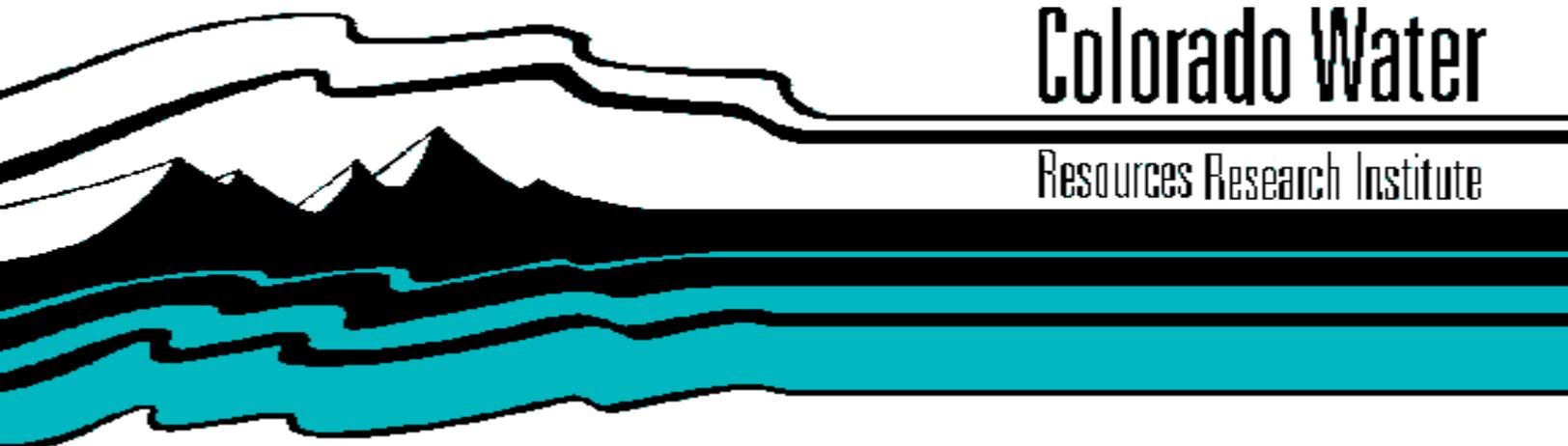


**URBAN WATER SUPPLY RELIABILITY: PREFERENCES OF
MANAGERS, ELECTED OFFICIALS AND WATER USERS IN
BOULDER, COLORADO**

by

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Smith, and Karl Wunderlich**



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Preferences of Managers, Elected
Officials and Water Users
in Boulder, Colorado

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Abstract

This study compares the attitudes of the water using public, water officials and elected officials towards water supply reliability (as measured by the likelihood of shortages). It also takes a step towards measuring the benefits and costs of different reliability levels in terms of water users' willingness-to-pay for increases in reliability and in terms of their willingness-to-accept compensation (in the form of lower water bills for lower levels of reliability).

At Boulder's high level of reliability, public officials appear quite willing to consider reductions in reliability that would reduce system costs or generate funds through raw water sales. The water-using public is split about half-and-half on the issue. Few members of the public and no officials favor increasing reliability.

Water officials seem not to overestimate the public's concern with water shortages, although customers tend to view the system as less reliable than do officials.

Estimates of willingness-to-pay for small increases in reliability appear to be the same as the willingness-to-accept compensation for small decreases in reliability. It appears possible to estimate these quantities (per household or per commercial establishment) and to use them, along with systems costs, in determining a desirable level of reliability.

Evidence in Boulder, including a high coincidence between the preferences of water officials and elected City Council members, shows that water officials pursue the public's interests and not narrower objectives of their own.

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I. Introduction

It is frequently conjectured that water officials prefer overly reliable systems, that is they strive to provide an overly secure and overly costly water supply in comparison with one that could be defended on the basis of objective system costs and damages and the public's real concerns about water shortages. Given the motivational framework within which water officials work, there are solid a priori reasons to expect this:.

1. the public often reacts strongly and negatively to the occurrence of water shortage;
2. the public fails to understand the costs and environmental implications of maintaining a high level of reliability and the consequences of shortages of different magnitudes;
3. the primitive state of municipal financial accounting often makes it possible to hide the costs of maintaining high reliability from both the public and elected officials;
4. officials seldom know the preferences of the public;
5. neither officials nor the public is likely to be familiar with the results of the few studies that have attempted to quantify the damages from urban water shortage (e.g. Russell, Arey, and Kates, 1970; Warrick, 1975).

The consequences of excessively high water system reliability include over-investment in raw water supplies and

related physical plant; secondary economic impacts on non-urban water users who are either denied water or who must rely on less reliable leased supplies or return flows; and environmental consequences (negative and positive) that stem from reservoir construction and instream effects.

The motivations of the public and those of elected officials are likely to be quite different from those of water officials. The public probably desires some "satisfactory" levels of water service with an eye on cost. Elected officials may seek to represent their own perception of the "public interest" in water supply and related environmental issues.

Each of these three groups (i.e., water managers, the public and elected officials) plays a role in determining actual water policy and system design. Yet, neither elected officials nor water officials know much about the public's feelings toward risk. Further, each group's attitude toward reliability is based on, at best, partial information concerning the implications and consequences of different water supply reliabilities. Since each group typically acts or reacts on the basis of partial information on the relevant factors, no group is likely to arrive at a socially optimum answer.

Given both the divergence in motivations among the groups and imperfect knowledge across the groups, "principal-agent" problems may also arise. Water managers can increase reliability by carrying excess capacity and spreading the additional cost over the large set of customers. During a drought, water

managers bear the additional burden of drought management and increased scrutiny of their activities. Thus, water managers may choose to carry extra capacity to reduce the occurrence of water shortages and the concomitant bother and attention.

This paper presents the results of surveying water customers, city council members and water officials in Boulder, Colorado.¹ Based upon our behavioral expectations that are further explained in Section II, five specific hypotheses are tested:

1. Water officials, elected officials, and the public hold quite different initial impressions about the risk of water shortage in their system.
2. Water officials prefer highly reliable systems that are not in keeping with attitudes of the public towards water shortage nor with the costs and benefits of different levels of system reliability.
3. Water officials overestimate the public's concern with water shortage.
4. The public tends to be satisfied with the existing level of reliability, whatever the level (except for extremely unreliable systems).
5. The public's "willingness-to-pay:" for higher levels of reliability differs significantly from their

¹ Boulder was one of three Colorado cities surveyed in a larger USGS study of preferences for reliability in urban water supply management. The others are Aurora and Longmont. Boulder was a pilot case for the larger study.

"willingness-to- accept compensation" for similar decreases in reliability.

II. Technical Background

The National Research Council Colloquium on "Drought Management and Its Impact on Public Water Systems" (September, 1986) concluded as follows (pp. 6,7):

1. There is substantial need for continued research on drought and its impact on the management of public water systems. Key research topics include... (c) probability analysis of drought, (d) quantification of the consequences of system failure during drought,....
2. Sizing of the physical facilities of a system should not be based solely on full-service requirements during the drought of record, nor should such facilities be sized by the arbitrary specification of hydrologic risk. Instead, the measure of facility adequacy should be established by orderly comparison of incremental facility requirements versus the use of demand management techniques over the range of probability conditions.

Very similar research needs were cited in the National Science Foundation's Conference on Drought Research Needs (Yevjevich et al, 1978).

Within the next 30 to 40 years, huge investments will be made to bolster the reliability of urban systems in the southwestern United States. In the Denver metropolitan region alone, the booming Denver suburb of Aurora is planning a \$320 million transmountain diversion system from the Gunnison River drainage plus continued transfers from the Arkansas River; Thornton is trying to transfer 36,000 acre-feet of agricultural water from Larimer and Weld Counties, and Denver is still seeking

to develop an acceptable new storage project on the South Platte River. Each of these projects is costly and will impose significant ecological effects. Much of the water being claimed and developed is intended for use only during infrequent droughts.

How important is it to have highly reliable urban supply systems? The study by Russell, Arey, and Kates (1970) is one of very few that have attempted to quantify the damages occurring as a result of urban water shortage. The 1962-66 drought they studied was estimated to have had a recurrence frequency of about 1/150, i.e. it was "the 150 year drought". It was substantially more severe than the maximum drought of record (1900-1911) that was used in most of the towns studied to define the "safe yields" of their systems. Among the cities studied by Russell, Arey, and Kates, no city experienced more than a 30 percent shortage in any one year of the drought. Negative economic impacts of the drought were "small", e.g. \$5.46 per capita in Braintree, \$5.33 in Pittsfield, and \$13.05 in Fitchburg. Much of what had been counted as costs of the drought turned out to be profitable investments in industrial, commercial, and public sector water systems that had been overlooked until the drought occurred. Even if these damages are up-dated to 1988 dollars, a factor of about 2.8, they are not high enough to justify much investment to reduce them, especially given the recurrence frequency of 1/150. Russell et al. conclude:

... system shortages do not mean disaster, and perhaps if more effort were made to spell out beforehand the consequences of various "failure" levels, public acceptance could be won for more rational planning. In short, "drought" need not constitute, as it now does, a convenient natural cloak for hiding past planning failures or garbing for public acclaim plans for building expensive monuments to the "right" to cheap water.

Kates and Dworkin (1973) estimated that, in a typical year, 2.5 million urban dwellers in the United States experience drought-induced water shortage at (1973) estimated costs of \$3 to \$5 per capita or a total of about \$12.5 million per year. This is certainly a modest sum in comparison with the costs that would be incurred to reduce the damages significantly. They found "water supply over capacity" to be greater in the arid parts of the U.S. than in humid areas. Warrick (1975) noted that in the drought of 1963, only a fifth of surveyed municipal systems in the Northeast and a tenth of those in the Midwest and Southwest were using their full safe yield.... " However, in over 100 years of urban water supply history in the United States, we have no examples of catastrophe related specifically to drought."

There is little question that smaller towns, especially if located in semi-arid areas, experience larger losses from severe drought than larger towns which typically have a broader "portfolio" of water sources. Howe, Alexander and Moses (1982) note that during the 1976-77 drought, some small Colorado towns first became aware that they owned no water rights and lost their traditional sources to the priority system.

The 1976-77 drought was particularly severe in Northern California, especially in Marin County. There is no question that the costs of that event were quite high - in the forms of emergency supplies, the inconveniences of severe rationing schemes, and commercial and residential losses (see Nelson, 1979). Yet no one essayed to estimate the inconveniences to water users in terms of a willingness to pay to avoid recurrence of such events.

A major complication in isolating and measuring preferences for supply system reliability is the fact that urban water supplies (especially the holdings of raw water) are directly and indirectly related to non-water supply goals such as stream flow maintenance and other environmental and political goals. For example, Boulder, Colorado has found that the city owns a "reliable" supply of over 50,000 acre-feet per year, while the projected "ultimate" demand is unlikely to exceed 30,000 acre-feet. While the 20,000 acre-feet may be interpreted as excess supply from a reliability viewpoint, some of that water could be used to help sustain near-by agriculture, late summer streamflow, and, through leasing to other towns, perhaps to influence patterns of growth of near-by towns. These goals are considered quite important by some members of the City Council and the public. The present study concentrates on reliability only, in a way that permits the separate identification of water that is desired for non-supply purposes.

This study employed interview and survey methods that have been developed over the past 40 years in the fields of economics, psychology and behavioral decision theory for measuring people's values (e.g., Edwards, 1961; Slovic, Lichtenstein, and Fischhoff, 1984; Einhorn and Hogarth, 1981; Pitz and Sachs, 1984), in parallel with the techniques of decision analysis (Raiffa, 1968; Keeney and Raiffa, 1976; Keeney, 1982). The techniques of behavioral decision theory have been usefully applied to a number of public policy issues involving risk (Covello, 1983; Petak, 1985; Rescher, 1983). Applications to water resource management issues in particular are described by Anderson (1981), Brown (1984), Harris (1984), Keeney and Wood (1977), Lord (1979), and Sander (1983). Those surveyed in the study were asked to value several supply programs involving different risks of shortage (cf Edwards and Newman, 1982).

The economics literature contains many studies of individual decision behavior in the face of risky outcomes (e.g. Arrow, 1974; Freeman, 1985; Jones-Lee, 1974; Machina, 1984; Mishan, 1971; Smith, Desvousges, and Freeman, 1985). Much of this theory evolved as an attempt to explain choices involving insurance, gambling, choice of risky occupation. The theoretical framework for the present study is provided by a model of option price, i.e. what a rational person should be willing to pay for a change in the probability of an adverse event. This framework has been used as the basis of survey designs for valuing changes in risks from hazardous wastes (Smith and Desvousges, 1987) and in design

of interruptable electric power contracts (Schulze, McClelland, and Russell, 1988).

A point directly relevant to the main purposes of this study (and representing a major controversy in economics) is whether or not an individual's willingness-to-pay (WTP) for an additional amount of some good or service (like water supply reliability) can logically differ significantly from the amount the individual would require as compensation to give up the same amount, i.e. the person's "willingness-to-accept compensation" (WTA) (Cummings, et al., 1986; Mitchell and Carson, 1989; Knetsch and Sinden, 1984; Knetsch, 1990). Willig (1976) convincingly showed that given the individual's initial holding of wealth, the two measures should not differ significantly if expenditures on the item constitute a small part of the individual's budget (i.e. if income effects are negligible). Experimental evidence continues to show, however, that WTA typically and persistently exceeds WTP. The point arises in the present study since we would like to determine people's benefits from increased reliability as measured by their willingness-to-pay and their disbenefits from decreased reliability as measured by their willingness-to-accept compensation. The data gathered for the present study has provided some insight into this general issue.

III. Survey Design

To test our hypotheses, we surveyed residential and commercial water customers in the city of Boulder, Colorado

regarding their perceptions of existing water supply reliability and their attitudes toward higher or lower levels of water supply reliability. We also surveyed the city water supply officials (3) and all members of the Boulder City Council (9). Water officials and council members were asked the same questions as water customers concerning their perceptions of the current level of reliability, but rather than being questioned about their own preferences for alternative levels of reliability, they were asked whether different levels of reliability were desirable given the implied cost savings or increases to the city. Interviews lasted approximately an hour. The interview forms and response summaries for officials and City Council members are exhibited in Appendices A - D.

The residential sample was drawn using a stratified sampling technique from the population of detached single family dwellings in the Boulder service area. Restriction to single family dwellings was required because multiple units usually are not separately metered. The sample was selected to be representative of the cross section of Boulder's single family dwelling neighborhoods. The presence of residences other than detached single family dwellings in the sample results from sampling errors. Our concentration on single family dwellings resulted in a sample which, on the average, is wealthier, better educated and has lived in Boulder longer than the general population of the city, which includes a large transient student population (Table 1). Mail surveys were sent out to 400 Boulder residential water

customers and 220 were returned for a response rate of 55%. The survey takes approximately ten minutes to complete. The residential questionnaire and response summary are exhibited in Appendices E & F.

[Table 1 here]

Commercial/industrial uses of water vary greatly across customers thus complicating the selection of a representative sample for this group. Many commercial/industrial customers use water only for drinking and sanitation purposes, others may have landscaping, still others have important process water needs that are critical to their operations. Some operations are owned by absentee owners who apparently had little interest in responding to the survey. Mail surveys were distributed to 350 commercial/industrial customers and 107 were returned, a response rate of 31%. The questionnaire and response summary are exhibited in Appendices G & H. Given both the diversity in the types of commercial/industrial firms responding to the survey and the low response rate, the results of the commercial/industrial survey may not be representative of commercial/industrial users in Boulder.

In designing the survey, we had to decide on a definition of "reliability". Reliability is the opposite of system failure, which, in turn, means the system fails to deliver the volume demanded under generally accepted quality and pressure standards. System shortages can occur for a variety of reasons, usually

either a shortage of raw water or constraints imposed by treatment and delivery system components.

Our major interest is the determination of appropriate raw water supplies for a city in relation to the level of supply reliability. Also, the reliability of treatment and delivery components is difficult to compute because of the possibilities of random failures of the various components.² For these reasons, it was decided to assume that the treatment and delivery system would operate up to design capacity 100% of the time, and that shortages would occur only because of a raw water shortage.

To formalize reliability, it was necessary to define "a shortage event," the probability of which could be computed. We chose to use as the "standard annual shortage event"³:

"a drought of sufficient severity and duration that residential outdoor water use would have to be restricted to three hours every third day for the months of July, August and September."

Alternate day restrictions are intended primarily to reduce peak

² On April __, 1989, an "impossible" event brought Boulder within two hours of having no treated water. A penstock in the small hydro plant that generates electricity from a major mountain supply line burst, requiring that the line be closed. The second mountain supply line mysteriously stopped flowing, apparently plugged with ice. When the attempt was made to draw supplies from Boulder Reservoir (usually not used in winter), the gate valve stem broke.

³ The duration of the restriction was not made clear in the Boulder residential questionnaire and was specified as two summer months in the commercial/industrial questionnaire. In later studies of Aurora and Longmont, the duration was specified as July, August, and September.

Scenario 4: P falls from 1/300 to 1/1000
(R rises from 0.997 to 0.999)

It is clear from any of these numbers that Boulder's system, under any of the scenarios, would be considered to be very safe.

In responding to Scenarios 1 and 2, the respondents were first asked to indicate (yes, no) whether or not they would be willing to accept the lower level of R with a concurrent reduction in their monthly water bill. Those who responded "yes" were then asked what the required reduction in their monthly bills would be. This was their "willingness-to-accept compensation," WTA. The average WTA's, \bar{WTA} , for all those responding "yes" are given later in Table 4.

There is a serious question of whether or not this \bar{WTA} is an adequate measure of the values held by the entire sample of households. What of those who said "no" and thereby gave no numerical value for WTA? Was the "no" intended as a "protest" against the idea of decreased reliability generally (Boyes, McClelland, and Schulze, 1989) or was it an indication that the WTA would have to be a very large number that the respondent either couldn't quantify or was embarrassed to mention?

Scenarios 3 and 4 involved increases in reliability and the corresponding WTP values. Since an increase in R is presumably good from the individual's viewpoint and at worst worth nothing, the "no's" can be interpreted as $WTP = 0$. The average WTPs with the "no's" averaged in at zero are shown as WTP^T in Table 4.

In summary, \bar{WTP} with the "no's" counted as zero seems the appropriate measure, while \bar{WTA} computed only over the numerical values given by the "yes" respondents may well be an underestimate of the real \bar{WTA} .

A final feature of the survey design was to compute both the savings available to the system if R were reduced or the additional cost if R were raised to higher levels. These savings and cost figures were then used in the interviews with water officials and city council to elicit their opinions about the desirability of changes in R.

IV. Results

Hypothesis 1: *Public officials, elected officials, and the water-using public hold quite different initial impressions about the risk of water shortage.*

Each of the four groups was initially asked two questions about their perceptions of the reliability of Boulder's water supply before being given any information about the current level of system reliability. These questions are reported in Table 2 with the mean responses of each group. The responses to both questions support the hypothesis that the residential and commercial customers have different initial impressions of the risk of water shortage than either water officials or the city council. Water customers in both cases felt water shortage to be more likely than water managers and elected officials. It also is worth noting that the impressions of water managers and city

council are similar. This may be attributed to discussions of the city's raw water master plan that occurred just prior to the time of the interviews.

[Table 2 here]

Hypothesis 2: *Urban water officials prefer highly reliable systems that are not in keeping with attitudes of the public towards water shortage nor with the costs and benefits of different levels of reliability.*

Table 3 reports the responses to questions on changes in water supply reliability. The first two questions deal with decreases in supply reliability. In Scenarios 1 and 2, residential and commercial water customers were asked whether they would accept a decrease in reliability if compensated by a reduction in their water bills. City council members and city water officials were asked whether they felt such a decrease in reliability was desirable, given a specified amount of cost savings to the city.

In Scenario 1 the proposed change in reliability is from the current level of 1/300 to 1/100.⁴ The comparison across groups (Table 3) shows that the two groups of water customers are less willing to accept the first reduction in reliability than either the water officials or the city council members in the sense that 50.5% of residential customers and 47% of commercial customers

⁴ Methods used for calculating the current level of reliability are explained in Appendix I.

said that they would accept the reduction if compensated whereas 56% of city council members and 67% of city water officials agreed that the reduction is desirable to realize cost savings. The average amount of compensation required by the two customer groups (their willingness-to-accept" [WTA] compensation) was \$4.53/month for residential and \$6.53/month for commercial customers (Table 4).

[Tables 3 and 4 here]

Scenario 2 proposed an even greater reduction in reliability from the current level of 1/300 to 1/50. As might be expected, a smaller number of respondents across all groups felt that this change was desirable. 42% of residential customers and 43% of commercial customers would accept the reduction if compensated. The average compensation required was \$5.44/month, residential, and \$8.08, commercial. Naturally, both groups require greater compensation to accept the lower level of reliability. On the management side, 33% of city council members, but none of the city water officials agreed that the larger reduction in reliability was desirable.

The comparison across groups for Scenario 1 contradicts the hypothesis that water managers and elected officials always are more risk averse than water customers. Both "management" groups were more willing than the two customer groups to move to lower system reliability. (This may stem from frequent Council briefings by the water managers that had included observations on

excessive raw water holdings.) On the other hand, when the proposed level of reliability was reduced further (Scenario 2), "management" became more conservative than water customers, a minority of which believed the additional reduction in reliability to be desirable.

Scenarios 3 and 4 describe movements toward higher levels of reliability at an additional cost to the customer. Scenario 3 proposes an increase in reliability from 1/300 to 1/600. The majority of respondents in all groups felt that such a move was unnecessary with only 23% of residential customers and 24% of commercial customers indicating a willingness-to-pay for more reliability. Neither city council members nor the city water officials supported such a move. Among those answering "yes" for more reliability, the average willingness-to-pay of residential customers was \$4.67/month and \$16.03/month for commercial customers. Assuming that a "no" vote for increased reliability is equivalent to WTP = 0, the residential average for the entire sample was \$1.07/month, and the commercial \$3.85/month.

In Scenario 4 the level of reliability would be increased from 1/300 to 1/1000. 19% of both residential and commercial customers were willing to pay for this increase while, again, none of the city council and city water officials felt the increase in reliability was worth the cost. Average willingness-to-pay for this increase was \$5.32/month residential and \$18.02/month commercial for those voting "yes" or \$1.01/month and \$3.42/month for the entire sample.

Hypothesis 3: *Water officials overestimate the public's concern with water shortage.*

Both Boulder water officials and city council members were asked, "Would Boulder water customers accept a reduction in water supply reliability given a reduction in their bill?". Two-thirds of both groups believed that customers would accept this tradeoff. As shown in Table 2, just over 50% of residential customers and 47% of commercial customers indicated a willingness-to-accept the reduction from 1 in 300 to 1 in 100. Only 42% of both residential and commercial groups would accept the more drastic reduction from 1 in 300 to 1 in 50.

The results indicate that although a majority of water officials and city council believe (from the interview data) that customers would accept a reduction in reliability for a lower water bill, customers have some reluctance to accept lower reliability even with compensation. In this sense, officials may be said to underestimate the public's concern with shortage. Therefore, the results tend to refute the hypothesis.

Hypothesis 4: *The public tends to be satisfied with the existing level of reliability, whatever it is, except for very unreliable systems.*

Looking at the Scenario 1 data in Table 3, it appears that the public is evenly divided between moving to a lower level of R and not moving. Water officials thought such a move would be

desirable (given the attainment of other goals like instream flow and growth control) and City Council appeared to be about evenly divided between reducing R and not doing so. In Scenario 2, a majority of the public and City Council preferred to keep R at its present level, while water officials were unanimous in objecting to the change. On the up side, few of any group saw any point in increasing R, given the already high level. Overall, we feel the data are consistent with Hypothesis 4, although a cross-city comparison really is necessary to test the hypothesis.

Hypothesis 5: *The public's WTP differs significantly from their WTA for increases and decreases in reliability of the same magnitude.*

The results reported in Table 4 give the average willingness-to-accept for reliability decreases and willingness-to-pay for reliability increases for those residential and commercial customers who responded "yes" to the proposed changes in reliability. In addition, a second WTP is calculated on the reasonable assumption that a "no" vote means $WTP = 0$. It should be remembered (see p. 14) that \bar{WTA} may understate the real willingness-to-accept since "no" votes may be protest votes representing high values.

First, to achieve comparability, it is necessary to compare the WTP for increases in reliability with the WTA for similar decreases in reliability. Scenario 1 involved an increase in the

annual probability of shortage from 1 to 300 (1/300) to 1 in 100 (1/100) (a decrease in reliability). Scenario 3 involved a decrease in annual probability of shortage from 1/300 to 1/600 (an increase in reliability). These intervals were rather arbitrarily chosen as "significant" changes in reliability, but they are not equal changes in either a numerical or behavioral sense (the Scenario 1 decrease in reliability is - 4/600 while the Scenario 3 increase in reliability is + 1/600). Thus, to compare WTA and WTP, it is necessary to express them per unit change in reliability. This is done in Table 5.

[Table 5 here]

The residential WTAs and WTPs per unit change in reliability (marked with *) look much alike, as one would expect with a commodity like water that constitutes a small part of household budgets. The results are not conclusive, however, since the WTA figures may be biased downward by the omission of the "no" responses.

The WTA and WTP responses for each respondent household were then systematically related to the corresponding changes in R and household characteristics that seemed likely to influence WTA or WTP. The socio-economic variables that were tried in the analysis were: household income, average monthly water-sewer bill, education of respondents, own versus rent, practice outdoor conservation, practice indoor conservation, single versus multiple housing units, and hours per week spent tending the lawn

and garden. The idea was to estimate two equations:

$$(1) \quad WTA = f (-\Delta R, x_1, \dots, X_n)$$

$$(2) \quad WTP = g (\Delta R, x_1, \dots, x_n)$$

Least-squares regression analysis is likely to yield biased estimates of the parameters of these equations because only a subset of the responses (the "yeses") were included (see discussion above about possible underestimation of the average WTA). This selection bias can be overcome through the inclusion of the so-called Mills ratio (Greene, 1988) that compensates for the bias. The Mills ratio corresponding to each "yes" response is calculated from a probit analysis of all yes (= 1) and no (= 0) responses regressed on ΔR and the socio-economic variables. The LIMDEP program was used for the calculations that resulted in the following estimated equations for residential users:

$$(3) \quad WTA = 0.289 \cdot \text{bill} + 0.997 \cdot \text{out con} \\ (7.127) \qquad (1.763) \\ - (0.109E-03) \cdot \Delta R - 1.243 \cdot \text{mills} \\ (2.164) \qquad (1.131)$$

where:

WTA ≡ monthly WTA in 1989 dollars
bill ≡ average monthly water/sewer bill for the
 respondent household in dollars
out con ≡ a (0, 1) variable for the practice of
 outdoor conservation
 ΔR ≡ the change in reliability (-6.667E-3 for
 1/100, -16.667E-3 for 1/50)
mills ≡ the Mills ratio described above

The numbers below the estimated coefficients are the "t" values which indicate that all coefficients are significantly different from zero at the 5% level of significance. Other data on equation (3) are given below:

number of observations:	186
average WTA value:	\$5.07 per month
adjusted correlation R ² :	0.230
F (3, 182):	19.402

The willingness-to-pay regression is:

$$(4) \quad \text{WTP} = 0.107 \cdot \text{bill} + 1.258 \cdot \text{out con} \\ (1.529) \quad (1.178) \\ + (0.552\text{E-}3) \cdot \Delta R + 1.208 \cdot \text{mills} \\ (0.747) \quad (1.304)$$

number of observations:	76
average WTP value:	\$4.95 per month
adjusted correlation R ² :	0.066
F (3, 72):	2.772

This equation has little significance, exhibiting a very low F value and R², with no coefficients significant at the 5% level of significance. We conclude that WTA and WTP are much the same (as predicted by economic theory) for small changes in reliability (Table 5) and that WTA is significantly related to the magnitude of decreases in reliability.

V. Conclusions

Analysis of the Boulder data contradicts the central hypothesis that water officials prefer higher levels of reliability than the public. The Boulder results indicate that the public initially believes the risk of water shortage to be

greater than do water and elected officials and is less willing than officials to accept lower levels of reliability once the high level of Boulder system reliability is known. Furthermore, 67% of water officials believe that the public would accept lower levels of reliability with an appropriate bill adjustment, while only 51% of residential users and 47% of commercial/industrial users indicate a willingness to accept lower levels of reliability. The 51% of Boulder residential customers who said they would accept a reduction in supply reliability exhibited an average WTA of \$4.53/month (i.e. a decrease in their water bill). The average commercial WTA is \$6.53 per month.

Why are Boulder water supply officials and City Council members less risk averse than their customers? Boulder has an extremely reliable water supply system. If Boulder reduced its level of reliability from 1/300 to 1/100, it would still have an extremely reliable system relative to other systems. Boulder water officials may be more willing to reduce reliability because they are aware of Boulder's relative reliability vis-a-vis other systems, whereas water customers are not. In the absence of comparative intercity information, the customers are roughly split half and half between a lowering of reliability and the status quo.

These results from the Boulder study are not reaffirmed by our recent results from Aurora. The Aurora system has a significantly lower base level of reliability, 1/10 in contrast to Boulder's 1/300. Nevertheless a majority of Aurora's

residential water customers (59%) were willing to accept a reduction in system reliability, from 1/10 to 1/5, for an average WTA of \$6.67 in their monthly water bills. Aurora water officials were unanimous that such a move is undesirable and that Aurora water customers would find such a reduction in reliability unacceptable. These results suggest the hypothesis that the level of reliability strongly affects officials' preferences while having little effect on the public's preferences.

Thus, our results so far suggest that where system reliability is high, water officials are more willing than the public to reduce reliability. Where system reliability is low water officials are less willing than the public to reduce reliability. In both cities the preferences of water managers appear to be more consistent with the expected costs of water shortage and water savings than those of the public. With regard to the larger question of whether the preferences of water managers are inconsistent with the "public interest", it appears that water officials pursue the public's interests and not their own narrower objectives. There appears to be consistency between the preferences of elected officials in Boulder and the professional water staff.

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TABLE 1

CHARACTERISTICS OF THE BOULDER POPULATION AND THE SAMPLE

<u>Characteristic</u>	<u>Boulder Population¹</u>	<u>Sample</u>
Income:		
Median	\$28,800	\$42,500
Education:		
Percentage high school graduates	98	99.5
Percentage college graduates	55	80.3
Type of Home:		
Single family detached	38	97.8
Duplex or Townhouse	17	0.4
Mobile Home or Trailer	2	0
Other (including apartments)	43	1.8
Residency:		
Years lived in Boulder	9.8	17.5
Water Bill:		
Average monthly water bill	\$22.50	\$15.40

¹ Thomas I. Miller et al., "The 1989 Boulder Citizen Survey," Division of Research and Evaluation, Department of Community Planning and Development, Boulder, CO, January 1990.

TABLE 2

SUMMARY OF RESPONSES TO QUESTIONS ON CURRENT
SYSTEM RELIABILITY BY GROUP

(Responses to both questions are on a 1-7 scale where
1 = very unlikely and 7 = very likely)

Question 1: How likely do you think it is that in any given year there will be mandatory restrictions on watering your lawn and/or garden due to water shortages? (for example, a three-hour maximum watering period every third day for June through September).

<u>Residential</u>	<u>Commercial</u>	<u>Officials</u>	<u>City Council</u>
4.0	3.6	2.0	2.4

Question 2: How likely do you think it is that in any given year mandatory restrictions would be extended to your indoor water use during all or part of the summer due to water shortage? (for example, a complete ban on watering for the months of June through September and, in addition, some rationing of indoor water use--dishwashers, toilets, showers, etc.).

<u>Residential</u>	<u>Commercial</u>	<u>Officials</u>	<u>City Council</u>
2.2	2.7	1.0	1.3

TABLE 3

SUMMARY OF RESPONSES TO RELIABILITY QUESTIONS BY GROUP

Would you be willing to accept this decrease in reliability if you were compensated by a reduction in your water bill? (For officials and City Council: Do you feel this move would be good for the City, given the available cost savings?)

Scenario 1: 1/300 to 1/100

	<u>Residential</u>	<u>Commercial</u>	<u>Officials</u>	<u>City Council</u>
Yes	50.5%	47%	67%	56%
No	49.5%	53%	33%	33%
Uncertain				11%

Scenario 2: 1/300 to 1/50

	<u>Residential</u>	<u>Commercial</u>	<u>Officials</u>	<u>City Council</u>
Yes	42%	43%	0%	33%
No	58%	57%	100%	67%

Compared to your current level of service, would you be willing to pay a higher water bill for this increase in service reliability? (For officials and City Council: Do you feel this move would be good for the City, given the implied cost increases?)

Scenario 3: 1/300 to 1/600

	<u>Residential</u>	<u>Commercial</u>	<u>Officials</u>	<u>City Council</u>
Yes	23%	24%	0%	0%
No	77%	76%	100%	100%

Scenario 4: 1/300 to 1/1000

	<u>Residential</u>	<u>Commercial</u>	<u>Officials</u>	<u>City Council</u>
Yes	19%	19%	0%	0%
No	81%	81%	100%	100%

TABLE 4

SUMMARY OF WTA AND WTP BIDS FOR RESIDENTIAL
AND COMMERCIAL/INDUSTRIAL CUSTOMERS (dollars)

	<u>Residential</u>	<u>Commercial</u>
Scenario 1: 1/300 to 1/100 Average Willingness-to-Accept	4.53	6.53
Scenario 2: 1/300 to 1/50 Average Willingness-to-Accept	5.44	8.08
Scenario 3: 1/300 to 1/600 Average Willingness-to-Pay	4.67	16.03
Average Willingness-to-Pay ^T	1.07	3.85
Scenario 4: 1/300 to 1/1000 Average Willingness-to-Pay	5.32	18.02
Average Willingness-to-Pay ^T	1.01	3.42

Note: Average Willingness-to-Pay^T is the average willingness-to-pay for the entire sample assuming that those responding "no" to the proposed change would be willing to take the higher level of reliability if it cost nothing.

TABLE 5

COMPUTATION OF AVERAGE WILLINGNESS-TO-ACCEPT
 COMPENSATION (SCENARIOS 1 & 2) AND
 WILLINGNESS-TO-PAY (SCENARIOS 3 & 4)
 PER UNIT CHANGE IN RELIABILITY

Scenario 1	Scenario 3
$\Delta R = (1 - 1/100) - (1 - 1/300)$ $= - 4/600$ $= -6.667 \times 10^{-3}$ $WTA_{res} = \$ 4.53$ $\frac{WTA_{res}}{\Delta R} = \$ 679^*$ $WTA_{com} = \$ 6.53$ $\frac{WTA_{com}}{\Delta R} = \$ 979^*$	$\Delta R = (1 - 1/600) - (1 - 1/300)$ $= 1/600$ $= 1.667 \times 10^{-3}$ $WTP_{res}^T = \$ 1.07$ $\frac{WTP_{res}^T}{\Delta R} = \$ 642^*$ $WTP_{com}^T = \$ 3.85$ $\frac{WTP_{com}^T}{\Delta R} = \$ 231^*$
Scenario 2	Scenario 4
$\Delta R = (1 - 1/50) - (1 - 1/300)$ $= - 50/3000$ $+ - 16.667 \times 10^{-3}$ $WTA_{res} = \$ 5.44$ $\frac{WTA_{res}}{\Delta R} = \$ 326^*$ $WTA_{com} = \$ 8.08$ $\frac{WTA_{com}}{\Delta R} = \$ 485^*$	$\Delta R = (1 - 1/1000) - (1 - 1/300)$ $= 7/3000$ $= 2.333 \times 10^{-3}$ $WTP_{res}^T = \$ 1.01$ $\frac{WTP_{res}^T}{\Delta R} = \$ 433^*$ $WTP_{com}^T = \$ 3.42$ $\frac{WTP_{com}^T}{\Delta R} = \$ 1,466^*$

BOULDER WATER SUPPLY RELIABILITY - CITY OFFICIAL SURVEY

PART 1

I am first going to ask you a few questions about your impressions of the reliability of Boulder water supply. On a scale of 1-7, 1 representing least likely or not likely and 7 representing very likely, please give me the number that most closely represents your impression of the likelihood of each of the following situations actually occurring.

1.1 How likely do you think it is that in any given year there will be mandatory restrictions on watering lawns and/or gardens due to a water shortage? Such a restriction could be, for example, a three hour maximum watering period every third day for June through September.

NOT LIKELY							VERY LIKELY
1	2	3	4	5	6	7	

1.2 How likely do you think it is that in any given year there will be mandatory restrictions severe enough to cause damage to trees and/or gardens due to water shortage? Such a restriction could be, for example, a complete ban on watering for the months of August and September and a three hour maximum watering period every third day for June and July.

NOT LIKELY							VERY LIKELY
1	2	3	4	5	6	7	

1.3 How likely do you think it is that in any given year mandatory restrictions would be extended to indoor water use during all or part of the summer due to water shortage? Such a restriction could, for example, involve a complete ban on watering for the months of June through September and in addition some rationing of indoor water use (dishwashers, toilets, showers, etc.)

NOT LIKELY							VERY LIKELY
1	2	3	4	5	6	7	

Appendix B

BOULDER CITY OFFICIALS' RESPONSES TO WATER SUPPLY RELIABILITY QUESTIONNAIRE

Responses:

Part 1

Q1.1 Mean = 2 Median = 2 Std. Dev. = 0

The three officials all chose 2 (scale 1-7); not very likely that there will be "moderate outdoor restrictions."

Q1.2 Mean = 1.33 Median = 1 Std. Dev. = .2

Two chose 1, one chose 1.5 - not likely there will be "severe outdoor restrictions."

Q1.3 Mean = 1 Median = 1 Std. Dev. = 0

All agree that it is not likely there will be "indoor restrictions."

Q1.4 Effectiveness of voluntary restrictions:

Mean = 5.83 Median = 6

Voluntary restrictions are effective, but it must also be noted that it is difficult to distinguish the effects of the climate versus voluntary restrictions. For example, in the past, requests for voluntary restrictions have been accompanied by sudden storms, decreasing the need for citizens' support.

Q1.5-1.11 The situation in Boulder is somewhat unique in that there has never been a need for mandatory restrictions during the time period these officials have been involved in Boulder water management (last 5-10 years). Thus the responses to these questions regarding mandatory restrictions are "best-guess" estimates as to what the situation would involve if it were to occur.

1.5 All three said yes mandatory restrictions do result in water saving. Some comments include: "raising the price is especially effective; 10-15% reductions in total use has been the case with voluntary restrictions."

1.6 No (all). Customers do not incur significant costs or losses when mandatory outdoor restrictions are imposed.

1.7 Mean = 1.5 Median = 1.5

There is little negative reaction to the impositions of restrictions. Comments: "provided the public is educated and is informed. If the public has no background preparation or education there will be a very negative response."

1.8 Under the more severe forms of mandatory restrictions: one official says no losses in short term (several weeks), another believes there may be losses to landscaping and the third believes that the public will not incur losses.

1.9 Yes the public overreacts to the imposition of water-

Appendix C

BOULDER WATER SUPPLY RELIABILITY - CITY COUNCIL SURVEY

PART 1

I am first going to ask you a few questions about your impressions of the reliability of Boulder water supply. On a scale of 1-7, 1 representing least likely or not likely and 7 representing very likely, please give me the number that most closely represents your impression of the likelihood of each of the following situations actually occurring.

1.1 How likely do you think it is that in any given year there will be mandatory restrictions on watering lawns and/or gardens due to a water shortage? Such a restriction could be, for example, a three hour maximum watering period every third day for June through September.

NOT LIKELY							VERY LIKELY
1	2	3	4	5	6	7	

1.2 How likely do you think it is that in any given year there will be mandatory restrictions severe enough to cause damage to trees and/or gardens due to water shortage? Such a restriction could be, for example, a complete ban on watering for the months of August and September and a three hour maximum watering period every third day for June and July.

NOT LIKELY							VERY LIKELY
1	2	3	4	5	6	7	

1.3 How likely do you think it is that in any given year mandatory restrictions would be extended to indoor water use during all or part of the summer due to water shortage? Such a restriction could, for example, involve a complete ban on watering for the months of June through September and in addition some rationing of indoor water use (dishwashers, toilets, showers, etc.)

NOT LIKELY							VERY LIKELY
1	2	3	4	5	6	7	

Appendix D

BOULDER CITY COUNCIL RESPONSES TO WATER SUPPLY RELIABILITY
QUESTIONNAIRE

Responses:

Part 1

Q1.1 Mean = 2.4 Median = 2 Mode = 2
Most Council members chose 2. All but 1 believe it is not very likely that there will be "moderate outdoor restrictions."

Q1.2 Mean = 1.7 Median = 1.5
not very likely there will be "severe outdoor restrictions."

Q1.3 Mean = 1.3 Median = 1
All except one member agree that it is not likely there will be "indoor restrictions." (Eight members chose 1 the other member chose 4.)

Q1.4 Effectiveness of voluntary restrictions:
Mean = 5 Median = 5
Voluntary restrictions are generally effective. Comments include: "as long as people feel the restrictions are fair; restrictions are most effective when they are least restrictive, i.e. people respond well to short-term one day restrictions during emergency situations such as fires and breaks in water main.

Q1.5-1.11 Again it must be noted that many council members have no experience in Boulder County with mandatory restrictions.

1.5 Unanimous yes, mandatory restrictions result in water savings. (responses ranged from 50% - 80% of goal, or 10-30% reduction in use)

1.6 Do water customers incur significant costs or losses when mandatory moderate outdoor restrictions are imposed:

yes = 3

no = 6

For those who responded yes, costs include plant loss, but no major losses.

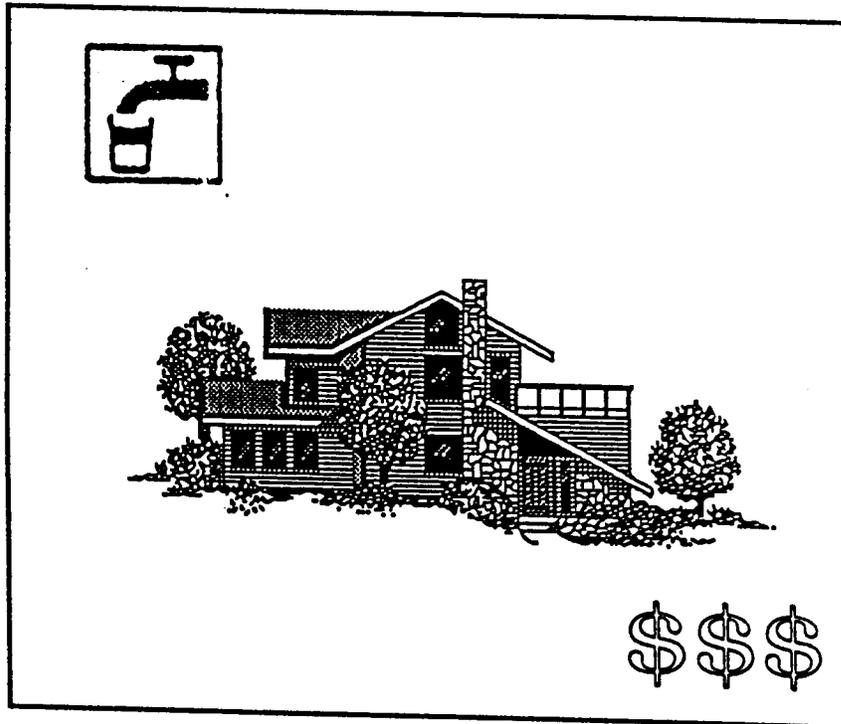
1.7 Mean = 3.6 Median = 4
Middle range response from public to water-use restrictions.

1.8 Under the more severe forms of mandatory restrictions:
yes = 8

no = 1

All but one member believe the public incurs significant costs. Comments include: "vegetation losses; people get

YOUR HOME WATER SUPPLY



A Survey of Your Preferences

This research is being conducted by:

**The Institute of Behavioral Science
Campus Box 468
University of Colorado at Boulder
Boulder, Colorado 80309-0468**

Appendix F

Boulder Water Supply Reliability
Residential Questionnaire Results

February 15, 1990

The Environment and Behavior Program, Institute of Behavioral Science at C.U.-Boulder, in cooperation with the Water Utility of the City of Boulder and with the assistance of WBLA, Inc. has been carrying out a study of water customer attitudes towards the reliability of water supply. While water supply systems generally are designed to provide adequate supply most of the time, shortages are bound to occur during severe drought events. When shortages do occur, water use must be restricted: first, outdoor uses are curtailed through appeals for watering cutback, followed by mandatory outdoor constraints, and finally by mandatory indoor and commercial/industrial cutbacks.

The question is "How reliable is reliable enough?" Boulder currently has a highly reliable system in terms of raw water availability. However, greater reliability would be achievable through the acquisition of additional water rights. On the other hand, a willingness to tolerate lower levels of reliability would reduce water utility costs and permit individual residential and commercial/industrial bills to be reduced.

The following data are from the residential customer survey. Analysis of commercial/industrial attitudes is still underway.

Residential Questionnaires mailed:	400
Questionnaires returned:	220
Response rate:	55%

Question 1: Rating of City of Boulder's Water Utility

<u>Poor</u> (low)							<u>Excellent</u> (high)	
1	2	3	4	5	6	7		
<1%	0%	<1%	1.8%	10.5%	38%	48%		

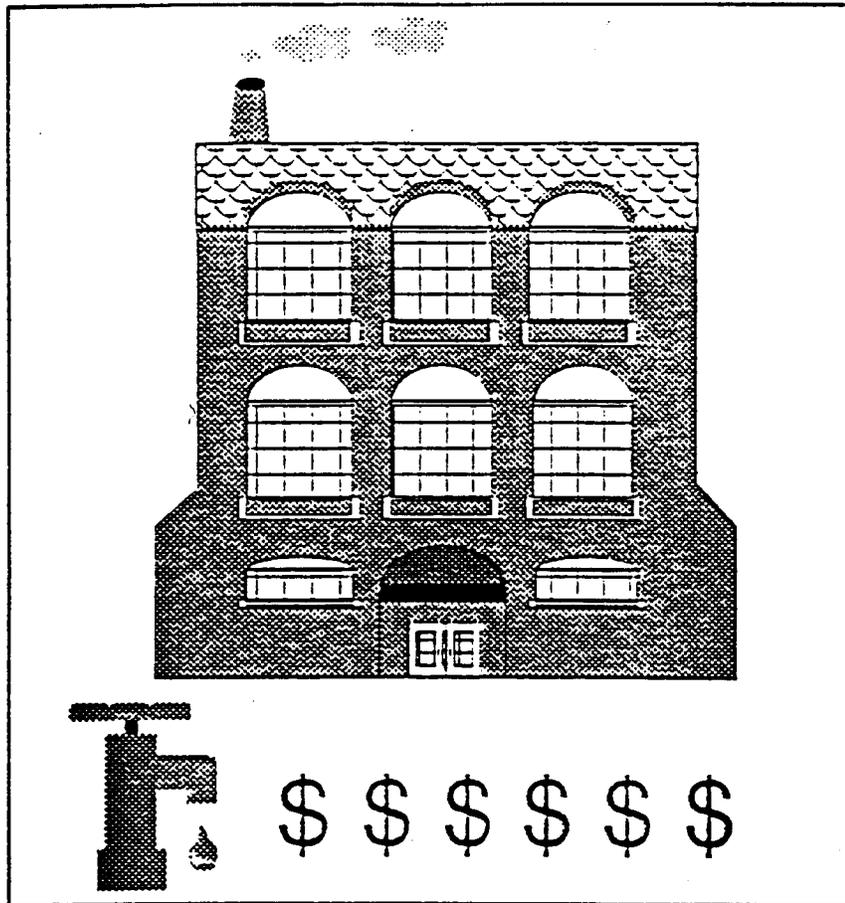
Question 2: Rating on reliability of service

1	2	3	4	5	6	7
0%	<1%	0%	1.8%	3.2%	34%	60.5%

Question 3: Perceived likelihood of mandatory outdoor restrictions

1	2	3	4	5	6	7
7.2%	18.2%	18.2%	14.5%	20%	11.4%	10.5%

Your Business Water Supply



A Survey of Business Preferences

This research is being conducted by:

The Institute of Behavioral Science
Campus Box 468
University of Colorado at Boulder
Boulder, Colorado 80309-0468

Appendix H

Boulder Water Supply Reliability
Commercial/Industrial questionnaire Results

February 26, 1990

As noted in the earlier report of February 15th, both residential and commercial/industrial customers of the Boulder Water Utility were surveyed. The major difference between the two surveys was that shortages were characterized in terms of restrictions on indoor or process water use for the commercial/industrial respondents, while restrictions on outdoor use were used in the residential survey.

Questionnaires mailed:	350
Questionnaires returned (In usable form)	107
Response rate	31%

The response rate was disappointing relative to the 55% residential response, although it is not low relative to typical survey experience. The commercial/industrial uses of water are more complex and varied than residential uses. Respondents had greater difficulty picturing and valuing water reliability in this context.

Question 1: Importance of a continuous water supply to your business.

<u>not important (low)</u>						<u>important (high)</u>	
----------------------------	--	--	--	--	--	-------------------------	--

1	2	3	4	5	6	7
4%	6%	2%	5%	7%	15%	65%

Average rating = 6

Question 2: Service reliability of the Boulder Water Utility.

1	2	3	4	5	6	7
0%	0%	0%	2%	5%	30%	63%

Average rating = 6.5

Question 3: Perceived likelihood of mandatory outdoor restrictions.

1	2	3	4	5	6	7
21%	9%	12%	25%	19%	7%	8%

Average rating = 3.6

Appendix I

Computation of Boulder's Reliability and Savings/Costs of Changing Reliability

Water supply reliability can be affected by a number of factors including adequacy of water rights, treatment facilities and pipelines, competence of operating staff, etc. For purposes of this study we are assuming that adequacy of water rights is the controlling factor for reliability.

The reliability of Boulder's water supply can be considered in three ways.

1. Boulder's policy statement regarding reliability specifies three levels of reliability corresponding to different levels of water delivery. Based on this policy statement, a summer-long, three-day, three-hour outdoor watering restriction program would be acceptable during droughts with severities of 1-in-100 or greater.
2. In contrast, the City's current situation given existing supplies and demands is such that outdoor restrictions would have only a 1-in-1000 chance of occurring.
3. The City's adopted water supply plan includes establishing an instream flow program for Boulder Creek while otherwise maintaining a status quo position with respect to its total level of water supply holdings to meet ultimate demands. (Windy Gap may be sold but only if its yield is replaced basically one-for-one with other more advantageous supplies.) The implications of this plan are that outdoor restrictions would have about a 1-in-300 chance of occurring.

Option 3 seems to be the most appropriate way of assessing the City's current reliability since it represents the City's adopted course of action and it considers both long-term growth in water demand and environmental goals.

At margin, the city's most likely options for increasing or decreasing its reliability involve purchase or sale of CBT and Windy Gap shares. Under current NCWCD rules and policies, Boulder finds itself in the curious position of facing unequal costs for increasing versus decreasing its supplies. To increase its supplies it could buy more CBT shares for about \$900 per share, or \$1,200 per acre-foot firm yield. In contrast, to decrease its supplies, it could sell its Windy Gap shares for \$3,800 per acre-foot.