMENT				
	60%	70%	80%	90%	100%
TDS AND HARDNESS					
TREATED SURFACE	364.0	424.5	485.1	545.9	607.9
TREATED GROUND	401.2	467.5	533.7	600.0	667.2
PRIVATE WELL	300.3	349.9	399.4	448.9	499.0
TOTAL	1065.5	1241.9	1418.2	1594.8	1774.1
TDS ONLY					
TREATED SURFACE	134.9	157.3	179.7	202.4	226.2
TREATED GROUND	152.2	177.0	201.7	226.5	252.3
PRIVATE WELL	103.2	120.0	136.7	153.4	170.7
TOTAL	390.3	454.2	518.1	582.3	649.2
HARDNESS ONLY					
TREATED SURFACE	229.1	267.2	305.4	343.5	381.7
TREATED GROUND	249.1	290.5	332.0	373.4	414.9
PRIVATE WELL	197.1	229.9	262.7	295.5	328.3
TOTAL	675.2	787.7	900.1	1012.5	1124.9

Table 6
HOUSEHOLD BENEFITS OF WATER SUPPLY TREATMENT IN THE U.S.
FOR 1970

DISCOUNT RATE = 7.5%

SUPPLY SOURCE	TOTAL BENEFITS ($1 M) AT VARIOUS LEVELS (PCT) OF WATER QUALITY IMPROVEMENT				
	10%	20%	30%	40%	50%
TDS AND HARDNESS					
TREATED SURFACE	60.1	120.1	180.1	239.9	299.7
TREATED GROUND	66.6	133.0	199.2	265.2	330.9
PRIVATE WELL	50.0	99.9	149.6	199.2	248.6
TOTAL	176.7	353.0	528.9	704.3	879.2
TDS ONLY					
TREATED SURFACE	21.2	42.3	63.3	84.3	105.1
TREATED GROUND	24.3	48.4	72.3	96.0	119.4
PRIVATE WELL	16.5	32.9	49.1	65.2	81.2
TOTAL	62.0	123.6	184.1	245.5	305.7
HARDNESS ONLY					
TREATED SURFACE	38.9	77.8	116.7	155.6	194.5
TREATED GROUND	42.3	84.6	126.9	169.2	211.5
PRIVATE WELL	33.5	67.0	100.5	133.9	167.4
TOTAL	114.7	229.5	344.1	458.8	573.4

Table 6 (continued).

SUPPLY SOURCE	TOTAL BENEFITS ($1 M) AT VARIOUS LEVELS (PCT) OF WATER QUALITY IMPROVEMENT 60%	70%	80%	90%	100%
TDS AND HARDNESS					
TREATED SURFACE	359.4	419.1	478.8	538.8	599.9
TREATED GROUND	396.5	461.9	527.2	592.5	658.8
PRIVATE WELL	297.8	346.9	395.9	444.9	494.5
TOTAL	1053.7	1227.9	1401.9	1576.2	1753.2
TDS ONLY					
TREATED SURFACE	125.9	146.8	167.6	188.7	211.0
TREATED GROUND	142.7	165.8	188.9	212.0	236.0
PRIVATE WELL	97.0	112.6	128.2	143.8	159.9
TOTAL	365.6	425.2	484.7	544.4	606.9
HARDNESS ONLY					
TREATED SURFACE	233.4	272.3	311.2	350.1	389.0
TREATED GROUND	253.8	296.0	338.3	380.5	422.8
PRIVATE WELL	200.8	234.3	267.7	301.1	334.5
TOTAL	688.1	802.7	917.2	1031.8	1146.3

Table 7
HOUSEHOLD BENEFITS OF WATER SUPPLY TREATMENT IN THE U.S.
FOR 1970

DISCOUNT RATE = 10%

SUPPLY SOURCE	TOTAL BENEFITS ($1 M) AT VARIOUS LEVELS (PCT) OF WATER QUALITY IMPROVEMENT				
	10%	20%	30%	40%	50%
TDS AND HARDNESS					
TREATED SURFACE	59.6	119.1	178.4	237.7	297.0
TREATED GROUND	66.0	131.9	197.5	262.9	328.0
PRIVATE WELL	49.8	99.4	148.8	198.1	247.2
TOTAL	175.4	350.3	524.7	698.7	872.2
TDS ONLY					
TREATED SURFACE	19.9	39.7	59.4	79.0	98.6
TREATED GROUND	22.9	45.6	68.0	90.3	112.3
PRIVATE WELL	15.6	31.1	46.4	61.5	76.5
TOTAL	58.4	116.3	173.8	230.8	287.4
HARDNESS ONLY					
TREATED SURFACE	39.7	79.4	119.1	158.7	198.4
TREATED GROUND	43.2	86.3	129.5	172.6	215.7
PRIVATE WELL	34.2	68.3	102.5	136.6	170.7
TOTAL	117.0	234.0	351.0	467.9	584.8

Table 7 (continued).

SUPPLY SOURCE	TOTAL BENEFITS ($1 M) AT VARIOUS LEVELS (PCT) OF WATER QUALITY IMPROVEMENT 60%	70%	80%	90%	100%
TDS AND HARDNESS					
TREATED SURFACE	356.1	415.3	474.5	533.9	594.5
TREATED GROUND	392.9	457.7	522.4	587.1	652.8
PRIVATE WELL	296.1	344.9	393.6	442.3	491.5
TOTAL	1045.2	1217.9	1390.5	1563.3	1738.8
TDS ONLY					
TREATED SURFACE	118.0	137.6	157.1	176.9	197.8
TREATED GROUND	134.1	155.8	177.4	199.0	221.6
PRIVATE WELL	91.3	106.0	120.6	135.2	150.4
TOTAL	343.5	399.3	455.1	511.2	569.8
HARDNESS ONLY					
TREATED SURFACE	238.1	277.7	317.4	357.0	396.7
TREATED GROUND	258.8	301.9	345.0	388.1	431.2
PRIVATE WELL	204.8	238.9	273.0	307.1	341.2
TOTAL	701.7	818.6	935.4	1052.2	1169.0

Table 8
HOUSEHOLD BENEFITS OF WATER SUPPLY TREATMENT IN THE U.S.
FOR 1970

DISCOUNT RATE = 5%

SUPPLY SOURCE	PER CAPITA BENEFITS ($) AT VARIOUS LEVELS (PCT) OF WATER QUALITY IMPROVEMENT 10%	20%	30%	40%	50%
TDS AND HARDNESS					
TREATED SURFACE	0.59	1.18	1.77	2.36	2.95
TREATED GROUND	1.12	2.24	3.36	4.47	5.58
PRIVATE WELL	1.25	2.49	3.73	4.96	6.20
TOTAL	0.88	1.76	2.63	3.50	4.37
TDS ONLY					
TREATED SURFACE	0.22	0.44	0.66	0.88	1.10
TREATED GROUND	0.43	0.86	1.28	1.70	2.12
PRIVATE WELL	0.43	0.86	1.29	1.71	2.13
TOTAL	0.32	0.65	0.97	1.29	1.60
HARDNESS ONLY					
TREATED SURFACE	0.37	0.74	1.11	1.49	1.86
TREATED GROUND	0.69	1.39	2.08	2.77	3.46
PRIVATE WELL	0.81	1.63	2.44	3.25	4.06
TOTAL	0.55	1.11	1.66	2.22	2.77

Table 8 (continued).

SUPPLY SOURCE	PER CAPITA BENEFITS ($) AT VARIOUS LEVELS (PCT) OF WATER QUALITY IMPROVEMENT				
	60%	70%	80%	90%	100%
TDS AND HARDNESS					
TREATED SURFACE	3.54	4.13	4.72	5.31	5.91
TREATED GROUND	6.69	7.80	8.90	10.01	11.13
PRIVATE WELL	7.43	8.65	9.88	11.10	12.34
TOTAL	5.24	6.11	6.98	7.85	8.73
TDS ONLY					
TREATED SURFACE	1.31	1.53	1.75	1.97	2.20
TREATED GROUND	2.54	2.95	3.36	3.78	4.21
PRIVATE WELL	2.55	2.97	3.38	3.79	4.22
TOTAL	1.92	2.24	2.55	2.87	3.19
HARDNESS ONLY					
TREATED SURFACE	2.23	2.60	2.97	3.34	3.71
TREATED GROUND	4.15	4.85	5.54	6.23	6.92
PRIVATE WELL	4.87	5.69	6.50	7.31	8.12
TOTAL	3.32	3.88	4.43	4.98	5.54

Table 9
HOUSEHOLD BENEFITS OF WATER SUPPLY TREATMENT IN THE U.S.
FOR 1970

DISCOUNT RATE = 7.5%

SUPPLY SOURCE	PER CAPITA BENEFITS ($) AT VARIOUS LEVELS (PCT) OF WATER QUALITY IMPROVEMENT				
	10%	20%	30%	40%	50%
TDS AND HARDNESS					
TREATED SURFACE	0.58	1.17	1.75	2.33	2.91
TREATED GROUND	1.11	2.22	3.32	4.42	5.52
PRIVATE WELL	1.24	2.47	3.70	4.93	6.15
TOTAL	0.87	1.74	2.60	3.47	4.33
TDS ONLY					
TREATED SURFACE	0.21	0.41	0.62	0.82	1.02
TREATED GROUND	0.41	0.81	1.21	1.60	1.99
PRIVATE WELL	0.41	0.81	1.22	1.61	2.01
TOTAL	0.30	0.61	0.91	1.21	1.50
HARDNESS ONLY					
TREATED SURFACE	0.38	0.76	1.14	1.51	1.89
TREATED GROUND	0.71	1.41	2.12	2.82	3.53
PRIVATE WELL	0.83	1.66	2.48	3.31	4.14
TOTAL	0.56	1.13	1.69	2.26	2.82

Table 9 (continued).

SUPPLY SOURCE	PER CAPITA BENEFITS ($) AT VARIOUS LEVLES (PCT) OF WATER QUALITY IMPROVEMENT 60%	70%	80%	90%	100%
TDS AND HARDNESS					
TREATED SURFACE	3.49	4.08	4.66	5.24	5.83
TREATED GROUND	6.61	7.70	8.79	9.88	10.99
PRIVATE WELL	7.36	8.58	9.79	11.00	12.23
TOTAL	5.19	6.04	6.90	7.76	8.63
TDS ONLY					
TREATED SURFACE	1.22	1.43	1.63	1.84	2.05
TREATED GROUND	2.38	2.77	3.15	3.54	3.94
PRIVATE WELL	2.40	2.79	3.17	3.56	3.96
TOTAL	1.80	2.09	2.39	2.68	2.99
HARDNESS ONLY					
TREATED SURFACE	2.27	2.65	3.03	3.40	3.78
TREATED GROUND	4.23	4.94	5.64	6.35	7.05
PRIVATE WELL	4.97	5.79	6.62	7.45	8.27
TOTAL	3.39	3.95	4.51	5.08	5.64

Table 10
HOUSEHOLD BENEFITS OF WATER SUPPLY TREATMENT IN THE U.S.
FOR 1970

DISCOUNT RATE = 10%

SUPPLY SOURCE	PER CAPITA BENEFITS ($) AT VARIOUS LEVELS (PCT) OF WATER QUALITY IMPROVEMENT				
	10%	20%	30%	40%	50%
TDS AND HARDNESS					
TREATED SURFACE	0.58	1.16	1.74	2.31	2.89
TREATED GROUND	1.10	2.20	3.29	4.38	5.47
PRIVATE WELL	1.23	2.46	3.68	4.90	6.11
TOTAL	0.86	1.72	2.58	3.44	4.29
TDS ONLY					
TREATED SURFACE	0.19	0.39	0.58	0.77	0.96
TREATED GROUND	0.38	0.76	1.13	1.51	1.87
PRIVATE WELL	0.39	0.77	1.15	1.52	1.89
TOTAL	0.29	0.57	0.86	1.14	1.41
HARDNESS ONLY					
TREATED SURFACE	0.39	0.77	1.16	1.54	1.93
TREATED GROUND	0.72	1.44	2.16	2.88	3.60
PRIVATE WELL	0.84	1.69	2.53	3.38	4.22
TOTAL	0.58	1.15	1.73	2.30	2.88

Table 10 (continued).

SUPPLY SOURCE	PER CAPITA BENEFITS ($) AT VARIOUS LEVELS (PCT) OF WATER QUALITY IMPROVEMENT 60%	70%	80%	90%	100%
TDS AND HARDNESS					
TREATED SURFACE	3.46	4.04	4.61	5.19	5.78
TREATED GROUND	6.55	7.64	8.71	9.79	10.89
PRIVATE WELL	7.32	8.53	9.73	10.94	12.15
TOTAL	5.14	5.99	6.84	7.69	8.56
TDS ONLY					
TREATED SURFACE	1.15	1.34	1.53	1.72	1.92
TREATED GROUND	2.24	2.60	2.96	3.32	3.70
PRIVATE WELL	2.26	2.62	2.98	3.34	3.72
TOTAL	1.69	1.97	2.24	2.51	2.80
HARDNESS ONLY					
TREATED SURFACE	2.32	2.70	3.09	3.47	3.86
TREATED GROUND	4.32	5.04	5.76	6.47	7.19
PRIVATE WELL	5.07	5.91	6.75	7.59	8.44
TOTAL	3.45	4.03	4.60	5.18	5.75

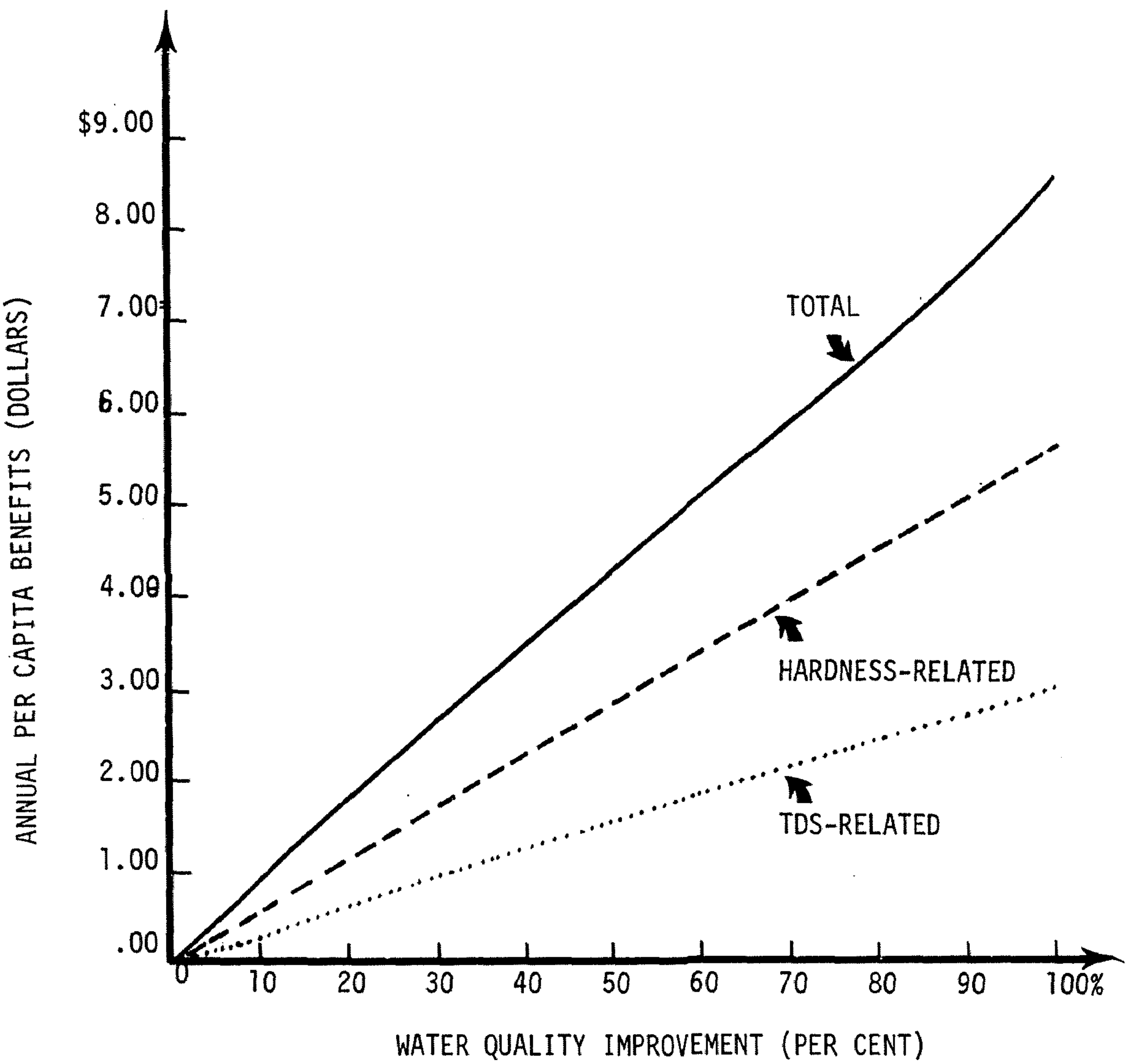


Fig. 4 1970 PER CAPITA BENEFITS OF WATER SUPPLY TREATMENT IN THE UNITED STATES BY WATER QUALITY PARAMETER.

Toward the upper end, some convex relations, i.e., equipment service life and excess detergents to counteract hardness, prevail. For practical purposes, however, the damage curve can be assumed as approximately linear over the removal efficiency range.

Figures 5 and 6 contrast damages associated with the primary sources of intake water. Per capita damages are ostensibly higher with ground water since it generally contains more minerals than surface supplies. Municipal plants normally bypass these constituents without treatment, while the absence of economies of scale preclude their removal from private systems. The next figure transforms these benefits into total population equivalents. In spite of the low per capita contribution from surface supplies, its share of total benefits exceeds one-third. Total benefits to private well owners rank last. This ordering follows from the distribution of water supplies among U.S. households: surface, 50.8%; treated ground, 29.3%; and private well water, 19.9%.

It is important to recognize that these estimates are derived from mean values of household unit damage observations. Because most observations are few in number, the sample mean may not accurately reflect the actual mean for U.S. households. Moreover, "typical" water quality data are compiled for these calculations, but again these figures may not be representative of actual conditions. Because of the uncertainties involved, a range of estimates is preferable to a point value. Figure 7 presents "interval estimates" in each state.

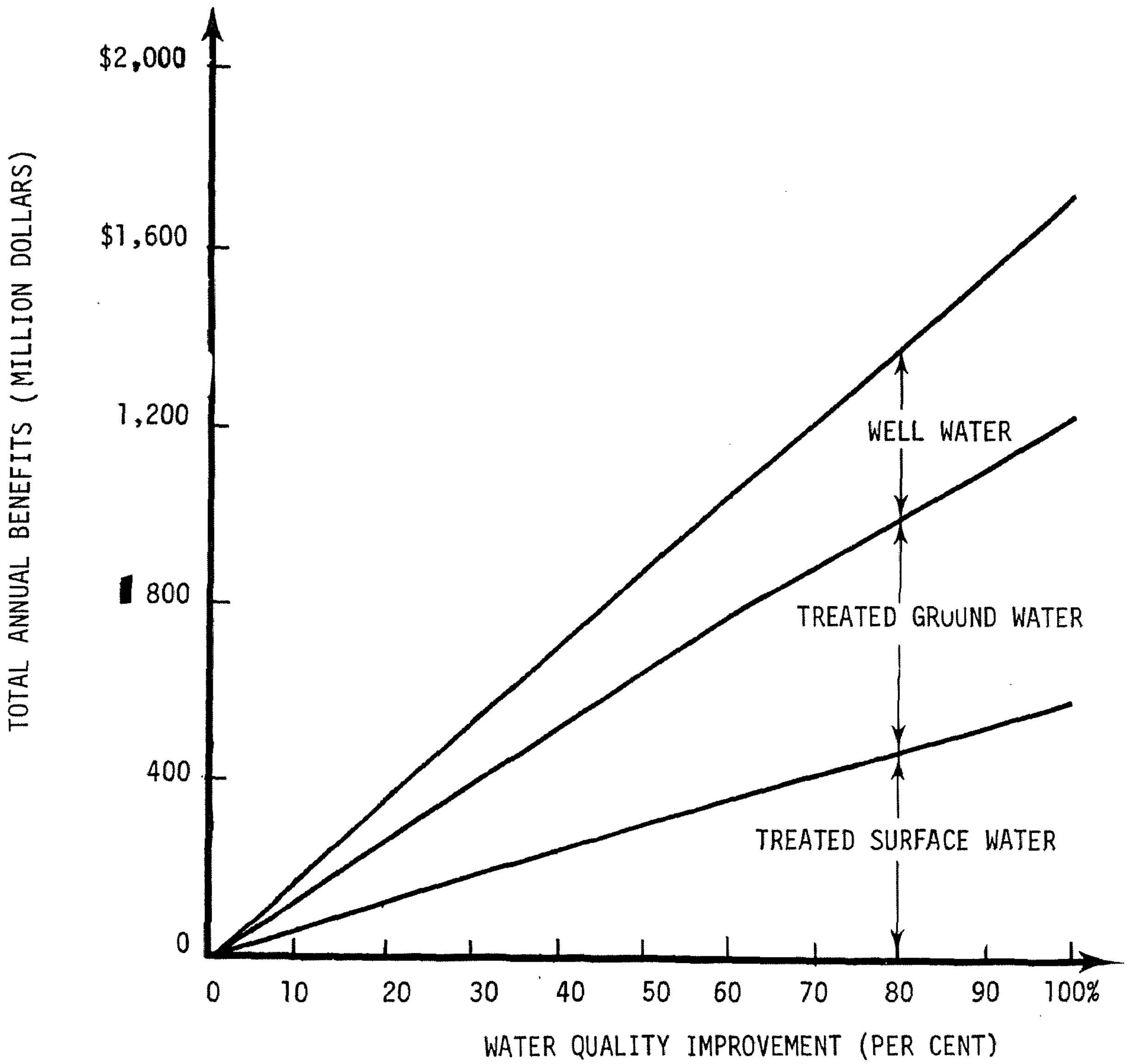


Fig. 5 1970 TOTAL HOUSEHOLD BENEFITS OF WATER SUPPLY TREATMENT IN THE UNITED STATES, CUMULATED BY SOURCE.

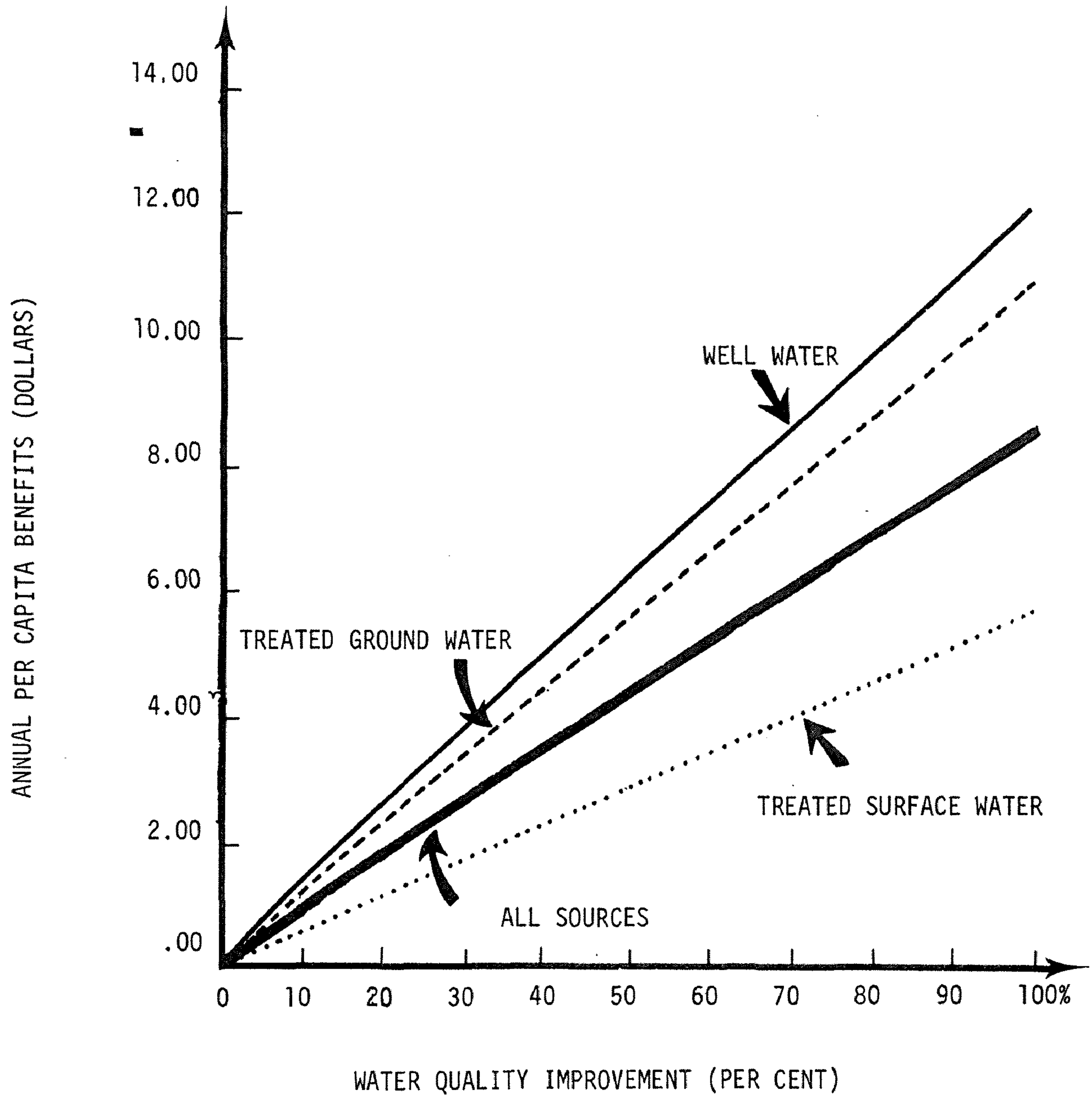
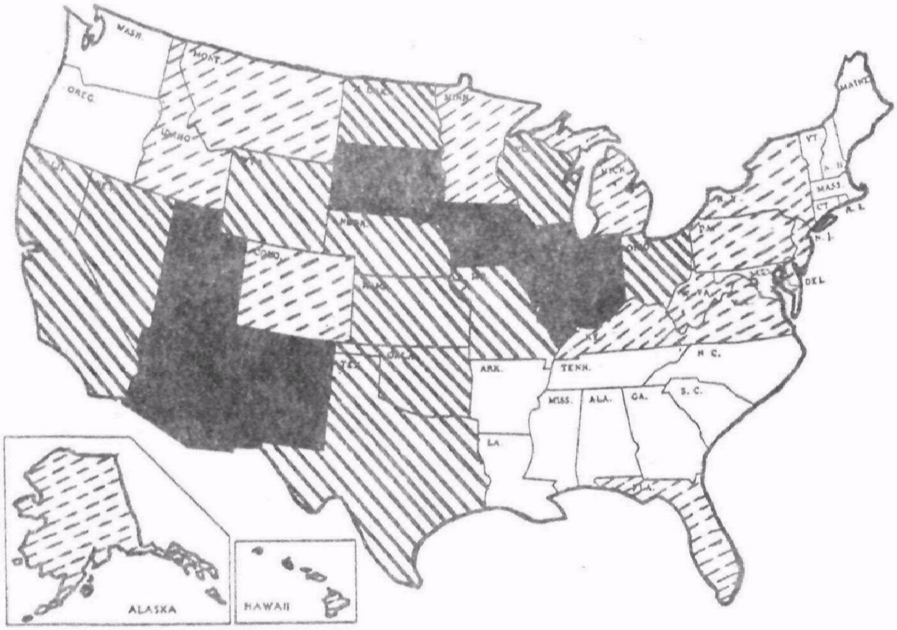


Fig. 6. 1970 PER CAPITA BENEFITS OF WATER SUPPLY TREATMENT IN THE UNITED STATES BY INDIVIDUAL SOURCE.



$15.00 - $24.99

$10.00 - $14.99

$ 5.00 - $ 9.99

$ .00 - $ 4.99

Fig. 7. 1970 PER CAPITA DAMAGES FROM DOMESTIC WATER SUPPLY USE IN THE UNITED STATES.

A range of values can be obtained by deriving confidence limits for each damage function and statistically aggregating them to yield confidence bands of total damages. To do so requires calculations and data requirements beyond the scope of this study. However, an approximate range is derivable by a straightforward method.

Extra soap costs due to hardness contribute almost two-thirds of total damages. From above referenced surveys, per capita costs for every 100 ppm increase in hardness vary from $1.55 to $8.21. If this range is applied to national estimates, total damages from hardness are between $0.43 and $2.27 billion with a mean of $1.15 billion. Standard errors of regressions for other household units also show a large spread about the mean. Assuming the same proportionate range as hardness-related costs, total U.S. damages are within $0.65 - $3.45 billion. On a per capita basis, the corresponding range is $3.21 - $17.06 given a mean of $8.63.

SECTION IX

SPECIAL WATER QUALITY CONSIDERATIONS

The above benefits are based on typical water quality observations, which are generally within recommended TDS standards of 500 ppm. It is thus unlikely that damaging agents in these water supplies will be removed in municipal plants unless benefit-cost comparisons show otherwise. Consequently, these benefits will probably not be realized in the near future. On the other hand, U.S. communities whose public water supplies contain TDS in excess of mandatory limits of 1,000 ppm are monitored (Patterson and Banker, 1970) if their population exceeds 1,000. Because these concentrations are so high, they are prime candidates for special treatment or control.

Economic damages for these communities are estimated by above methods, where TDS levels in each community are weighted by population served. Hardness levels in state calculations are assumed, although levels in these communities are probably higher. This assumption contributes, of course, to an underestimate of total damages.

Economic damages to these communities are in the range, \$8.2 - \$43.5 million with a mean of \$22.0 million (at 7.5% interest). The number of people served is slightly over 900,000, which gives per capita damages of \$9.09 - \$48.26 with an average of \$24.41. These estimates assume complete removal of water quality constituents.

The average benefits realized by meeting TDS limits of 500 ppm are almost $10.00 per individual. For the nation these savings amount to $8.9 million. This total is probably quite low since communities with fewer than 1,000 people are not added in the calculations.

SECTION X

MAN-MADE AND NATURAL RESOURCES

Although minerals reduction prior to domestic water use could provide worthwhile benefits in many states, controls may ultimately depend upon non-economic factors. Of primary concern is the identification of sources of mineral loads as they contribute to the extent of water pollution. Some policymakers define pollution as "the impairment of water quality with resultant significant interference with beneficial water use" (Haney, 1966). To them, minerals are classified as pollutants irrespective of their origin. There are others, however, who view pollution more narrowly in terms of its impacts "as a result of man's domestic, industrial, agricultural, and recreational activities" (Kneese, and Bower, 1968). Equivalently, this concept refers to the incremental minerals content above natural background levels.

Damage estimates in Figure 7 pertain to the former definition of minerals pollution, since they are based on total ambient water quality conditions. To isolate man-made damages and thus to satisfy the latter definition, one is faced with the complex task of tracing the flow of minerals in natural waters. If the relative magnitude of these sources cannot be identified, then it is unlikely that the economic impact of controlling waste discharges (from human activities) can be properly assessed.

Minerals and salts enter surface waters from a variety of sources. Man contributes his share chiefly through irrigation, although salt de-icing of streets, domestic routines such as washing and laundering, and industrial waste emissions add to this burden. In some regions, mining and oil drilling operations extract large quantities of brackish water from aquifers and discharge them onto the surface. Natural origins of minerals are traced to springs, seepages, and runoffs from heavy precipitation or melting snow. By itself, spring runoff often accounts for greater mineral loads than all other natural and man-made sources combined.

With respect to groundwater aquifers, very little evidence points toward causal factors of mineral quality. Sources of constituents vary from direct flow through wells and springs, percolation of water supply from surface and near-surface locations, and intrusion of salt water along the coastal belt. Man-made causes include leaking sewers and pipelines, deep well waste disposal, and losses from waste-storage lagoons, in addition to infiltration from mineralized surface waters. But natural leaching and filtration processes generally reduce their potential threat to aquifers, although there are many exceptions to this rule.

Empirically reliable surveys of mineral quality trends in water bodies are indeed rare. Past studies have alluded to such changes, but until recently there was no segregation of changes due to human activities and normal fluctuations in hydrologic patterns. Within most areas, historical data on these trends are non-existent. Moreover, non-point discharges of minerals, e.g., spring runoff, are difficult to monitor.

A trend analysis of mineral loads was conducted for the Colorado River Basin (EPA, 1971). It was found that in the Upper Basin, irrigation is responsible for 37 percent of the TDS load, while domestic and industrial (mining) water uses introduce barely 2 percent. The remaining 61 percent originates from net runoff and, to a lesser extent, natural springs and wells. The Lower Basin derives almost the same proportion, 38 percent, from man-related sources. In this arid region, however, runoff is less important than natural point sources. In another study, TDS levels were investigated for the Passaic River in New Jersey (Anderson and Faust. 1965). These findings indicate that municipal and industrial waste discharges contribute, on the average, at least 30 percent of dissolved solids. Natural sources are primarily from weathering or dissolution of soils and rocks over which water passes, as well as overland runoff and some groundwater inflow to streams.

Trend analyses of subsurface mineralization are usually qualitative because of uncertainties in tracing groundwater movement. Most surveys in the West conclude that natural processes account for an overwhelming share of mineral content, although irrigation and oil field brine disposal cause localized problems (Fukriman and Barton, 1971). Near towns in Massachusetts, road salts were blamed for more than 50 percent of the minerals level of groundwater supplies (Huling and Hollocher, 1972). In general, however, man's role in contaminating these supplies is minimized by adsorption, dilution, and microbial degradation of minerals as they pass through the soil and into subsurface aquifers. Supporting this observation, a nationwide survey of aquifers located beneath waste disposal sites revealed that only 10 percent of them were polluted (Stone and Friedland, 1973). Similar studies in Illinois, California, and South Dakota concluded that high concentrations of groundwater hardness were confined close to these sites, while little proof of man's influence was found elsewhere (Stone and Friedland, 1969).

On the basis of these literature references, a rough estimate can be derived for man-induced damages to household water use. For all surface water supplies, the man-made proportion of minerals content is assumed to average 30 percent, which is conservative with respect to above references of 30+, 38 and 39 percent in river basins. On the other hand, infiltration of groundwater supplies is assumed to add only 10 percent to natural levels. Near population centers and mining areas, the proportion is probably higher, but to counteract this trend, man's input to other regions is likely to be minor.

These assumptions are then applied to previously derived national estimates of total damages in order to approximate man-related impacts. Annual damages pertaining to surface water supplies totalled $600 million in 1970; thus the man-induced portion is 30 percent, or equivalently $180 million. For private or public groundwater supplies, similar calculations give $115 million. Together, these estimates imply almost $300 million per year as the most likely value of marginal damages to all U. S. households. The actual value lies somewhere in the interval between $110 and $590 million. This assessment is based on complete removal of minerals generated by human activities. Almost directly proportional to the degree of removal, this estimate can be adjusted to reflect partial treatment. For example, a 20 percent reduction of TDS and hardness levels in waste emissions would yield incremental benefits of $60 million for domestic water users.

SECTION XI

CONCLUDING REMARKS

This study presented damage estimates for the residential use of water. First, the literature was culled, and methods for calculating damages were evaluated. Next, based on these results, a computational algorithm was derived to predict household benefits from water quality enhancement. Last, state and national estimates were predicted for various discount rates and sources of water supply. Total damages to U.S. households are in the range, $0.65 to $3.45 billion. The mean estimate is almost $1.75 billion, of which $0.66 billion is attributed to treated ground water supplies, $0.59 billion to surface water bodies, and $0.49 to privately owned wells (and, in a few instances, local streams). Hardness is the most damaging water constituent, costing $1.14 billion annually compared to $0.61 billion for total dissolved solids. Every 10% improvement of water quality increases national benefits by approximately $175 million. Average damages to the individual exceed $8.50. The typical rural resident on well water, however, faces $12.23 in damages, compared to $5.75 for the majority of urban residents supplied with surface water. On an individual state basis, per capita damages are highest in the Southwest (Arizona, $22.18) and the Midwest (Illinois, $18.24), but lowest in the Southeast (South Carolina, $1.12), New England (Massachusetts, $2.14), and the Northwest (Oregon, $1.69). Total damages, proportional to population, are highest in California ($225.7 million), Illinois ($163.3 million), and Texas ($126.6 million).

These estimates are conservative since they neglect household expenses for lawn irrigation, disposal of water softening salts and other residues, swimming pool maintenance, extra purchase of dishes, etc. Municipal water quality data were selected for the largest cities, which usually have cleaner water than small towns. The recent Patterson and Banker survey (1969) lists over 400 small U.S. communities whose public water supplies contain more than 1,000 ppm TDS. Only the major water quality factors, TDS and hardness, are assessed in this study. A more complete analysis would include other damaging agents, such as chlorides, iron, and acidity.

SECTION XII

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The opinions expressed in this paper are those of the author and do not represent the official position of the Environmental Protection Agency.

SECTION XIII

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SECTION XIV

APPENDIX

COMPUTER PROGRAM

AND

INPUT DATA

COMPUTER PROGRAM

```
FORTRAN IV G LEVEL  20                MAIN              DATE = 72310          15/33/29                 PAGE 0001
              C      PURPOSE...
              C           CALCULATE 1970 BENEFITS, BY STATE AND BY DISCOUNT RATE, FOR
              C           HOUSEHOLD USE OF WATER SUPPLY AT VARIOUS QUALITIES.
              C           DISTINGUISH USAGE OF TREATED SURFACE, TREATED GROUND, AND
              C           PRIVATE WELL WATER SOURCES.
 0001                DIMENSION BEN(19,2,51,3,2),INCOME(52),POPUL(52),USBEN(4,11),
                    1FAMILY(52),STBEN(52,4),X(51,3),Y(51,3),SUPPLY(52,4),STATE(52,4),
                    2STCCST(52,4),SOURCE(4,4),USHARD(4,11),USTDS(4,11)
 0002                REAL N,NX,INCOME
              C      CAPITAL RECOVERY FACTOR...
 0003                ALPHA(RX,NX)=(RX*(1.+RX)**NX)/((1.+RX)**NX-1.)
              C      INPUT DATA...
              C           X(I,J)=TDS IN STATE I FROM WATER SUPPLY SOURCE J,
              C           Y(I,J)=HARDNESS IN STATE I FROM WATER SUPPLY SOURCE J,
              C           INCOME(I)=INCOME IN STATE I  (=52 FOR U.S.),
              C           POPUL(I)=POPULATION IN STATE I,
              C           FAMILY(I)=FAMILY POPULATION IN STATE I,
              C           SUPPLY(I,J)=PERCENTAGE OF STATE I POPULATION USING SOURCE J.
 0004                DO 50 I=1,52
 0005                READ(5,1020)  (STATE(I,L),L=1,4),INCOME(I),POPUL(I),FAMILY(I),
                    1(SUPPLY(I,J),J=1,3)
 0006             50 CONTINUE
 0007                DO 60 I=1,51
 0008                READ(5,1010)  (X(I,J),J=1,3),(Y(I,J),J=1,3)
 0009             60 CONTINUE
 0010           1010 FORMAT(20X,6F10.1)
 0011           1020 FORMAT(4A4,4X,3F10.0,2PF10.1,2PF10.1,2PF10.1)
 0012                READ(5,1025)  ((SOURCE(J,L),L=1,4),J=1,4)
 0013           1025 FORMAT(4(4X,4A4))
              C      INITIALIZE DISCOUNT RATE...
 0014                R=.025
              C      CALCULATE ALL BENEFITS USING VARIOUS DISCOUNT RATES...
 0015                DO 950 IP=1,3
 0016                R=R+.025
              C      BENEFITS BY DEGREE OF WATER QUALITY IMPROVEMENT...
 0017                DO 400 IPART=1,11
 0018                IF(IPART.EQ.1) IP=1
 0019                IF(IPART.GT.1) IP=2
 0020                PCT=110-10*IPART
              C      BENEFITS BY SUPPLY SOURCE...
 0021                DO 380 J=1,3
 0022                DO 300 I=1,51
 0023                XPART=X(I,J)*PCT/100.
 0024                YPART=Y(I,J)*PCT/100.
              C      ANNUALIZED CAPITAL COSTS BY HOUSEHOLD UNIT...
 0025                ADJ=INCOME(I)/INCOME(52)
 0026                N=12.+EXP(3.40555)*EXP(-.00179*XPART)
 0027                BEN(1,1,I,J,IP)=250.*1.120*ALPHA(R,N)*ADJ*SUPPLY(I,J)
 0028                N=10.+EXP(3.78496)*EXP(-.00064*XPART)
 0029                BEN(2,1,I,J,IP)=450.*1.120*ALPHA(R,N)*ADJ*SUPPLY(I,J)
 0030                N=5.+EXP(2.42483)*EXP(-.00139*XPART)
 0031                BEN(3,1,I,J,IP)=110.*1.050*ALPHA(R,N)*ADJ*SUPPLY(I,J)
 0032                N=-.00275*XPART+11.5
 0033                BEN(4,1,I,J,IP)=165.*1.116*ALPHA(R,N)*ADJ*SUPPLY(I,J)
 0034                N=2.+EXP(2.39903)*EXP(-.00145*XPART)
 0035                BEN(5,1,I,J,IP)=20.*1.116*ALPHA(R,N)*ADJ*SUPPLY(I,J)
 0036                N=5.+EXP(1.55815)*EXP(-.00116*XPART)
 0037                BEN(6,1,I,J,IP)=8.*1.050*ALPHA(R,N)*ADJ*SUPPLY(I,J)
```

```
0038          N=5.+EXP(1.82445)*EXP(-.00079*XPART)
0039          BEN(7,1,I,J,IP)=120.*1.050*ALPHA(R,N)*ADJ*SUPPLY(I,J)
0040          N=-.0007*XPART+10.1750
0041          BEN(8,1,I,J,IP)=20.*1.050*ALPHA(R,N)*ADJ*SUPPLY(I,J)
0042          N=-.00013*XPART+4.6333
0043          BEN(9,1,I,J,IP)=1080.*1.082*ALPHA(R,N)*ADJ*SUPPLY(I,J)
0044          N=-.0033*XPART+30.8333
0045          BEN(10,1,I,J,IP)=120.*1.120*ALPHA(R,N)*ADJ*SUPPLY(I,J)
0046          N=60.+EXP(3.91927)*EXP(-.00091*XPART)
0047          BEN(11,1,I,J,IP)=450.*1.120*ALPHA(R,N)*ADJ*SUPPLY(I,J)
0048          N=-.0033*XPART+50.8333
0049          BEN(12,1,I,J,IP)=60.*1.120*ALPHA(R,N)*ADJ*SUPPLY(I,J)
0050          N=-.0067*XPART+46.6667
0051          BEN(13,1,I,J,IP)=100.*1.120*ALPHA(R,N)*ADJ*SUPPLY(I,J)
0052          N=-.0020*XPART+30.5
0053          BEN(14,1,I,J,IP)=40.*1.120*ALPHA(R,N)*ADJ*SUPPLY(I,J)
0054          N=-.0033*XPART+30.8333
0055          BEN(15,1,I,J,IP)=90.*1.120*ALPHA(R,N)*ADJ*SUPPLY(I,J)
0056          BEN(16,1,I,J,IP)=0.
0057          BEN(17,1,I,J,IP)=0.
0058          N=12.
0059          BEN(18,1,I,J,IP)=.0007*YPART*300.*1.000*ALPHA(R,N)*ADJ*SUPPLY(I,J)
0060          BEN(19,1,I,J,IP)=0.
        C     ANNUAL OPERATION AND MAINTENANCE COSTS BY HOUSEHOLD UNIT...
0061          BEN(1,2,I,J,IP)=1.120*(.00113*XPART+2.01667)*ADJ*SUPPLY(I,J)
0062          BEN(2,2,I,J,IP)=1.120*(.0007*XPART+1.6250)*ADJ*SUPPLY(I,J)
0063          BEN(3,2,I,J,IP)=1.050*(.00127*XPART+16.8117)*ADJ*SUPPLY(I,J)
0064          BEN(4,2,I,J,IP)=1.116*(.0007*XPART+1.6250)*ADJ*SUPPLY(I,J)
0065          BEN(5,2,I,J,IP)=1.116*(.00157*XPART+.6083)*ADJ*SUPPLY(I,J)
0066          BEN(6,2,I,J,IP)=1.050*(.00005*XPART+.1125)*ADJ*SUPPLY(I,J)
0067          BEN(7,2,I,J,IP)=1.050*(.00102*XPART+3.345)*ADJ*SUPPLY(I,J)
0068          BEN(8,2,I,J,IP)=0.
0069          BEN(9,2,I,J,IP)=0.
0070          BEN(10,2,I,J,IP)=1.120*(.00031*XPART+4.5225)*ADJ*SUPPLY(I,J)
0071          BEN(11,2,I,J,IP)=1.120*(.00115*XPART+3.1633)*ADJ*SUPPLY(I,J)
0072          BEN(12,2,I,J,IP)=1.120*(.00063*XPART+.34167)*ADJ*SUPPLY(I,J)
0073          BEN(13,2,I,J,IP)=0.
0074          BEN(14,2,I,J,IP)=1.120*(.00023*XPART+.5917)*ADJ*SUPPLY(I,J)
0075          BEN(15,2,I,J,IP)=1.120*(.00023*XPART+3.3919)*ADJ*SUPPLY(I,J)
0076          BEN(16,2,I,J,IP)=1.082*(.0027*XPART+11.6500)*ADJ*SUPPLY(I,J)
0077          BEN(17,2,I,J,IP)=1.000*EXP(-3.72725)*(XPART**.80420)*ADJ*SUPPLY(I,
             1J)
0078          BEN(18,2,I,J,IP)=1.000*.1594*YPART*(.0007*YPART)*ADJ*SUPPLY(I,J)
0079          BEN(19,2,I,J,IP)=1.000*(.1578*YPART*(1.0-.0007*YPART)+11.6500)*
             1ADJ*SUPPLY(I,J)
0080      300 CONTINUE
        C     NATIONAL BENEFITS SUMMED OVER STATE BENEFITS...
0081          USBEN(J,IPART)=0.
0082          USHARD(J,IPART)=0.
0083          IF(IPART.EQ.1) GO TO 360
0084          DO 350 ICOST=1,2
0085          DO 350 I=1,51
0086          DO 340 IUNIT=1,19
        C     MARGINAL BENEFITS OF CLEANUP RELATIVE TO POOREST WATER QUALITY...
0087          USBEN(J,IPART)=(BEN(IUNIT,ICOST,I,J,1)-BEN(IUNIT,ICOST,I,J,2))*
             1FAMILY(I)+USBEN(J,IPART)
0088      340 CONTINUE
0089          USHARD(J,IPART)=(BEN(18,ICOST,I,J,1)+BEN(19,ICOST,I,J,1)-
```

```
     1BEN(18,ICOST,I,J,2)-BEN(19,ICOST,I,J,2))*FAMILY(I)+USHARD(J,IPART)
 350 CONTINUE
     USTDS(J,IPART)=USBEN(J,IPART)-USHARD(J,IPART)
     GO TO 380
 360 CONTINUE
     DO 370 ICOST=1,2
     DO 370 I=1,51
     DO 365 IUNIT=1,19
C    TOTAL DAMAGES OF USING POOREST WASTER QUALITY...
     USBEN(J,IPART)=BEN(IUNIT,ICOST,I,J,1)*FAMILY(I)+USBEN(J,IPART)
 365 CONTINUE
     USHARD(J,IPART)=(BEN(18,ICOST,I,J,1)+BEN(19,ICOST,I,J,1))*
    1FAMILY(I)+USHARD(J,IPART)
 370 CONTINUE
     USTDS(J,IPART)=USBEN(J,IPART)-USHARD(J,IPART)
 380 CONTINUE
     USBEN(4,IPART)=0.
     USHARD(4,IPART)=0.
     USTDS(4,IPART)=0.
     DO 390 J=1,3
     USBEN(4,IPART)=USBEN(J,IPART)+USBEN(4,IPART)
     USHARD(4,IPART)=USHARD(J,IPART)+USHARD(4,IPART)
     USTDS(4,IPART)=USTDS(J,IPART)+USTDS(4,IPART)
 390 CONTINUE
 400 CONTINUE
C    STATE-BY-STATE COMPARISON OF BENEFITS...
     STCOST(52,4)=0.
     STBEN(52,1)=0.
     STBEN(52,2)=0.
     STBEN(52,3)=0.
     STBEN(52,4)=0.
     DO 520 I=1,51
     DO 500 J=1,3
     STCOST(I,J)=0.
     STBEN(I,J)=0.
     DO 500 IUNIT=1,19
     DO 500 ICOST=1,2
     STCOST(I,J)=BEN(IUNIT,ICOST,I,J,1)*FAMILY(I)+STCOST(I,J)
     STBEN(I,J)=(BEN(IUNIT,ICOST,I,J,1)-BEN(IUNIT,ICOST,I,J,2))*
    1FAMILY(I)+STBEN(I,J)
 500 CONTINUE
     STCOST(I,4)=STCOST(I,1)+STCOST(I,2)+STCOST(I,3)
     STBEN(I,4)=STBEN(I,1)+STBEN(I,2)+STBEN(I,3)
C    COMPUTE STATE BENEFIT TOTALS...
     STCOST(52,4)=STCOST(I,4)+STCOST(52,4)
     STBEN(52,1)=STBEN(I,1)+STBEN(52,1)
     STBEN(52,2)=STBEN(I,2)+STBEN(52,2)
     STBEN(52,3)=STBEN(I,3)+STBEN(52,3)
     STBEN(52,4)=STBEN(I,4)+STBEN(52,4)
 520 CONTINUE
     IF(R.GT..05) GO TO 800
C    PRINT INPUT DATA REQUIREMENTS...
     WRITE(6,1050)
1050 FORMAT(1H1,60X,'INPUT DATA',/////,52X,'WATER SUPPLY SOURCE (PCT)',
    16X,'TDS IN SOURCE (PPM)',4X,'HARD. IN SOURCE (PPM)',/,8X,'STATE'
    2,7X,'POPULATION',2X,'FAMILIES',2X,'INCOME',3X,'SURFACE',2X,
    3'TR.GROUND',1X,'RAW WELL',4X,'SURF.',2X,'TR.GR.',2X,'RAW WL.',2X,
    4'SURF.',2X,'TR.GR.',2X,'RAW WL.',/)
```

```
0137            DO 700 I=1,52
0138            IF(I.EQ.52) WRITE(6,1060) (STATE(I,L),L=1,4),POPUL(I),FAMILY(I),
               1INCOME(I),(SUPPLY(I,J),J=1,3)
0139            IF(I.EQ.52) GO TO 700
0140            WRITE(6,1070) (STATE(I,L),L=1,4),POPUL(I),FAMILY(I),INCOME(I),
               1(SUPPLY(I,J),J=1,3),(X(I,J),J=1,3),(Y(I,J),J=1,3)
0141        700 CONTINUE
0142       1060 FORMAT(/,3X,4A4,1X,F10.0,1X,F9.0,2X,F6.0,4X,2PF4.1,7X,F4.1,5X,
               1F4.1)
0143       1070 FORMAT(3X,4A4,1X,F10.0,1X,F9.0,2X,F6.0,4X,2PF4.1,7X,F4.1,5X,F4.1,
               15X,0PF5.1,5(3X,F5.1))
0144        800 CONTINUE
          C     PRINT BENEFIT ESTIMATES FOR EACH DISCOUNT RATE...
          C     LIST BENEFITS BY STATE...
0145            WRITE(6,1080) R
0146       1080 FORMAT(1H1,42X,'HOUSEHOLD DAMAGES OF WATER SUPPLY USE BY STATE',
               1/,61X,'FOR 1970',
               1//,55X,'DISCOUNT RATE = ',F4.3,///,26X,'HOUSEHLD EXPND',11X,
               1'TOTAL DAMAGES ($1 M) BY SOURCE',14X,'PER CAPITA DAMAGES ($) BY SO
               2URCE',/,8X,'STATE',11X,'TOTAL',3X,'PER CAPITA',4X,'SURFACE',3X,
               3'TR.GROUND',3X,'RAW WELL',5X,'TOTAL',5X,'SURFACE',3X,'TR.GROUND',
               43X,'RAW WELL',5X,'TOTAL',/)
0147            DO 810 I=1,52
0148            COS4PC=STCOST(I,4)/POPUL(I)
0149            BEN1PC=STBEN(I,1)/(POPUL(I)*SUPPLY(I,1))
0150            BEN2PC=STBEN(I,2)/(POPUL(I)*SUPPLY(I,2))
0151            BEN3PC=STBEN(I,3)/(POPUL(I)*SUPPLY(I,3))
0152            BEN4PC=STBEN(I,4)/POPUL(I)
0153            WRITE(6,1090) (STATE(I,L),L=1,4),STCOST(I,4),COS4PC,STBEN(I,1),
               1STBEN(I,2),STBEN(I,3),STBEN(I,4),BEN1PC,BEN2PC,BEN3PC,BEN4PC
0154        810 CONTINUE
0155       1090 FORMAT(4X,4A4,2X,-6PF7.1,3X,0PF7.2,6X,-6PF7.1,4X,F7.1,4X,F7.1,
               15X,F7.1,4X,0PF7.2,3(4X,F7.2))
          C     LIST BENEFITS FOR THE UNITED STATES...
0156            WRITE(6,1100) R
0157       1100 FORMAT(1H1,41X,'HOUSEHOLD BENEFITS OF WATER SUPPLY TREATMENT IN TH
               1E U.S.',/,60X,'FOR 1970',
               1//,55X,'DISCOUNT RATE = ',F4.3,///,22X,'TOTAL',/,21X,
               2'HOUSEHLD',16X,'TOTAL BENEFITS ($1 M) AT VARIOUS LEVELS (PCT) OF W
               3ATER QUALITY IMPROVEMENT',/,3X,'SUPPLY SOURCE',5X,'EXPND',5X,'10%'
               4,7X,'20%',7X,'30%',7X,'40%',7X,'50%',7X,'60%',7X,'70%',7X,'80%',
               57X,'90%',6X,'100%',/)
0158            WRITE(6,1130)
0159       1130 FORMAT(//,' TDS AND HARDNESS')
0160            DO 850 J=1,4
0161            WRITE(6,1110) (SOURCE(J,L),L=1,4),(USBEN(J,IPART),IPART=1,11)
0162        850 CONTINUE
0163            WRITE(6,1160)
0164       1160 FORMAT(//,' TDS ONLY')
0165            DO 860 J=1,4
0166            WRITE(6,1110) (SOURCE(J,L),L=1,4),(USTDS(J,IPART),IPART=1,11)
0167        860 CONTINUE
0168            WRITE(6,1170)
0169       1170 FORMAT(//,' HARDNESS ONLY')
0170            DO 870 J=1,4
0171            WRITE(6,1110) (SOURCE(J,L),L=1,4),(USHARD(J,IPART),IPART=1,11)
0172        870 CONTINUE
0173            WRITE(6,1150) R
```

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0174      1150 FORMAT(1H1,36X,'HOUSEHOLD BENEFITS OF WATER SUPPLY TREATMENT IN TH
              1E U.S.',/,60X,'FOR 1970',
              1//,55X,'DISCOUNT RATE = ',F4.3,///,18X,'PER CAPITA',/,
              219X,'HOUSEHLD',12X,'PER CAPITA BENEFITS ($) AT VARIOUS LEVELS (PCT
              3) OF WATER QUALITY IMPROVEMENT',/,3X,'SUPPLY SOURCE',5X,'EXPND',
              45X,'10%',7X,'20%',7X,'30%',7X,'40%',7X,'50%',7X,'60%',7X,'70%',7X,
              5'80%',7X,'90%',6X,'100%',/)
0175            WRITE(6,1130)
0176            DO 900 J=1,4
0177            IF(J.EQ.4) SUPPLY(52,J)=1.00
0178            DO 890 IPART=1,11
0179            USBEN(J,IPART)=USBEN(J,IPART)/(POPUL(52)*SUPPLY(52,J))
0180            USHARD(J,IPART)=USHARD(J,IPART)/(POPUL(52)*SUPPLY(52,J))
0181            USTDS(J,IPART)=USTDS(J,IPART)/(POPUL(52)*SUPPLY(52,J))
0182       890 CONTINUE
0183      1110 FORMAT(2X,4A4,1X,-6PF7.1,11(3X,-6PF7.1))
0184            WRITE(6,1120) (SOURCE(J,L),L=1,4),(USBEN(J,IPART),IPART=1,11)
0185       900 CONTINUE
0186      1120 FORMAT(2X,4A4,1X,F7.2,11(3X,F7.2))
0187            WRITE(6,1160)
0188            DO 910 J=1,4
0189            WRITE(6,1120) (SOURCE(J,L),L=1,4),(USTDS(J,IPART),IPART=1,11)
0190       910 CONTINUE
0191            WRITE(6,1170)
0192            DO 920 J=1,4
0193            WRITE(6,1120) (SOURCE(J,L),L=1,4),(USHARD(J,IPART),IPART=1,11)
0194       920 CONTINUE
0195       950 CONTINUE
0196            END
```

INPUT DATA FOR DAMAGE CALCULATIONS

STATE	POPULATION	FAMILIES	INCOME ($)	WATER SUPPLY SOURCE (PCT) SURFACE	TR.GROUND	RAW WELL
MAINE	992048	248154	9045	58.1	14.9	27.0
MASSACHUSETTS	5689170	1390982	12238	65.7	24.3	10.0
VERMONT	444330	107411	10099	41.2	21.8	37.0
NEW HAMPSHIRE	737681	183825	10776	38.0	35.0	27.0
CONNECTICUT	3031709	767651	13795	63.3	19.7	17.0
RHODE ISLAND	946725	236667	11041	67.4	22.6	10.0
NEW YORK	18236960	4609638	12491	67.3	22.7	10.0
NEW JERSEY	7168164	1838809	13025	34.3	30.7	35.0
DIST. COLUMBIA	756510	163482	12189	95.0	0.0	5.0
PENNSYLVANIA	11793909	3011130	10877	74.0	12.0	14.0
WEST VIRGINIA	1744237	454493	8195	51.4	24.6	24.0
MARYLAND	3922399	974143	12682	75.8	10.2	14.0
VIRGINIA	4648494	1162256	10568	62.2	9.8	28.0
DELAWARE	548104	136915	11771	39.5	44.5	16.0
KENTUCKY	3218706	825222	8560	57.6	9.4	33.0
TENNESSEE	3923687	1024446	8619	45.8	28.2	26.0
MISSISSIPPI	2216912	534444	7292	11.5	63.5	25.0
ALABAMA	3444165	874659	8412	48.7	26.3	25.0
GEORGIA	4589575	1149771	9491	42.2	25.8	32.0
NORTH CAROLINA	5082059	1292466	8872	42.2	13.8	44.0
SOUTH CAROLINA	2590516	628689	8577	65.6	14.4	20.0
FLORIDA	6789443	1811367	10120	8.2	66.8	25.0
OHIO	10652017	2691130	11488	53.7	22.3	24.0

INPUT DATA (continued).

STATE	POPULATION	FAMILIES	INCOME ($)	WATER SUPPLY SOURCE (PCT) SURFACE	TR.GROUND	RAW WELL
INDIANA	5193669	1321674	10959	39.9	30.1	30.0
ILLINOIS	11113976	2794194	12338	50.9	29.1	20.0
MICHIGAN	8875083	2190269	12296	64.1	15.9	20.0
WISCONSIN	4417731	1077475	11135	35.3	34.7	30.0
MINNESOTA	3804971	921332	11098	34.1	40.9	25.0
ARKANSAS	1923295	505195	7459	32.3	30.7	37.0
LOUISIANA	3641306	872772	8799	41.2	38.8	20.0
OKLAHOMA	2559229	679256	9100	58.0	22.0	20.0
TEXAS	11196730	2818123	9955	47.4	46.6	6.0
NEW MEXICO	1016000	242740	9193	6.3	60.7	33.0
MISSOURI	4676501	1204751	10236	61.0	19.0	20.0
IOWA	2824376	717776	10138	20.0	60.0	20.0
NEBRASKA	1483493	374160	9792	15.1	64.9	20.0
KANSAS	2246578	581849	10063	40.1	39.9	20.0
NORTH DAKOTA	617761	148235	9086	31.8	29.2	39.0
SOUTH DAKOTA	665507	161941	8795	15.4	34.6	50.0
MONTANA	694409	171812	9662	48.3	20.7	31.0
WYOMING	332416	84703	10127	36.0	39.0	25.0
UTAH	1059273	249741	10428	32.4	36.6	31.0
COLORADO	2207259	547165	10875	76.1	13.9	10.0
CALIFORNIA	19953120	5001255	12227	54.4	40.6	5.0
ARIZONA	1770900	438389	10501	26.5	51.5	22.0
NEVADA	488783	124170	11872	33.1	49.9	17.0
HAWAII	768561	170729	13077	3.5	71.5	25.0
WASHINGTON	3409169	862542	11511	55.0	33.0	12.0
OREGON	2091385	542483	10695	52.8	22.2	25.0
IDAHO	712567	179448	9455	9.2	59.8	31.0
ALASKA	300382	66670	13056	27.9	27.1	45.0

INPUT DATA (continued).

STATE	TDS IN SOURCE (PPM) SURF.	TR.GR.	RAW WL.	HARD, IN SOURCE (PPM) SURF.	TR.GR.	RAW WL.
MAINE	33.0	89.0	144.0	20.0	62.0	103.0
MASSACHUSETTS	27.0	93.0	158.0	11.0	47.0	82.0
VERMONT	64.0	95.0	126.0	51.0	67.0	82.0
NEW HAMPSHIRE	36.0	106.0	175.0	12.0	50.0	87.0
CONNECTICUT	59.0	105.0	151.0	33.0	51.0	68.0
RHODE ISLAND	51.0	64.0	72.0	30.0	30.0	30.0
NEW YORK	64.0	283.0	177.0	40.0	191.0	106.0
NEW JERSEY	71.0	121.0	121.0	42.0	67.0	67.0
DIST. COLUMBIA	201.0	201.0	201.0	135.0	135.0	135.0
PENNSYLVANIA	136.0	184.0	232.0	81.0	141.0	201.0
WEST VIRGINIA	117.0	190.0	262.0	70.0	118.0	166.0
MARYLAND	89.0	104.0	118.0	57.0	51.0	44.0
VIRGINIA	100.0	130.0	160.0	59.0	101.0	142.0
DELAWARE	89.0	191.0	191.0	48.0	101.0	103.0
KENTUCKY	202.0	227.0	251.0	101.0	148.0	195.0
TENNESSEE	123.0	83.0	96.0	83.0	40.0	67.0
MISSISSIPPI	95.0	124.0	153.0	45.0	43.0	40.0
ALABAMA	119.0	132.0	144.0	69.0	66.0	63.0
GEORGIA	44.0	91.0	151.0	23.0	50.0	124.0
NORTH CAROLINA	69.0	110.0	151.0	42.0	55.0	68.0
SOUTH CAROLINA	52.0	62.0	72.0	17.0	13.0	8.0
FLORIDA	212.0	250.0	235.0	148.0	123.0	171.0
OHIO	196.0	190.0	420.0	114.0	107.0	337.0
INDIANA	263.0	419.0	382.0	195.0	350.0	327.0
ILLINOIS	157.0	291.0	460.0	128.0	279.0	347.0

INPUT DATA (continued).

STATE	TDS IN SOURCE (PPM) SURF.	TR.GR.	RAW WL.	HARD. IN SOURCE (PPM) SURF.	TR.GR.	RAW WL.
MICHIGAN	136.0	198.0	260.0	100.0	162.0	224.0
WISCONSIN	162.0	303.0	331.0	129.0	289.0	289.0
MINNESOTA	112.0	205.0	298.0	65.0	166.0	267.0
ARKANSAS	40.0	155.0	270.0	21.0	72.0	123.0
LOUISIANA	185.0	231.0	215.0	78.0	2.0	31.0
OKLAHOMA	223.0	418.0	664.0	147.0	138.0	314.0
TEXAS	238.0	429.0	706.0	102.0	178.0	205.0
NEW MEXICO	250.0	604.0	873.0	73.0	263.0	408.0
MISSOURI	207.0	488.0	488.0	75.0	236.0	236.0
IOWA	244.0	393.0	542.0	108.0	233.0	357.0
NEBRASKA	382.0	312.0	428.0	144.0	177.0	263.0
KANSAS	374.0	325.0	504.0	163.0	121.0	301.0
NORTH DAKOTA	314.0	602.0	890.0	131.0	130.0	129.0
SOUTH DAKOTA	196.0	596.0	994.0	86.0	206.0	325.0
MONTANA	193.0	364.0	535.0	115.0	110.0	104.0
WYOMING	200.0	202.0	500.0	123.0	169.0	301.0
UTAH	224.0	548.0	492.0	183.0	216.0	310.0
COLORADO	136.0	200.0	937.0	77.0	100.0	495.0
CALIFORNIA	254.0	382.0	380.0	105.0	146.0	170.0
ARIZONA	720.0	730.0	550.0	239.0	307.0	254.0
NEVADA	91.0	235.0	256.0	40.0	206.0	187.0
HAWAII	211.0	211.0	211.0	60.0	60.0	60.0
WASHINGTON	41.0	141.0	118.0	21.0	127.0	83.0
OREGON	22.0	99.0	99.0	5.0	41.0	41.0
IDAHO	136.0	208.0	350.0	102.0	131.0	210.0
ALASKA	100.0	146.0	146.0	67.0	114.0	114.0

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SELECTED WATER RESOURCES ABSTRACTS

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1. Report No. | 2 | W

"Economic Damages to Household Items from Water Supply Use"

5. Report Date

6

8. Performing Organization Report No

Dennis P. Tihansky

Economic Analysis Branch
Washington Environmental Research Center
Office of Research and Development

13. Type of Report and Period Covered

12. Sponsoring Organization U.S. Environmental Protection Agency

Environmental Protection Agency report number, EPA-600/5-73-001, July 1973.

Household appliances and personal items in contact with water supply are subject to physical damages from chemical and other constituents of the water. This study translates these damages into economic losses for a typical household. Then it aggregates these losses at the national and individual state levels. To do so requires several stages of analysis. First, the types of physical damages expected and associated water quality determinants are identified. The physical effects are next translated into economic losses. Second, damage functions are formulated to predict likely impacts of water quality changes on each household unit affected. Third, a computer program based on these functions is designed to estimate total damages per typical household and to aggregate them over selected regions. Finally, the program is applied to state-to-state data on water supply sources and socioeconomic descriptors. Total damages to U.S. residents in 1970 are estimated in the range, \$0.65-\$3.45 billion, with a mean of \$1.75 billion. The mean translates into \$8.60 per person. States contributing most to total damages are California (\$230 million) and Illinois (\$164 million). On a per capita basis Arizona (\$22.53) and New Mexico (\$18.58) rank highest, whereas South Carolina (\$1.15) and Oregon (\$1.73) are at the other end of the spectrum. When per capita damages are compared by source of water supply, those from private wells are worst at an average of \$12.34, treated ground next at \$11.20, and treated surface water sources at only \$5.83. This report was funded under Program Element 1H1094 of the Office of Research and Development, Washington Environmental Research Center, Economic Analysis Branch, E.P.A.

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