1970

Cost Evaluation of Municipal Water Hardness Reduction and Private Softening for the City of Brookings, South Dakota

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COST EVALUATION OF MUNICIPAL WATER HARDNESS REDUCTION AND PRIVATE SOFTENING FOR THE CITY OF BROOKINGS, SOUTH DAKOTA

BY

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A thesis submitted
in partial fulfillment of the requirements for the
degree Master of Science, Major in
Civil Engineering, South Dakota
State University

1970

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This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable as meeting the thesis requirements for this degree, but without implying that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Thesis Adviser — Date

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ACKNOWLEDGMENTS

The author is deeply indebted to Dr. John R. Andersen and Dr. James N. Dornbush for their earnest assistance and knowledgeable advice.

Appreciation is extended to the responsible City officials for allowing access to water department records and to the clerical staff for their valuable assistance.

Recognition is also made to the various employees of the Physical Plant at South Dakota State University for their assistance in obtaining data.

This study was supported in part by Federal Water Pollution Control Administration Training Grant No. 5T1-WP-93.

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INTRODUCTION

The demand for softened water in the United States is rapidly increasing to the point where every municipality will have to investigate its responsibility to its citizenry to furnish a water supply with reduced hardness.

Soft water was once considered a luxury that only a few could afford but with increasing national affluence it is common that many people now expect and even demand that softened water be made available. The demand for soft water is evidenced by people paying from 5 to 10 times the amount for privately softened water that it would cost them to obtain the same volume of water from a municipal water hardness reduction plant (1). Soft water is desirable because of the economic savings and the comforts provided to the user.

The original residential soft water "service" was the rain barrel placed under a spout extending from the eaves. This was the forerunner of the brick and cement-lined cistern which provided storage for soft rain water. The practice of slowly adding lime and soda ash to a cistern full of hard water began around 1914. This method provided the user with a continuous supply of soft water that was not dependent upon the frequency of rainfall (2). The first water softening plant in the United States using the lime-soda ash process was constructed in Oberlin, Ohio, in 1903 and by 1930, 110 plants had been built. In 1960, it was estimated that there were about 1,100 to 1,200 municipal plants providing water with reduced hardness to approximately 15 million people (1). Around 1914, the use of base-exchange minerals was introduced into this country, which resulted in the first home operated water softeners. In 1947, it was estimated that over 770,000 homes in the United States and Canada used home water softening (2).

Water softened by the lime-soda ash process generally has a hardness in the range of 85 to 100 mg/l while water softened by ion-exchange processes has a hardness of nearly zero. Most municipal softening plants employ the lime-soda ash method of softening while the ion-exchange process has been used primarily for individual household softening. People receiving water softened by the lime-soda ash method and who desire water of zero hardness would have to further reduce the hardness by the use of home softeners. However, since municipally softened water entering the home would be of superior quality the frequency of serviced tank exchange or regeneration of home softening units would be greatly reduced.

One of the primary benefits of a municipal softening plant is that water with reduced hardness is provided to those people who would be unable to afford soft water supplied by any other manner. Therefore, these people can also realize the economic savings that soft water can provide.

Nature of the Project

The City of Brookings, South Dakota, is a university town with a total estimated population of 13,000, including a campus enrollment of 6,000. On March 3, 1970, Brookings' voters passed a bond issue to expand the present water treatment facilities by increasing both production and storage.

The new treatment plant will have a maximum daily production capacity of 4 million gallons, storage for 3 million gallons and will supplement the supply being treated by the existing plant. The new plant will consist of aeration to remove iron and manganese, lime and alum treatment to partially soften the water and to assist in the precipitation of the iron and manganese, an upflow basin for sludge sedimentation, a rapid sand filtration unit, chlorination and fluoridation. The lime and sludge will be pumped to a lagoon for dewatering prior to final disposal. The cost of the plant including construction costs for additional water storage has been estimated at $631,000.

Brookings, located in a hard water area, has an average raw water hardness of 643 mg/l and a finished water hardness of 485 mg/l. The primary objective of this project was to assess the economic feasibility of incorporating additional water hardness reduction capabilities into the new municipal plant.

Brookings' residents presently obtain soft water by using the ion-exchange process, either by subscribing to home-serviced softening provided by companies or by operating home-owned softening units. It was desired to determine whether softened water could be obtained in the most economical manner by a combination of improved municipal hardness reduction in conjunction with home softening. The specific objectives of the study were:

1. to determine the percentage of the water used in Brookings that was softened and the cost to the residents per unit volume of soft water,

2. to determine the extent to which the water could be economically softened,

3. to determine the combination of softening practices that would be most economical to the water user, and

4. to evaluate the economic feasibility of installing additional softening capabilities in the new municipal water treatment plant.

If the reduction of the water hardness by municipal treatment would prove economical then it would appear desirable to incorporate additional softening into the new plant. In this manner, the users would be provided with a softened water supply at a cost that would be less than they have paid to soften only a portion of their water supply.

LITERATURE REVIEW

The acceptability of a water supply for public use depends to a large degree upon the hardness of the water. The dissolved calcium and magnesium compounds react with the soap used in washing operations to form an insoluble product which will adhere to the items being washed and to the sides of the washing container. These precipitates also consume soap and thus reduce the desired cleaning action. In addition, when water is heated, dissolved calcium and magnesium compounds may be precipitated and may cause the formation of scale deposits on the walls of the heating vessel. Both of these conditions render the supply less desirable to use and the water is termed "hard".

Hardness is classified in two ways: (a) with respect to the metallic ions, i.e., calcium and magnesium hardness, and (b) with respect to anions associated with the metallic ions, i.e., carbonate and noncarbonate hardness. Calcium and magnesium are by far the largest contributing cations causing hardness. Carbonate hardness is chemically equivalent to the bicarbonate plus carbonate alkalinities in the water. Hardness in excess of carbonate hardness is called noncarbonate hardness and is determined by subtracting the carbonate hardness from the total hardness. Noncarbonate hardness exists primarily in the form of sulfate compounds and was formerly termed permanent hardness (3-349).

The terms hard water and soft water are relative. People living in South Dakota where the water hardness averages about 300 mg/l might think that water from Lake Michigan with a hardness of 125 mg/l was soft (4). People from the Pacific Northwest where water may have a hardness of 50 mg/l might think that Lake Michigan water was very hard. Sawyer and McCarty (3-349) have classified water in the following terms of relative hardness:

0-75 mg/l..............Soft

75-150 mg/l............Moderately Hard

150-300 mg/l...........Hard

above 300 mg/l.........Very Hard

Advantages of Soft Water

The desirability of soft water can best be evaluated from the standpoint of the material savings that are afforded to the user of soft water. The use of soft water can provide a monetary savings in various ways. In the following list of savings, soft water was considered to be water with 85 mg/l or less of hardness:

1. The quantity of soaps, detergents and other cleaning agents consumed is greatly reduced when soft water is used. This represents a considerable savings per capita per year (1) (5) (6) (7) (8). The most recent work, by DeBoer and Larson (6), indicated that savings in gross cleaning products due

to hardness reduction was $1.15 per capita per year per 100 mg/l of hardness removed. Previous research showed larger savings but these studies had been conducted before synthetic detergents were so widely used. Much more soap than synthetic detergent is required for the same cleaning action to occur. Syndets contain from 30 to 50 percent complex phosphates that sequester hardness ions and thereby decrease the money spent for cleaning products (6).

C. W. Foulk developed a formula for calculating the pounds of soap required to soften water as follows (8):

$$\frac{\text{Pounds of Soap Required}}{\text{1,000 Gallons of Water Used}} = 2 + 0.2H$$

where H is the total hardness of the water in mg/l as $CaCO_3$.

Generally it is expected that a 50 percent reduction in soap consumption can be realized when water hardness is reduced from 350 mg/l to 85 mg/l (7). It was reported that the amount of soap consumed in reducing water hardness in the range of 51-510 mg/l to the point where cleaning action could proceed was equal to the amount of soap actually used to do the cleaning. No appreciable soap saving is achieved by softening water below 35-45 mg/l of hardness (2) (6).

2. Scale deposits which can retard heat flow are eliminated when heating soft water. This can provide a 25 percent saving on fuel costs (7).
3. Expense for repairing, cleaning and replacing piping and equipment caked with scale can be decreased by using soft water (9) (10). Aultman (7) reports that 18 percent can be saved on plumbing expense by using soft water.
4. Fabrics washed in soft water will last up to 25 percent longer than those washed in hard water (7). White clothes will be whiter and colored fabrics brighter and all fabrics will be more pliable when washed in soft water (11).
5. Food and vegetables have better texture, color, flavor and digestive qualities when cooked in soft water (7) (8) (9).
6. In making tea and coffee it takes 50 percent less grounds with soft water than with hard water and the flavor of the beverage is improved (7) (10).
7. Aultman (7) stated that razor blades will last up to 20 percent longer when shaving with soft water. Also, less shampoo and other personal hygiene items are required.
8. Washing machines and other utensils will last longer when soft water is used (7).
9. Household cleaning time can be reduced by as much as $1\frac{1}{2}$ hours per week when soft water is used (11).

Towne (10) reported that the total saving for the average family using soft water could be as high as $16 per month, while Gilcreas (12) stated that a family could save $5.26 per year for each 100 mg/l of hardness removed from the water supply.

Perhaps even more important than the economic justification for using soft water is the personal comfort provided to the user. Soft water benefits personal hygiene in that it helps to prevent skin dryness and irritation and leaves a natural luster to the hair after washing. Soft water also eliminates the formation of a soap scum that can trap bacteria on the skin which could cause skin irritation and illness (7) (10) (11) (13). It has been reported that once people become accustomed to the benefits provided by soft water they will not willingly return to the use of hard water.

Disadvantages of Soft Water

Water softened by the ion-exchange process and the lime-soda ash method will contain relatively high concentrations of sodium ions. High sodium concentrations in water may have a detrimental effect on plant growth and may be harmful to people suffering from heart diseases that require low salt diets.

Recent research has shown a correlation between water hardness and deaths from cardiovascular disease (4) (14) (15). These reports showed that the death rate from cardiovascular diseases was higher in areas where soft water occurred naturally. It was found that this death rate decreased approximately 10 percent with each 100 mg/l increase in water hardness. By using regression analysis at the 0.1 level it has been shown that the presence of calcium or magnesium (or other substances normally present or absent when either calcium or magnesium is present) is responsible for substantial reductions in the death rates from cardiovascular disease (4). However, since no acceptable explanation for the associations between water hardness and mortality has been found the need for a more detailed investigation of the problem exists before the above correlation can be accepted (15).

Methods Used to Reduce Hardness in Domestic Water Supplies

There are generally three ways in which domestic water supplies are reduced in hardness. These include: (a) the lime-soda ash process, (b) the ion-exchange process and (c) the use of excess soap.

The lime-soda ash method of softening is based upon the low solubilities of calcium and magnesium compounds. With the addition of lime to water the calcium and magnesium compounds precipitate according to the following chemical equations:

Carbonate Hardness

$$Ca^{++} + 2HCO_3^- + Ca(OH)_2 \longrightarrow \underline{2CaCO_3} + 2H_2O$$

$$Mg^{++} + 2HCO_3^- + Ca(OH)_2 \longrightarrow \underline{CaCO_3} + Mg^{++} + CO_3^= + 2H_2O$$

Magnesium Hardness (excess lime)

$$Mg^{++} + CO_3^{=} + Ca(OH)_2 \longrightarrow \underline{CaCO_3} + \underline{Mg(OH)_2}$$

$$Mg^{++} + SO_4^{=} + Ca(OH)_2 \longrightarrow Ca^{++} + SO_4^{=} + \underline{Mg(OH)_2}$$

The last equation indicates the formation of noncarbonate hardness which must be precipitated by the addition of soda ash (sodium carbonate). This reaction is shown in the following equation:

$$Ca^{++} + SO_4^{=} + Na_2CO_3 \longrightarrow \underline{CaCO_3} + 2Na^{+} + SO_4^{=}$$

The softened water obtained after lime-soda ash softening is normally supersatured with $CaCO_3$. The calcium carbonate will continue to precipitate as scale on filters and in pipelines unless the water is stabilized. Stabilization is accomplished by passing carbon dioxide through the water until the pH is adjusted to approximately 8.6 (3-356).

The ion-exchange or zeolite method of softening relies upon the ability of certain resinous materials to exchange cations. These resins, either natural or artificial, are commonly called zeolites. Zeolites have a natural preference for multivalent ions because of the more stable compounds that can be formed with them. As a result zeolite resins tend to give up monovalent cations and take on divalent cations. In this process sodium ions are released by the zeolite media and calcium and magnesium zeolite compounds are formed. The zeolite media can be regenerated by passing a strong salt brine through the media which replaces the calcium and magnesium ions with sodium ions. In this way the softening system is restored and more water can be softened. This method of softening produces a water with practically zero hardness and with a high sodium content. During regeneration approximately three milligrams of NaCl are needed to displace each milligram of hardness (3-361).

The third method of water softening is accomplished by using excess soap to soften the water to the point where cleaning can occur. This process yields a very undesirable soap scum and is very expensive to use. Modern synthetic detergents contain complex phosphates that sequester the hardness ions thereby eliminating soap scum but this process is also expensive.

Lime does a much more economical job of softening than does soap. Bajat reported, in 1964, that one pound of lime costing one-half a cent will neutralize as much hardness as 20 pounds of soap costing $3.00 (16).

Considerations in Selecting a Water Softening Method

There are basically four factors to consider when choosing between lime-soda ash hardness reduction and cation-exchange softening for a community water supply (17). These are:

1. the amount and relative types of hardness present in the water,
2. the bacteriologic and turbidimetric quality of the water,
3. the available space for the disposal of the sludge produced by the lime-soda ash method, and
4. the cost of salt, lime and soda ash.

It was found that for municipal water hardness reduction the lime-soda ash method offered a lower chemical cost than ion-exchange unless

75 to 90 percent of the hardness to be removed is in the form of sulfate compounds (18).

If a water supply is to be softened by using the cation-exchange process the water must be low in turbidity, contain few bacteria and have little iron and manganese (19). Turbidity tends to filter out and leave organic matter on the zeolite resin which will support bacterial growths and produce a slime layer that soon can foul the softener. This slime can impart undesirable tastes and odors to the water. High iron and manganese concentrations in the water will tend to cement the zeolite media together and reduce the softening capacity of the unit if washing is not performed thoroughly. Fouling of the softener leads to more frequent regenerations, higher salt consumption and greater loss of zeolite mineral. It would, therefore, be advisable to use water with high bacteriologic, chemical and physical qualities when softening by the zeolite process (19).

Ion-exchange is used in some municipal softening plants with satisfactory economical results but these plants are generally less than 1 mgd of capacity and treat a very hard water supply (20) (21). However, most municipal softening plants use the lime-soda ash method of hardness reduction. Some softening plants practice a combination of the two softening methods.

Quality Comparison of Water Softened by the Ion-Exchange and Lime-Soda Ash Processes

Water softened by ion-exchange methods has a hardness of nearly zero as compared to a hardness of 85 to 100 mg/l for water softened by the lime-soda ash method. Zero hardness renders the water more desirable to the consumer primarily from the additional comfort it provides (1) (6) (12) (22).

Water with zero hardness is very seldom stable and has the tendency to corrode distribution mains and household plumbing. Proper municipal softening eliminates the tendency of water to form scale deposits. Complete softening by the zeolite process removes all scale forming tendencies and renders the water less protective. If a water was corrosive before softening, it will never become less corrosive by zeolite softening but will probably become more corrosive by such treatment (23).

Water softened by the zeolite process has a very high sodium concentration and therefore may be detrimental to people suffering from heart trouble. Also, when zeolite media is regenerated the rinse water carries a high concentration of dissolved salts to the sewage treatment plant that could conceivably cause operational difficulties.

Water treated by the lime-soda ash process has several advantages over water softened by the zeolite process in that: the pH is higher so that corrosiveness and red water problems are reduced, it has more efficient removal of turbidity particularly if the magnesium content of the water is high, there is a better bacteria kill, iron and manganese are removed, water color is improved, the suspended solids loading on the filters is reduced so that filtration rates may be increased, chlorine dosage may be reduced and the quantity of coagulating chemical may be reduced (24).

The disposal of the large amounts of lime sludge produced by lime-soda ash softening is the greatest disadvantage of this method of softening. This problem is not new and until recently it had been handled by discharging the sludge to surface waters. Federal and state legislation now prohibit this method of disposal and new practices must be devised. An estimated 1 million tons per year of dry lime solids are produced as sludge from 3,600 municipal water treatment plant operations (25).

Essentially the problem of disposing of lime sludge consists of dewatering the sludge to the point where it can be handled easily. Once the sludge is dried sufficiently it can be reclaimed and the lime recovered or it can be transported to a land fill site for final disposal. For a plant producing less than 20 tons per day of dry lime solids a recalcining plant is not usually economically feasible (26-214).

Many methods have been introduced to dewater lime sludge. These include: vacuum filtration, centrifugation, sand drying beds, pressure filtration, freezing, addition of polyelectrolytes and lagoons (25).

Of these methods lagooning has proven to be the most practical solution for the small treatment plant. With a properly operated lagoon it is possible to concentrate the sludge to 50 percent solids before it is removed to a point of final disposal (25). If sufficient land area is available for a lagoon site and the lagoon is properly operated there is no need to let the production of lime sludge prevent softening of water by the lime-soda ash method.

It would seem apparent from the above comparisons that water produced by the lime-soda ash method would be more desirable than zeolite softened water if both were treated municipally. However, it should be determined whether municipal hardness reduction is preferable to home-serviced softening and home-owned softening. This can be determined in part by listing the advantages and the relative costs to the user for each softening method.

Comparison of Municipal Water Hardness Reduction with Home Softening

When other factors are equal, industries are frequently attracted to communities that are capable of providing them with reasonably soft water. If a town can furnish water with reduced hardness, industries that require soft water in their operation do not have the added expense of completely softening their water. Some of the industries that require soft water in their manufacturing processes include: the textile, paper, sugar, chemical, starch, glue, ice, brewing, distilling, canning, tanning, laundering and packing industries (22).

Monetary saving for a city can be obtained when water with reduced hardness is pumped through the distribution mains rather than hard or completely softened water. Hard waters tend to build up a hard mineral scale in pipelines and household plumbing. This can reduce the carrying capacity of the lines and can eventually completely clog them. Complete softening removes all existing scale forming tendencies of the water and renders it less protective. These two conditions tend to necessitate costly plumbing repairs and water main maintenance programs (23). Lime-soda ash softening plants lend themselves to the production of an effluent that is palatable and stable, that is, noncorrosive and non-depositing (26-209).

Perhaps the greatest single benefit provided by a municipal water hardness reduction program is that softened water is available to those people who were previously unable to afford it. While it has been shown that soft water pays for itself, Olson (2) reported that in Madison, Wisconsin, the people who could least afford to pay for soft water were bearing the burden of hard water expenses. This was because they did not feel that they could afford to install softeners or use a home-softening service. It was found that, in Madison, 60 percent of the people softened their water. It was computed that if only 40 percent had softened their water the money it cost them would have been sufficient to soften the entire municipal water supply.

Municipally softened water benefits the people in the lower income brackets more than those in the middle and upper income brackets (23). A survey conducted, in 1952, by the soft water service companies classified the percentage of their customers in the various income brackets as follows:

Buying Income per Year	Percent of Services
$7,000	27
$2,000 to $7,000	57
Less than $2,000	16

It is readily seen from this classification that the percentage of people in the lower income bracket that enjoyed the benefits of soft water was less than the percentage of people in the higher income levels. With municipally softened water it would be possible for the lower income group to realize the economic savings and the personal comforts provided by soft water without the expense of individually softening their water.

A review of the literature revealed many articles that compared the costs of municipal hardness reduction with home softening (1) (2) (5) (6) (7) (8) (12) (17) (27). Since these various articles were written over a period of years in different parts of the country and compare vastly different water supplies it is interesting to note that none of them reported home softening by itself to be less expensive than any other combination of softening methods. However, these papers represent a variety of conditions and are not in agreement as to the amount of savings that could be expected by using municipal hardness reduction.

Most studies generally report the cost of soft water production in cents per 1,000 gallons produced. Additional costs for lime-soda ash softening vary according to the raw water quality and the type of treatment already present. Construction costs of a typical plant where filtration of a hard surface water has been planned will be increased about 15 percent when provisions for softening are included (1). This cost percentage would necessarily be increased if filtration had not originally been planned.

Chemical costs for lime-soda ash softening have been calculated on the basis of 2.25 cents per 1,000 gallons of soft water produced per 100 mg/l of hardness removed (1). In plants smaller than 10 mgd the normal labor force required in a non-softening plant would be adequate for a plant in which water hardness is to be reduced. When softening has been figured as an auxiliary to filtration the softening cost will be about three cents per 1,000 gallons per 100 mg/l of hardness reduction with little variation, regardless of plant size (1). Other softening cost estimates ranged from 3 to 10 cents per 1,000 gallons of water softened depending upon water quality and whether filtration had been planned or had to be incorporated as a result of softening (6) (7) (17) (23).

Howson (1) estimated that the average water consumer paying for individual softening would be able to cut his yearly water conditioning bill in half if municipal softening was incorporated.

Larson (12) presented the following table of comparative softening costs in his study:

Table 1. Cost Relationships for Various Softening Methods

Softening Method	Cost Relationships for Initial Hardness in mg/l			
	85	250	340	510
Municipal to 85 mg/l		2.0	2.7	4.0
Home-owned (salt cost only)*	1.0	3.0	4.0	5.7
Home-serviced softening	10.0	17.5	23.0	34.0
Soap	2.6	5.8	7.6	10.8

* Amortization on softener costs not included

Table 1 shows that water softened on a municipal basis to 85 mg/l is the most economical method of softening. Since the cost of excess soap necessary for softening is approximately two and a half times higher than municipal softening costs, this alone should justify municipal treatment. It has been found that water reduced in hardness from 285 mg/l to 85 mg/l would yield a reduction in soap expense of

$2.50 per capita per year (17). For an average family of four this would represent a savings of $10.00 per year which would easily pay for the increased cost of water resulting from municipal softening.

DeBoer and Larson (6), tabulated the costs for 1,000 gallons of water per 100 mg/l of hardness removed for various methods of softening.

Table 2. Costs for Various Methods of Softening per 100 mg/l of Hardness Removed

Method of Softening	Cost per 1,000 gallons per 100 mg/l of hardness removed in cents
Municipal to 85 mg/l	5.3
Soap	11.7
Home owned softening units	32.0
Home serviced softening	61.0

This cost analysis was made assuming a family of four using 27 gpd/cap of soft water with a total water usage of 40-60 gpd/cap.

From the literature reviewed only one study was found that indicated a combination of municipal and home softening to be more economical than other combinations of water softening methods (27). However, this work considered that zero hardness was to be obtained instead of the 85 to

100 mg/l of hardness that would be expected from just municipal softening.

It has been found that when a water supply of 350 mg/l or more of hardness is used 90 percent of the consumers soften their water. When the hardness was reduced to 200 mg/l the percentage of consumers using water softeners decreases to 30 percent (1). Many people soften only their hot water and temper it with cold, hard water. With water supplies of 170 to 200 mg/l of hardness this tempering can result in a water hardness nearly equal to that produced by the lime-soda ash process (12). These two reasons indicate that when a lime-soda ash method of softening is used the water produced will have a hardness that very few people will find objectionable. In the literature reviewed no documented cases were found where people having tried municipal water hardness reduction were dissatisfied with the results and had returned to other methods of softening.

Summary of Literature Reviewed

Municipal softening unquestionably improves hard water. Home-owned softening is a further improvement, as is home-serviced softening. Either of the latter is made more economical and convenient by municipal softening (12). Municipal softening provides an effluent that has a nearly constant hardness and as a result the regeneration of home-owned softening units and the dissipation of softening capacity in home-serviced units occurs at a more uniform rate.

Municipal hardness reduction, complete home softening and the use of soap or synthetic detergents are all compatible. For those who prefer a polished, completely soft water, municipal softening economically and effectively supplements home-owned and home-service softening, thus benefiting not only the consumer but also the soft water service industry.

RESEARCH PROCEDURE

Introduction and Method of Approach

The overall objectives of this study were to determine the percentage of water softened in Brookings and the most economical method by which this softening could be accomplished. To achieve these objectives it was necessary to compare the cost differences between existing softening practices and computed municipal softening. City and university records were used to determine water usage, which was categorized into residential, commercial and university usages. Residential water usage was considered to be the water used in single family dwellings. Commercial water usage included all the water used in churches, schools, apartment houses and places of business. University usage included all water metered and billed to South Dakota State University during the period studied.

The period of time chosen for the study was January, February and March, of 1969, because this was the most recent period for which representative water usage records were available. The water usage for the first three months of the year was selected for several reasons. Records indicated that water usage was lowest during this time of the year. It was assumed that the quantity of water softened during this period, when outdoor water uses were at a minimum, would remain relatively constant throughout the year even though the total water usage was subject to seasonal fluctuations. In addition, Brookings computes its sewer rental charges on the mean water usage during January, February and March, therefore, it was advantageous to use the same period for this study. University enrollment for the period studied was representative of the total yearly enrollment and, therefore, the data obtained should be more reliable than if summer months had been used for the period of study.

Before an analysis could be made of the various categories of water usage it was necessary to examine Brookings Water Department records. From these records yearly averages, compiled from daily entries, of water production and of raw and finished water qualities were obtained. Data for the years 1961-1969 are tabulated in Appendix I. The hardness water quality data were used to compute chemical requirements for municipal softening. These data were used because the wells for the new treatment plant had not been developed and reliable water quality data from the new aquifer could not be attained. It was assumed that since the two well sites were located within five miles of each other that the water qualities would be similar.

Residential and Commercial Sampling Technique

To obtain information concerning residential and commercial water softening practices a questionnaire was prepared and mailed to a representative number of Brookings' water users. Dr. W. Lee Tucker, Experiment Station Statistician for South Dakota State University, was consulted and with his assistance it was determined that a survey of

10 percent of the metered water accounts would provide an adequate sample size.

The sample of residential water users surveyed was prepared by selecting every tenth residence listed in water department records. The sample of commercial water users was compiled by conducting a random number selection on a complete list of the churches, schools, apartment houses and businesses in Brookings. A copy of the questions that were mailed to 264 residential and 28 commercial water users can be found in Appendix I. In an attempt to improve questionnaire response a postage-paid self-addressed envelope was included with the questionnaire. In addition, the local newspaper carried an article explaining the purpose of the questionnaire and requested that cooperation be extended to the University by promptly completing and returning the questionnaires.

City water records were used to obtain the average monthly water usage for those residential and commercial water users replying to the questionnaire. By knowing the average monthly water usage and the survey results the amount of soft water used by those people and establishments responding to the questionnaire could be calculated. From these data the quantities and the percentages of water softened by home-serviced and home-owned softening were calculated.

In May, of 1967, the city meter readers conducted a survey for the University to obtain an idea as to the amount and type of water softening being conducted in Brookings. Because it was desired to substantiate the information gained from the questionnaire survey the City agreed to conduct another meter readers' survey. The results of the two meter readers' surveys were compared with questionnaire results.

Determination of South Dakota State University Water Usages

The total University water usage, for 1969, was obtained from water department records and has been summarized in Appendix I. To achieve an accurate representation of the University's soft water usage it was necessary to separately determine the water usage for the dormitories, food services, student union, power plant, agricultural projects and other uses. University records were used in obtaining data concerning the distribution of water for various University uses. Soft water usage for the University was determined from information obtained from the University personnel who maintained the various softening units.

Basis for Softening Cost Calculations

The calculations for determining the percentages of water softened in the three general areas of water usage were based on several assumptions. It was assumed that the softening capacity of the exchange tanks when returned to the soft water service companies would, on the average, be completely dissipated. It was also assumed, that three milligrams of NaCl are needed to displace each milligram of hardness during regeneration of zeolite media (3-362). These calculations can be found in Appendix II.

The Permutit Water Conditioning Data Book (28-49, 53) was used to compute the amount of lime, soda ash and carbon dioxide necessary for municipal water hardness reduction. By using this reference the amounts of commercial chemical lime and soda ash required per million gallons of water for various degrees of hardness removal were calculated. The concentration of alkalinity in the effluent could also be determined and used to compute the carbon dioxide needed to stabilize the water after softening (29). The sample calculations for water softening costs are shown in Appendix III.

PRESENTATION AND DISCUSSION OF DATA

The data presented and discussed in this section consist of tables and figures showing the percentage of water softened in Brookings for residential, commercial and university uses; as well as, the cost to soften this water from varying degrees of hardness. The cost per residence per year for water softened from varying degrees of hardness has been calculated for water softened by home-serviced, home-owned, and municipal softening and also for combinations of the aforementioned methods. The terminology used to define the various softening methods is as follows:

1. Home-serviced softening was considered to be all private softening accomplished by using zeolite media exchange tanks supplied by soft water service companies.
2. Home-owned softening was considered to be all softening accomplished by softening units that were privately owned, either by a residence, a commercial establishment, or by the University.
3. Municipal softening was considered to be water hardness reduction accomplished by treatment with lime and soda ash, by the municipality.

Residential and Commercial Soft Water Usage

A summary of the response obtained to the questionnaire survey for both residential and commercial water users is shown in Table 3.

Table 3. Summary of Questionnaire Response and Percentage of Softening

	Residential Accounts	Commercial Accounts
Total Water Accounts	2457	280
Questionnaires Distributed	264	28
Questionnaires Returned	176	19
Percentage of Questionnaires Returned	66.7	68
Percentage of Metered Water Accounts Returning Questionnaires	7.2	6.8
Percentage of Replies Indicating Water Softening Capabilities	92.5	52.6
Percentages of Replies Subscribing to Serviced Softening	56.2	36.8
Percentage of Replies Owning or Renting Automatic Softening Units	36.3	26.3

Of the 292 total questionnaires mailed, 66.8 percent were returned which represented 7.1 percent of the total metered water accounts in Brookings. Since the results indicate that only 7.5 percent of the residential water users did not soften their water, it is apparent that very few Brookings' water users are satisfied with the finished water presently being produced. A study of the replies, that indicated no water softening capabilities, revealed that those people used less than 200 cubic feet of water per month which classified them in the minimum usage category. Nearly 50 percent of the commercial replies reported that their water was not softened.

Table 4 is a summation of residential water softening practices as used by those people replying to the survey. This table indicates the quantities and the percentages of water softened by both home-serviced and home-owned softening. The percentage of water softened by those people using home-serviced softening was calculated, based on the frequency of softening tank replacement assuming that the tank exchange capacity was 30,000 grains of hardness and that the hardness of the water was constant at 485 mg/l. It was also assumed that the softening capacity of the exchange tanks when returned would, on the average, be completely dissipated. For those people softening with home-owned units the percentage of soft water used was determined from the amount of salt used for regeneration of the softening units. From this table it may be noted that for residential usage those people having home-owned

Table 4. Residential Water Usage -- Mean Values for January, February and March, of 1969

	Replies	Total Water Used[a] gal/month	Soft Water Used gal/month	Percentage Softened %	Total Water per Residence gal/day	Soft Water per Residence gal/day
Home-serviced softening	94	355,349	153,278[b]	43.1	126	54
Home-owned softening	63	418,818	298,500[c]	71.2	222	158
No water softening capabilities	13	35,536	--	--	91	--
Total Residential Softening	170	809,703	451,778	55.8	159	89

[a] - Figures based on information from city records
[b] - Figure based on 30,000 grains of hardness removal per exchange tank
[c] - Figure based on salt consumption for softener regeneration

softening units used and softened much more water than those people subscribing to home-serviced softening. The figures for residential softening indicate that 55.8 percent of the water used during the period studied was softened and that the average Brookings residence used 89 gallons of soft water per day.

The percentage of soft water used by commercial establishments was calculated, based upon a consumption of three grains of salt for every grain of hardness displaced during the regeneration of the softening unit. The sample calculations are shown in Appendix II. It was found that 34.6 percent of the commercial water usage during the period studied was softened.

University Soft Water Usage

The data pertaining to the total and soft water consumption by students living on campus during the period studied can be found in Table 5. Total dormitory occupancy for the spring semester, of 1969, was 92.5 percent of capacity and was approximately 2,600 students. The average soft water usage per student varied from 13 gallons per day for boys living in Development Hall to 17 gallons per day for girls living in Pierson Hall. The average soft water usage for all students was 15 gallons per day which amounted to 35 percent of the total water usage by the students. The two food services, Grove Commons and Medary Commons, contributed 1.8 and 2.0 gallons of soft water per day per student respectively to the total soft water usage per student. The

Table 5. On-Campus per Capita Water Usage -- Mean Values for January, February and March, of 1969

Building	Occupancy per Building Students[a]	Total Water Usage cu ft/month	Soft Water Usage cu ft/month	Total Water gpd/cap	Soft Water gpd/cap
Development Hall	45	5,660[b]	2,000[b]	31[b]	11[b]
Harding Hall	176	22,100[b]	8,800[b]	31[b]	13[b]
Brown Hall	385	48,416	20,000	31	13
Mathews Hall	360	48,416	20,000[b]	34	14
Pierson Hall	414	62,303	24,400[b]	38	15
Grove Commons (Food Service)	(1,380)	53,653[c]	10,000[b]	9.7[b]	1.8[b]
Waneta Hall	253	38,223	14,400	38	14
Wecota Annex	131	19,791[b]	7,600	38[b]	14[b]
Wecota Hall	85	12,842[b]	4,000	38[b]	12[b]
Wenona Hall	65	9,820[b]	2,800	38[b]	11[b]
Scobey Hall	278	34,960[b]	12,000[b]	31[b]	11[b]
Hansen Hall	414	49,818	20,000	30	12
Medary Commons (Food Service)	(1,227)	40,657[c]	10,000	8.3	2.0
Totals	2,607	446,459	156,000	43 Average	15 Average

[a] - 92.5 percent of capacity
[b] - Estimated values
[c] - Soft water subtracted for dormitory usage

soft water usage for the dormitories and food services was determined in part from available information and the remaining usage was estimated after consultation with university maintenance personnel.

The data for the water consumption by dormitories and food services have been recorded in Table 6 along with the remaining University water uses. It was assumed that the water used for agricultural projects would not be softened and that 10 percent of the water usage entered under "other university uses" would be softened. Therefore, the soft water usage by the University during the period studied was 33.2 percent of the total University water usage.

Summary of Soft Water Usage

According to survey results for the first three months, of 1969, 44.6 percent of all the water used by residences, commercial establishments and the University was softened. These data are shown in Table 7. From city records it was found that total water usage increased during the summer months, however, it was assumed that the volume of soft water used remained relatively constant throughout the year. From this assumption it was calculated that 36 percent of the total water usage for Brookings was softened, in 1969.

During the period studied the residential water usage accounted for approximately 49 percent of the total city water consumption. When the value of 49 percent is multiplied times the total yearly water usage in Brookings, for 1969, the total daily residential water consumption as

Table 6. Distribution of Average University Water Usage for January, February and March, of 1969

Water User	Total Water Usage cu ft/month	Soft Water Usage cu ft/month	Percentage Softened %
Dormitories	352,149	134,000	38
Food Services	94,310	20,000	21
Student Union	50,621	10,000[a]	20
Power Plant	110,000	110,000	100
Agricultural Projects	41,300	0	0
Other University Uses	253,100	25,300[b]	10
Totals	901,480	299,300	33.2

[a] - Assumed to be the same as a food service

[b] - Assumed that 10 percent was softened

Table 7. Percentage of Brookings' Water Softened During January, February and March, of 1969

Water Distribution	Extrapolated Total Water Usage gal/month	Percentage of Total %	Extrapolated Soft Water Usage gal/month	Percentage of Water Softened %
Residential Usage	11,700,000	48.7	6,550,000	55.8[a]
Commercial Usage, Includes Churches Apartments and Schools	5,550,000	23.1	1,920,000	34.6[a]
University Usage	6,750,000	28.2	2,240,000	33.2
Total Water Usage	24,000,000[b]	100.0	10,710,000	44.6

[a] - Percentages determined from questionnaire replies

[b] - This value deviates 0.60 percent from metered city water usage records

reported in Table 4 increases from 159 to 195 gallons per day per residence.

The total water usage for an average month during the period studied was calculated by extrapolating survey results to include all metered water accounts. As an indication of the precision of the survey the extrapolated total water usage as recorded in Table 7 deviated only 0.60 percent from the metered volume of water billed to customers by the City during the same period of time. Data used in this calculation can be found in Appendix I.

Data from Tables 4, 6, and 7 have been summarized in Figure 1 by using an exploded pie diagram. This figure shows the distribution of Brookings' water usage and the percentage of water softened for the first three months, of 1969.

Table 8 is a summary of the results obtained from surveys conducted by city meter readers. These surveys were designed to provide an estimate as to the extent of water softening practices in Brookings. The surveys showed that approximately 11 percent of the residents probably did not soften their water. This value compares to the 7.5 percent as found by the questionnaire survey. The percentage of outside meters increased from 17.3 to 27.7 during the time interval between surveys. This could account for the variation that occurred in the percentages for the softening methods reported. If the assumption is made that those residences with outside meters all have water softening capabilities

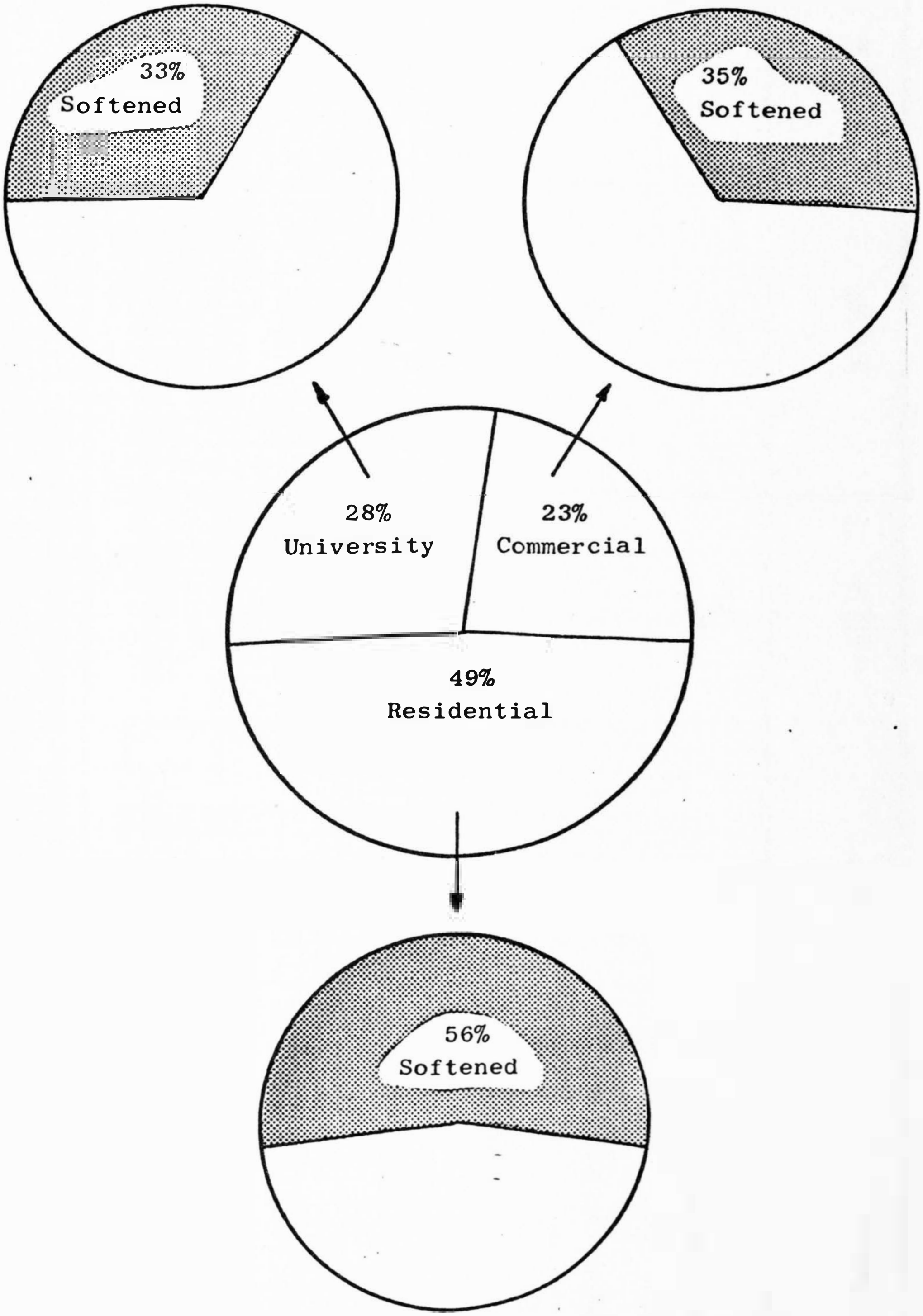

Figure 1. Distribution of Brookings' water usage and the percentage of water softened for January, February and March, of 1969.

Table 8. Meter Readers' Surveys -- Summary of Water Softening Practices in Brookings

Categories	May 1967		March 1970	
	Metered Accounts Observed[a]	Percentage	Metered Accounts Observed[a]	Percentage
Home-serviced Softening	1,168	48.7	894	40.0
Home-owned Softening	421	17.6	360	16.0
Probably No Softener	260	10.8	245	10.9
Softener Not Observed	135	5.6	121	5.4
Outside Meter - Thus No Information	413	17.3	619	27.7
Totals	2,397[a]	100.0	2,239[a]	100.0

[a] - Not all of the metered accounts were included in the surveys

and that 50 percent use home-serviced softeners and that 50 percent use home-owned softeners the results are similar to those derived from the survey questionnaire.

Analysis of Residential Water Softening Costs

Residential softening costs have been computed on the basis of an annual cost per residence. It was found from survey results that the average residence would have a total water usage of 195 gallons per day of which 90 gallons per day would be softened. In order to extrapolate survey data it was necessary to determine the number of residential water accounts in Brookings. From water department records it was found that of the 2,737 metered water accounts, in Brookings, approximately 2,457 were residential accounts.

The cost analysis has been determined from the viewpoint of an established Brookings' resident considering the effective savings in dollars per year that municipal softening could provide. The cost analysis was conducted for a combination of municipal hardness reduction, to varying degrees of hardness, in conjunction with both home-serviced and home-owned softening to zero hardness. The extent to which municipal softening should be conducted depends upon an economic evaluation of the total softening costs. For the purpose of this analysis the following degrees of hardness removal by municipal softening were considered: the present Brookings' treatment plant effluent of 28.3 grains per gallon, complete carbonate hardness removal to 20 grains per gallon, calcium noncarbonate hardness removal to 15 grains per gallon and complete lime-soda ash softening to 5 grains per gallon.

Residential Home-serviced Softening Costs - The cost in dollars per month for residential home-serviced softening is shown in Table 9. The calculations were made for city water hardnesses of 28.3, 20, 15 and 5 grains per gallon.

Survey results indicated the percentage of home-serviced residential water accounts that used each of the various exchange intervals offered by the soft water service companies. Since 56.2 percent of all residential softening is accomplished by home-serviced softening units (Table 3) the total number of residences using home-serviced softening was calculated. The number of residences using each exchange interval was determined by proportioning the total number of home-serviced softening accounts from percentages determined from survey results. The total cost per month was calculated based upon the present rates charged by the soft water service companies. At the present city water hardness of 28.3 grains per gallon the cost per average residence per year was calculated at $50.93. This calculation can be found in Appendix III.

To calculate the softening costs at different degrees of city water hardness it was necessary to estimate the number of services subscribing to the various exchange intervals. This estimation was accomplished by proportioning the number of home-serviced softening

Table 9. Home-serviced Softening -- Estimated Annual Costs per Residence to Soften from Varying Degrees of City Water Hardness to Zero Hardness

Exchange Interval days	Residential Accounts from Survey	City Water Hardness 28.3 gpg		City Water Hardness 20 gpg	
		Estimated Number of Home-serviced Softening Units	Cost $/month	Estimated Number of Home-serviced Softening Units	Cost $/month
56	5	74	203.50	74	203.50
28	37	543	1764.75	690	2242.50
21	20	294	1249.50	338	1436.50
14	26	382	2005.50	279	1464.75
10	6	88	638.00	0	0.00
Totals	94	1381	5861.25	1381	5347.25
Cost/Residence/Year		$50.93		$46.46	

Table 9. Continued

Exchange Frequency days	City Water Hardness 15 gpg		City Water Hardness 5 gpg	
	Estimated Number of Home-Serviced Softening Units	Cost $/month	Estimated Number of Home-Serviced Softening Units	Cost $/month
56	346	951.50	1337	3676.75
28	565	1836.25	44	143.00
21	426	1810.50	0	0.00
14	44	231.00	0	0.00
10	0	0.00	0	0.00
Totals	1381	4829.25	1381	3819.75
Cost/Residence/ Year	$41.96		$33.19	

units according to the expected shift in the exchange intervals for softening tanks due to the change in water quality. It was assumed for this calculation that the soft water service companies would not change either their scheduled exchange intervals or their monthly service charges. The cost per residence per year is reduced as the water hardness in the municipal supply is reduced. A reduction in water hardness from 28.3 grains per gallon to 5 grains per gallon reduces home-serviced softening costs from $50.93 to $33.19 for a reduction of $17.74 per residence per year.

Residential Home-Owned Softening Costs - Table 10 shows the relationship of home-owned softening costs with water hardness as the hardness increases from 0 to 40 grains per gallon. The cost data presented in this table required the computation of capital recovery costs, fixed annual costs (taxes and maintenance) and regeneration costs. The sample calculations for determining softening costs for home-owned softening are shown in Appendix III. The cost for capital recovery is computed from an average first cost of $332 per softener. After the first cost, the expense of softening per year varies from $24.02 for a 28 grain per gallon water to $16.31 for a five grain per gallon water. For the resident considering home-owned softening the first cost should be included as an annual expenditure.

Annual costs per residence to soften from varying degrees of city water hardness are plotted in Figure 2 for home-serviced softening and

Table 10. Home-owned Softening -- Annual Cost per Residence to Soften from Varying Degrees of City Water Hardness to Zero Hardness

Water Hardness mg/l	Water Hardness gpg	Capital Recovery $/res/yr	Taxes and Maintenance $/res/yr	Regeneration $/res/yr	Actual Annual Expenditure $/res/yr	Total Cost $/res/yr
0	0	32.00	14.76	0.00	14.76	46.76
34	2	32.00	14.76	0.66	15.42	47.42
68	4	32.00	14.76	1.32	16.08	48.08
85	5	32.00	14.76	1.65	16.41	48.41
103	6	32.00	14.76	1.99	16.75	48.75
137	8	32.00	14.76	2.65	17.41	49.41
171	10	32.00	14.76	3.31	18.07	50.07
205	12	32.00	14.76	3.97	18.73	50.73
239	14	32.00	14.76	4.64	19.40	51.40
274	16	32.00	14.76	5.30	20.06	52.06
308	18	32.00	14.76	5.96	20.72	52.72
342	20	32.00	14.76	6.62	21.38	53.38
376	22	32.00	14.76	7.28	22.04	54.04
410	24	32.00	14.76	7.94	22.70	54.70
445	26	32.00	14.76	8.60	23.36	55.36
479	28	32.00	14.76	9.26	24.02	56.02
513	30	32.00	14.76	9.92	24.68	56.68
547	32	32.00	14.76	10.58	25.34	57.34
581	34	32.00	14.76	11.24	26.00	58.00
616	36	32.00	14.76	11.90	26.66	58.66
650	38	32.00	14.76	12.57	27.33	59.33
684	40	32.00	14.76	13.23	27.99	59.99

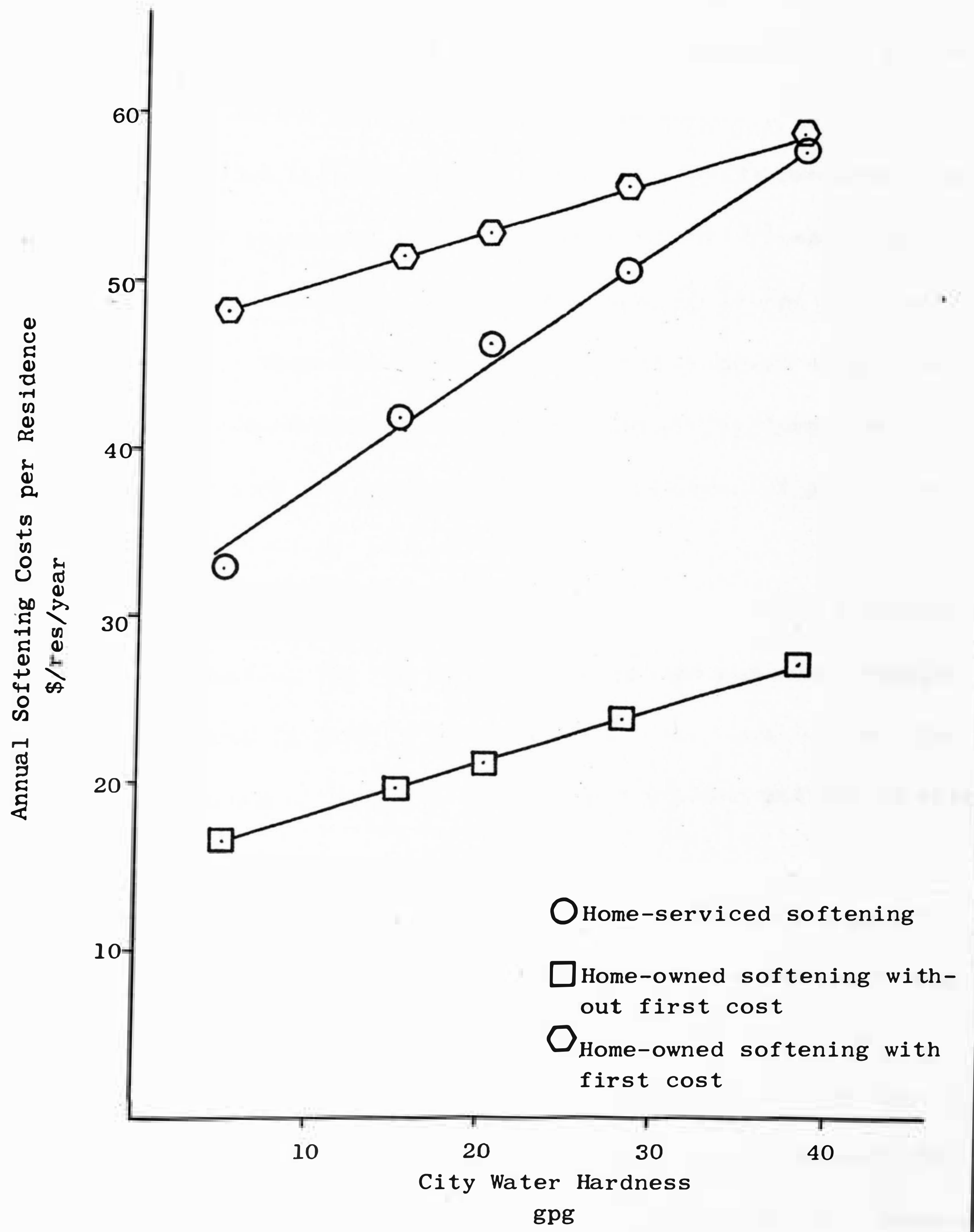

Figure 2. Annual cost per residence to completely soften from varying degrees of city water hardness for home-serviced and home-owned softening to zero hardness.

for home-owned softening with and without first costs figured into the total cost. Figure 2 shows that for home-owned softening units without the first cost the annual operating cost is approximately $17 less than that for home-serviced softening units when a five grain per gallon water is softened to zero hardness. As city water hardness increases the differential between home-owned and home-serviced softening costs becomes even greater. When the purchase price is considered as part of the annual cost, home-owned softening is more expensive than home-serviced softening when the water hardness is less than 41 grains per gallon.

Municipal Water Softening Costs - The chemical cost for municipal water hardness reduction for the 38 grain per gallon raw water treated in Brookings is shown in Table 11 and Figure 3. The chemical cost to remove varying degrees of hardness is shown per million gallons of water softened.

The new water treatment plant for Brookings was designed so that equipment to feed soda ash would be the only additional treatment unit necessary for complete lime-soda ash softening to five grains per gallon of hardness. Basically the increased chemical costs for the lime, soda ash and carbon dioxide needed to soften the water would be the only additional expenses incurred for municipal softening. However, an allowance of two cents per thousand gallons of water softened has been allotted to provide for additional labor costs and for the handling and

Table 11. Municipal Softening -- Chemical Costs for Varying Degrees of Hardness Removal per Million Gallons of Water Softened

Hardness Removed gpg	Lime Cost $/mil gal	Soda Ash Cost $/mil gal	Carbon Dioxide $/mil gal	Total Cost $/mil gal
CO_2	2.10	--	0.00	2.10
1	3.09	--	0.60	3.69
2	4.09	--	0.60	4.69
3	5.09	--	0.60	5.69
4	6.08	--	0.60	6.68
5	7.08	--	0.60	7.68
6	8.08	--	0.60	8.68
7	9.07	--	0.60	9.67
8	10.07	--	0.60	10.67
9	11.07	--	0.60	11.67
10	12.06	--	0.60	12.66
11	13.06	--	0.60	13.66
12	14.06	--	0.60	14.66
13	15.05	--	0.60	15.65
14	16.05	--	0.60	16.65
15	17.05	--	0.60	17.65
16	18.05	--	0.60	18.65
17	19.04	--	0.60[a]	19.64
18	19.45	2.25	1.36	23.06
19	19.45	6.10	1.36	26.91
20	19.45	9.95	1.36	30.76
21	19.45	13.80	1.36	34.61
22	19.45	17.65	1.36	38.46
23	19.45	21.50	1.36[a]	42.31
24	20.44	25.35	2.04	47.83
25	21.44	29.20	2.04	52.68
26	22.44	33.05	2.04	57.73
27	23.43	36.90	2.04	62.57
28	24.43	40.75	2.04	67.42
29	25.43	44.60	2.04	72.27
30	26.42	48.45	2.04	77.11
31	27.42	52.75	2.04	82.21
32	29.00	58.40	2.04	89.44
33	30.69	64.95	2.04[a]	97.68

[a] - Calculated values for CO_2 cost

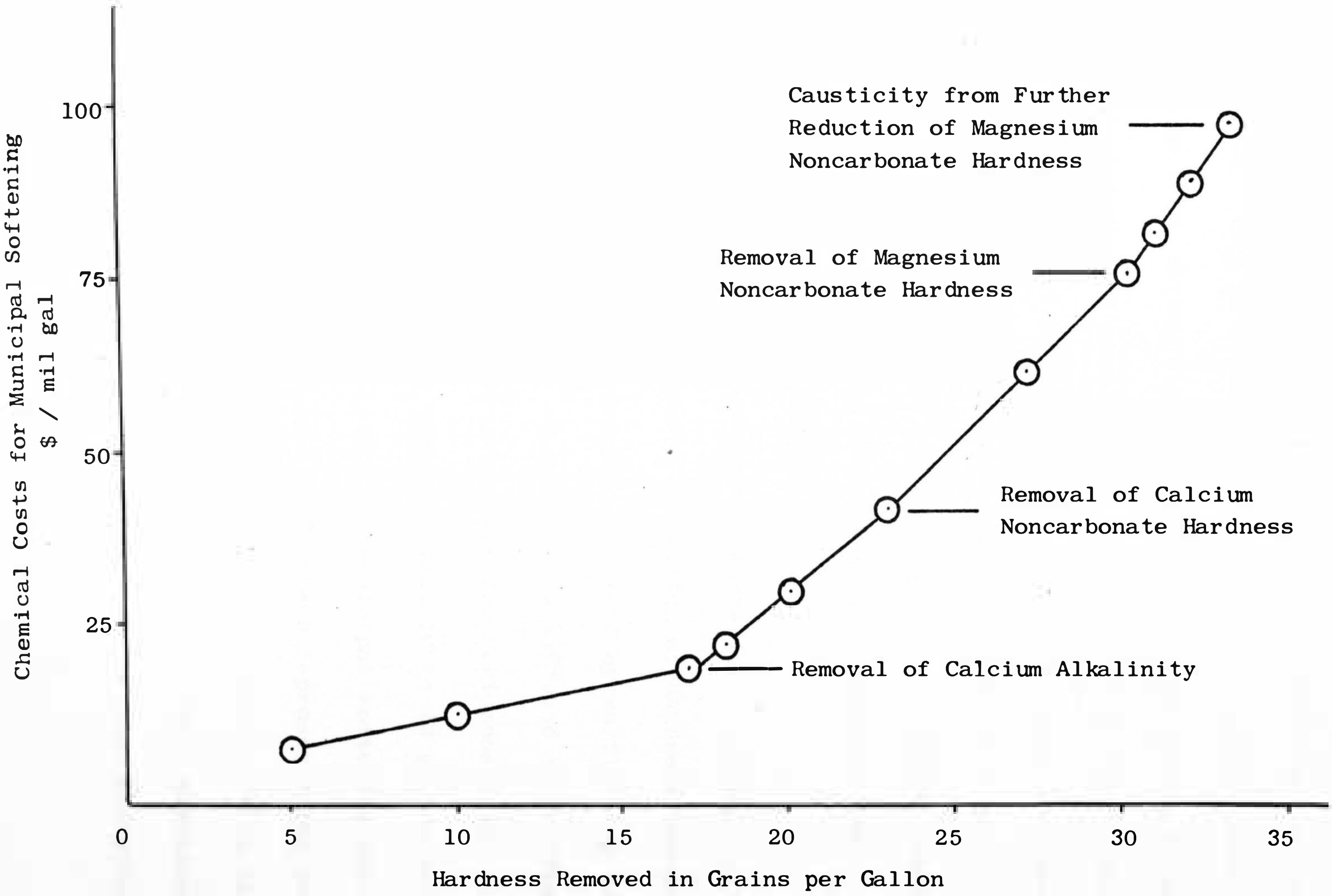

Figure 3. Chemical costs per million gallons of water softened per grain of hardness removed from a 38 grain per gallon water.

disposal of lime sludge. The total cost to remove 33 grains per gallon of hardness is approximately 12 cents per 1,000 gallons of water softened. When it is considered that enough lime is presently added to remove the carbon dioxide and 10 grains per gallon of hardness the additional cost to remove another 23 grains per gallon of hardness would be less than nine cents per 1,000 gallons of water softened. The cost in dollars per million gallons needed to soften a 38 grain per gallon water is plotted against varying degrees of hardness removal in Figure 3. It may be noted from this figure that chemical costs increase sharply after the removal of calcium alkalinity.

In Figure 4 the annual cost per residence for municipal softening has been plotted against the grains per gallon of hardness removed. The values plotted on this figure were obtained by multiplying the total cost per million gallons of municipally softened water times an average water usage of 195 gallons per day per residence. The figure shows that as hardness removal increases from 10 to 18 grains per gallon the annual cost per residence for municipal softening increases from $2.32 to $3.04. This increase of 72 cents represents the cost to reduce water hardness from 28.3 to 20 grains per gallon. This cost amounts to only six cents per residence per month. This additional cost will be compensated for by a cost reduction in home softening methods.

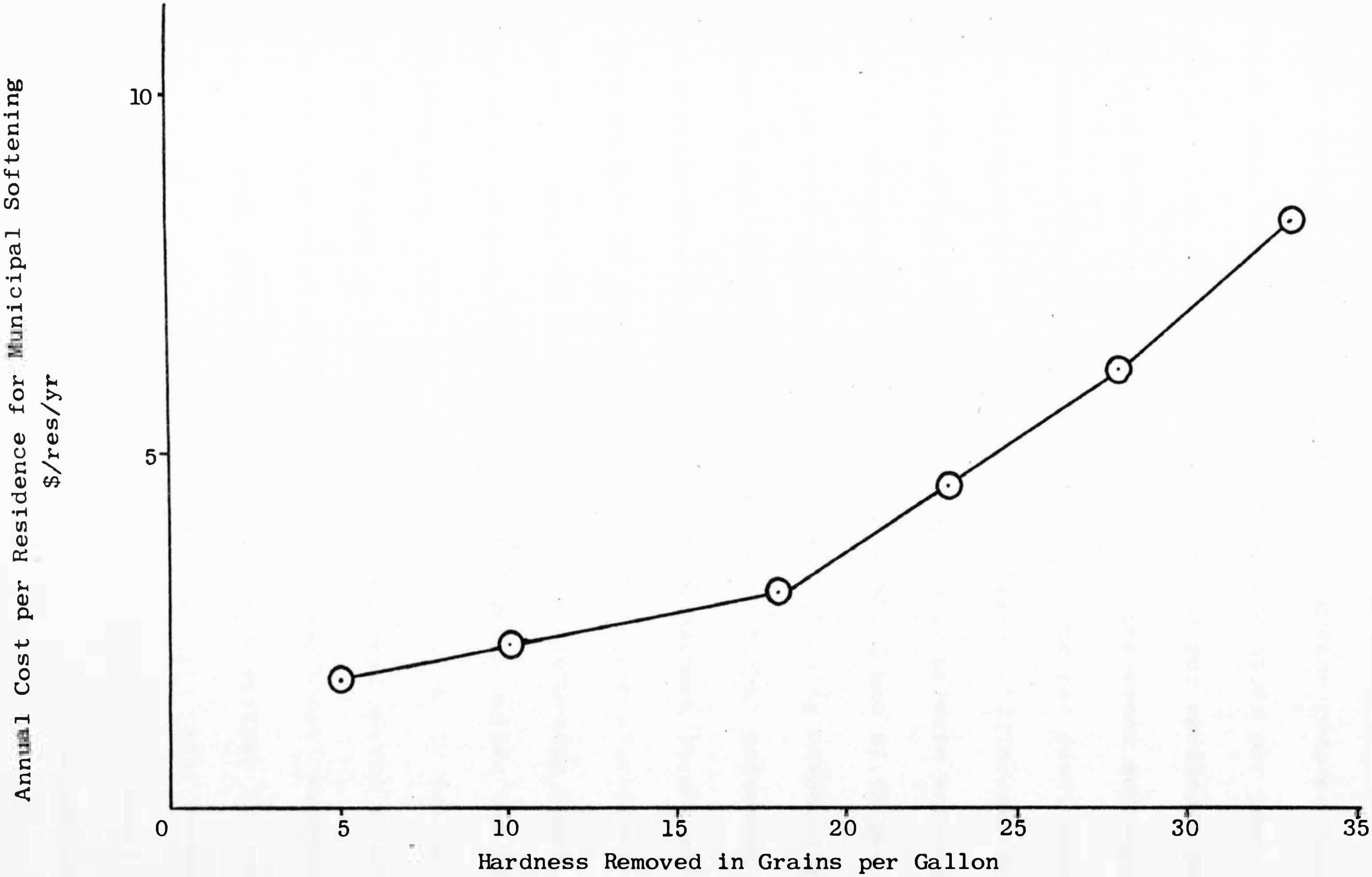

Figure 4. Annual municipal softening cost per residence to reduce city water hardness from 38 grains per gallon.

Effective Savings - Municipal reduction of an additional eight grains per gallon from 28 to 20 grains per gallon reduces home-serviced softening costs from $50.93 to $46.46 per residence per year as shown in Table 12. This reduction amounts to $4.47 per residence per year. For the same municipal hardness reduction, home-owned softening costs are reduced from $24.02 to $21.38 per residence per year, which amounts to a reduction of $2.64. The effective savings (difference between the municipal softening costs and the reduction in private softening costs effected by municipal softening) would be $3.75 and $1.92 per residence per year for home-serviced and home-owned softening respectively. As city water hardness is reduced further by municipal softening the effective savings for home-serviced softening becomes larger while the effective savings for home-owned softening remains relatively constant.

Table 13 shows the estimated residential softening costs, for 1969, compared with the calculated cost to municipally soften the total water used by residential services. The cost to municipally reduce hardness from 28 to 20 grains per gallon is increased from $5,700 to $7,500 per year, an increase of $1,800 per year. This additional expenditure of $1,800 by the City would result in an effective savings for residential softening of $6,700 per year. A reduction in city water hardness from 28 to 5 grains per gallon would result in a decrease in total softening costs from $97,400 to $81,000 per year for an effective savings of $16,400 per year for residential softening costs.

Table 12. Annual Cost per Residence for Private Softening from Varying Degrees of Municipal Softening

Municipal Softening of a 38 gpg water	Municipal Softening Cost $/res/yr	Residential Softening Costs to Obtain Zero Hardness $/res/yr	
		Home-serviced	Home-owned
to 38 gpg	--	58.25	27.33
to 28 gpg	2.32	50.93	24.02
to 20 gpg	3.04	46.46	21.38
to 15 gpg	4.57	41.96	19.75
to 5 gpg	8.36	33.19	16.41

Table 13. Estimated Residential Water Softening Costs, for 1969, Compared with the Calculated Cost to Municipally Soften all the Water Used Residentially

Municipal Softening of a 38 gpg Water	Municipal Softening Cost $/year	Residential Softening Costs to Obtain Zero Hardness $/year		Total Softening Cost $/year
		Home-serviced	Home-owned	
to 38 gpg	--	80,400	24,400	104,800
to 28 gpg	5,700	70,300	21,400	97,400
to 20 gpg	7,500	64,100	19,100	90,700
to 15 gpg	10,900	58,000	17,600	86,500
to 5 gpg	20,600	45,800	14,600	81,000

Commercial and University Water Softening Costs

Even though commercial establishments and the University use approximately one-half of the total soft water produced in Brookings, the data obtained were not sufficient to determine the cost of this soft water. It is expected that municipal hardness reduction would provide a cost savings for commercial water softening that would be comparative to residential savings if the savings were computed on a basis of unit volumes of soft water. It is not expected that municipal hardness reduction would appreciably lower softening costs for the University. Probably the only savings that would be realized is the amount of salt used to regenerate softening units.

CONCLUSIONS

From the investigation, the following conclusions have been drawn:

1. Results obtained from the questionnaire survey indicated that 92.5 percent of all Brookings' residents use softened water in their homes. It was found that 36 percent of the total Brookings' water usage, in 1969, was privately softened.
2. Residential softening by a combination of municipal hardness reduction with either home-serviced or home-owned softening will provide softened water at a lower cost than will either home-serviced or home-owned softening alone. Municipal hardness reduction to a hardness of 20 grains per gallon would cost the City an additional $1,800 per year and would result in an effective residential savings of $6,700 per year, based on present cost considerations. The cost for soft water produced for commercial usage may be reduced comparatively.
3. It was found that it costs $50.93 per residence per year for home-serviced softening and $24.02 per residence per year for home-owned softening to reduce the hardness of Brookings' present finished water from 28.3 grains per gallon to zero. The additional chemical cost to municipally soften water to five grains per gallon of hardness would be $8.36 per residence per year or less than 9 cents per 1,000 gallons softened.

4. Perhaps the greatest single benefit of municipal softening is that water with reduced hardness is available to those people who previously were unable to afford it so that they may also enjoy the conveniences provided by softened water.

5. Lime-soda ash softening to five grains per gallon of hardness would necessitate a fourfold increase in chemical dosage with subsequent increases in sludge volume and handling costs. A soda ash feeder would be the only additional piece of equipment needed for municipal softening.

FUTURE STUDY

The study has suggested that further work be conducted to define more completely the extent to which commercial establishments and the University soften their water. With more extensive data in these two areas the total soft water usage for Brookings could be calculated with increased accuracy. Possible procedural methods for further study could include the following:

1. A more complete questionnaire survey of commercial establishments could be attempted. This survey should determine the exchange capacity of commercial softening units, their cost, the frequency of regeneration and the annual salt consumption of these units.
2. A more extensive investigation should be undertaken to determine the soft water usage by the University. This could possibly include a metered account of the soft water used in every building.

To obtain more complete analyses of municipal softening costs and sludge production it may be possible to operate the present Brookings' water treatment plant on a pilot basis. The plant could be operated to obtain data for various degrees of hardness removal. An analysis of the effluent should be conducted to determine the stability of the water at different degrees of effluent hardness.

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APPENDIX I

Water Quality and Water Usage Records

Copy of Survey Questionaire

Annual Averages of Brookings Raw and Finished Water Constituents in mg/l

Year	Total Hardness		M Alkalinity		Noncarbonate Hardness		Fe		Mn		pH		Cl_2	F
	Raw	Fin.	Raw	Fin.	Raw	Fin.	Raw	Fin.	Raw	Fin.	Raw	Fin.	Fin.	Fin.
1961	560	423	315	157	244	267	3.0	0.09	0.7	0.12	7.3	8.0	0.64	1.3
1962	604	441	327	140	276	301	3.4	0.10	0.9	0.23	7.2	8.0	0.73	1.2
1963	630	472	336	158	294	314	2.5	0.07	0.6	0.19	7.0	7.7	0.63	1.1
1964	623	490	323	157	300	333	2.7	0.06	0.6	0.15	7.1	7.9	0.57	1.0
1965	650	494	332	154	318	340	3.8	0.04	0.8	0.04	7.4	8.2	0.65	1.0
1966	678	515	339	160	339	355	4.2	0.05	0.8	0.02	7.5	8.2	0.63	1.0
1967	655	494	338	151	317	343	4.1	0.03	0.9	0.06	7.4	8.2	0.63	1.1
1968	616	461	336	149	280	310	4.2	0.04	0.8	0.02	7.4	8.3	0.65	1.1
1969	624	471	322	147	302	324	3.7	0.06	0.8	0.02	7.3	8.2	0.66	1.1
9-year Ave.	626	473	330	153	297	321	3.5	0.06	0.8	0.09	7.3	8.1	0.64	1.1
1966-1969 Average	643	485	334	152	310	333	4.1	0.05	0.8	0.03	7.4	8.2	0.64	1.1

1969 Brookings' Water Pumpage Records

Month	Water Pumped from Wells gal	Water Pumped to City gal	Water Billed to Customers gal	Water Loss[a] %
January	33,445,000	31,216,000	24,802,200	20.5
February	32,215,000	30,038,900	24,767,325	17.6
March	36,339,000	33,881,400	22,854,450	32.5
April	34,970,000	32,738,500	29,555,475	9.7
May	41,002,000	38,464,100	31,157,775	19.0
June	37,208,000	34,978,200	32,785,500	6.4
July	39,113,000	36,819,500	28,097,250	24.0
August	49,362,000	47,010,000	39,909,150	15.2
September	40,779,000	38,491,500	37,243,275	3.2
October	39,763,000	37,543,900	29,907,150	20.3
November	36,083,000	33,816,900	28,183,763	16.8
December	35,932,000	33,668,700	28,096,500	16.8
First Quarter Average	33,999,666	31,712,100	24,141,325	23.8
Yearly Average	38,017,583	35,722,300	29,779,984	16.6

[a] - Difference between water pumped to the city and water billed to customers

Annual Totals of Brookings' Water Pumpage Records

Year	Water Pumped from Wells gal	Water Pumped to City gal	Water Billed to Customers gal	Water Loss[a] %
1961	332,092,000	321,242,000	290,089,398	9.7
1962	332,914,000	315,114,000	267,122,450	15.2
1963	338,565,000	329,345,000	268,418,775	13.0
1964	389,198,000	379,670,260	299,897,250	20.8
1965	404,278,000	372,725,300	334,879,201	10.1
1966	452,332,000	424,578,700	374,393,596	11.8
1967	461,123,000	431,720,200	375,419,800	13.0
1968	434,644,000	406,126,200	359,296,718	11.5
1969	456,211,000	428,667,600	357,359,813	16.6
9-year Ave.	399,039,666	378,798,806	327,208,550	13.5
1966-1969 Average	451,077,500	422,773,175	366,617,481	13.2

a - Difference between water pumped to the city and water billed to customers

Metered University Water Usage in Cubic Feet for 1969							
	Medary Ave & 11th St cu ft	Sheep Unit cu ft	Pharmacy Gardens cu ft	Hort. Irrig. cu ft	Hog Farm cu ft	Fed. Research Lab cu ft	Golf Course cu ft
January	807,240	1,020			2,870	41,540	
February	883,090	310			1,850	40,050	
March	890,250	500			2,200	33,530	
April	1,215,670	500			3,350	47,530	
May	1,227,920	500	3,350	14,080	950	51,830	200
June	796,030	500	9,460	13,540	10,200	67,370	8,860
July	671,370	720	3,000	16,000	4,530	56,630	2,970
August	969,910	690	5,680	10,880	10,650	145,960	4,180
September	847,050	530	3,360	18,690	6,750	54,330	1,850
October	1,028,910	200	1,590	11,950	7,380	44,280	600
November	981,240	140	20	8,830	6,150	38,860	270
December	942,770	160		6,330	6,400	40,030	Meter Removed
Totals	11,216,450	5,770	26,460	100,300	63,280	653,940	18,930

SURVEY QUESTIONNAIRE

Name______________________________ Address________________________

1. Do you presently have a water softener in your home?
   YES_____ NO_____

2. Total number of water taps in your home? _____
   Number of hot soft water taps in your home? _____
   Number of cold soft water taps in your home? _____

3. Do you use a tank exchange service (Culligan _____, Artz Filter Soft _____), or do you own or rent a unit from (Culligan _____, Artz Filter Soft _____, Lindsey _____, Other _____)?

4. If you use a tank exchange service how often is the tank exchanged? (in days)?

   7 _____, 10 _____, 14 _____, 21 _____, 28 _____, 56 _____, other ____
   What does it cost per month?______________________

5. If you own or rent a unit (fully automatic ____, or semiautomatic ____) to the best of your knowledge how many pounds of salt do you use in a year?___________________

6. How often is the unit mentioned in question 5 regenerated? _______

7. If you own a home softener what did it cost new? _________

8. If you rent an automatic home softener what does it cost per month? ______________

APPENDIX II

Sample Calculations for Determining Soft Water Usage

Sample Calculations for the Determination of Residential Water Usage

Home-Serviced Softening

This calculation was made using the frequency of tank exchanges per month based upon a tank capacity of 30,000 grains of hardness removal. Using a water hardness of 28.3 grains per gallon for the calculation it was found that 1,060 gallons of soft water could be produced before the tank capacity was exhausted. It was assumed that the exchange capacity of returning tanks on the average would be completely dissipated.

For an exchange frequency of 56 days per tank the amount of soft water used per month is calculated as follows:

$$1{,}060 \text{ gal/tank} \times \frac{30 \text{ days per month}}{56 \text{ days per tank}} = 568 \text{ gal/month}$$

The water softened in gallons per month for the remaining exchange frequencies has been tabulated as follows:

Frequency of Exchange days	Water Softened gal/month
56	568
28	1,136
21	1,514
14	2,271
10	3,180

This information was used for the 94 questionnaires returned and the total soft water usage was calculated to be 43.1 percent of the total water usage. The average soft water usage per residence was found to be 54 gallons per day.

Home-Owned Softening

This calculation was based on a total salt usage of 37,565 lbs per year for 54 replies that used a total water volume of 359,613 gallons per month. The calculation was made using a water hardness of 28.3 grains per gallon and it was assumed that three grains of salt are needed to displace one grain of hardness during regeneration of a softening unit (3-362). The total water usage for all replies using home-owned softening was 418,818 gallons per month.

359,613 gal/month x 28.3 gpg = 10,177,047 grains of hardness/month

$$37{,}565 \text{ lbs of salt/yr} \times 7{,}000 \text{ gr/lb} \times \frac{1 \text{ gr of hardness}}{3 \text{ gr of salt}} = 7{,}248{,}750$$

grains of hardness that can be removed in a month

$$\frac{7{,}248{,}750 \text{ gr/month}}{10{,}177{,}047 \text{ gr/month}} \times 100 = 71.2 \text{ percent of the water is softened}$$

Water softened per month is calculated as follows:

418,818 gal/month x 71.2% = 298,500 gallons per month

Sample Calculations for Determining the Percentage of Commercial Soft Water Usage

Data from commercial questionnaire response showed that: five businesses using 16,100 pounds of salt per year used a total of 304,884 gallons of water per month; seven businesses subscribing to serviced-softening softened 19,419 gallons per month; nine businesses that did not soften their water used 23,039 gallons per month; and the total commercial water usage was 376,243 gallons per month.

The calculation for soft water usage is as follows:

$$\frac{16{,}100 \text{ lbs of salt/yr}}{12 \text{ months/yr}} \times 7{,}000 \text{ gr/lb} \times \frac{1 \text{ gr of hardness}}{3 \text{ gr of salt}} = 3{,}130{,}000$$

grains of hardness that can be removed per month

$$304{,}884 \text{ gal/month} \times 28.3 \text{ gr/gal} = 8{,}640{,}000 \text{ gr/month total hardness}$$

$$\frac{3{,}130{,}000 \text{ gr/month removed}}{8{,}640{,}000 \text{ gr/month total}} \times 100 = 36.2\% \text{ of the hardness removed}$$

$$304{,}884 \text{ gal/month} \times 36.2\% = 110{,}500 \text{ gal/month softened}$$

$$110{,}500 \text{ gal/month} + 19{,}419 \text{ gal/month} = 129{,}919 \text{ gal/month softened}$$

$$\frac{129{,}919 \text{ gal/month softened}}{376{,}243 \text{ gal/month total}} \times 100 = 34.6\% \text{ softened commercially}$$

Sample Calculations for Determining Total Residential and Commercial Water Usage

Total Residential Usage

The total residential water usage for 170 questionnaire replies was 809,703 gal/month or 4,760 gal/month/residence. Since there are approximately 2,457 residential water accounts in Brookings the total residential usage for the City was as follows:

4,760 gal/month/res x 2,457 res = 11,700,000 gal/month

Total Commercial Usage

The 19 commercial questionnaire replies indicated a total water usage of 376,243 gal/month or 19,800 gal/month/reply. Since there are approximately 280 commercial establishments in Brookings the total commercial usage for the City was calculated to be:

280 accounts x 19,800 gal/month/reply = 5,500,000 gal/month

APPENDIX III

Sample Calculations for Determining Softening Costs

Sample Calculations for Determining Softening Costs for Home-Serviced Softening

Home-serviced softening costs per residence per year for a 28.3 grain per gallon water were determined from an estimated cost per month for all of the home-serviced softening units in Brookings. The total number of residential home-serviced softening accounts was calculated to be 1381, from analysis of survey results. The number of home-serviced softening units replaced for each of the exchange intervals was determined by extrapolating percentages from survey results to include all home-serviced softening accounts.

Exchange Interval	Home-Serviced Softening Units from Survey	Estimated Total Number of Home-Serviced Softening Units		Cost $/month
56	5	74 x 2.75	=	203.50
28	37	543 x 3.25	=	1764.75
21	20	294 x 4.25	=	1249.50
14	26	382 x 5.25	=	2005.50
10	6	88 x 7.25	=	638.25
Totals	94	1381		5861.25

To obtain the average cost per residence per year the total cost per month was divided by the total number of home-serviced softening units and multiplied by the 12 months of the year.

$$\frac{\$5861.25 \text{ / month x 12 months / year}}{1381 \text{ softening units}} = \$50.93 \text{ per residence per year}$$

The calculation for softening cost for other degrees of city water hardness was accomplished by proportioning the number of home-serviced softening units according to the expected shift in the exchange frequencies due to the change in water quality.

Sample Calculations for Determining Softening Costs for Home-Owned Softening

Fixed Costs per Year per Residence

1. Increased Property Taxes

   The average cost of home-owned softeners was found to be \$332 and Brookings' property taxes are levied at 70 mills on 42 percent evaluation.

   \$332 x 0.42 x 70 mills = \$ 9.76

2. Interest on Investment at 5%

   \$332 x 0.05 = 16.60

3. Amortization for 15 years at 5%

   $$\frac{\$332 \times 0.05}{(1 + .05)^{15} - 1} = 15.40$$

4. Maintenance Costs (estimated) = 5.00

Total = \$46.76 / year

Regeneration Costs per Regeneration

Survey results indicated that softening units were regenerated every 2.70 days and that the average residence used 696 lbs of salt per year for regeneration.

1. Salt Costs

   $$\frac{365 \text{ days/year}}{2.70 \text{ days/regeneration}} = 135 \text{ regenerations/year}$$

$$\frac{\text{696 lbs of salt/year/residence}}{\text{135 regenerations per year}} = \text{5.15 lbs of salt/regeneration}$$

5.15 lbs of salt at 2.25 cents/lb = 11.6 cents per regeneration

2. Water Costs

Regeneration of a home softening unit requires an average of 50[a] gallons of water for washing the zeolite media.

50 gallons x 30 cents per 100 cubic feet[b] = 2.0 cents/regeneration

3. Sewer Rental Charges

0.75 x water cost = 1.5 cents/regeneration

Total cost per regeneration equals 15.1 cents.

Average Soft Water Cost per Year per Residence for a 40 Grain per Gallon Water

From survey results it was computed that 90 gallons per day per residence was the average soft water usage in Brookings. The exchange capacity of home-owned softening units was assumed to average 15,000 grains of hardness removal.

90 gal/day/res x 365 days/year = 32,850 gal/res/year soft water

$$\frac{\text{32,850 gal/res/year}}{\text{15,000 gr/regeneration}} \times \text{40 gpg} = \text{87.6 regenerations per year}$$

87.6 regenerations/year x 15.1 cents/regeneration =$13.23 per year

---

[a] - Quantity experienced by local soft water service companies.

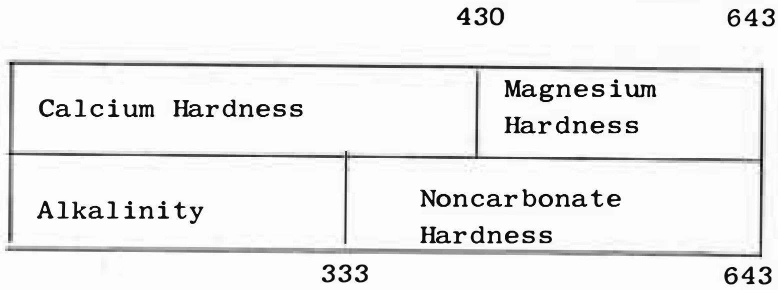
[b] - Brookings' residential water rate for a water usage of 200 to 3,200 cubic feet per month.

Total softening equals the sum of the fixed costs and the regeneration costs.

$46.76 + $13.23 = $59.99 per year for a 40 gpg water

$$\frac{\$59.99 \text{ per year}}{32.85 \text{ thousand gallons/year}} = \$1.83 \text{ per } 1{,}000 \text{ gallons softened}$$

Data Used for Determining Chemical Cost for Lime-Soda Ash Softening



Calcium Alkalinity = 333 mg/l as $CaCO_3$

Calcium Noncarbonate Hardness = 430 mg/l - 333 mg/l = 97 mg/l as $CaCO_3$

Magnesium Noncarbonate Hardness = 643 mg/l-430 mg/l = 213 mg/l as $CaCO_3$

The carbon dioxide concentration in the raw water was calculated to be 40 mg/l as CO_2. It was assumed that 60 percent of the CO_2 would be removed by aeration.

Delivered Chemical Cost

Chemical	Cost per Ton
Lime	$22.40[a]
Soda Ash	$50.00[b]

The cost of the carbon dioxide needed for recarbonation was calculated from the natural gas rates charged in Brookings. The amounts of chemicals necessary for lime-soda ash softening were calculated directly from the Permutit Data Book on water conditioning (28-53).

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a - Present cost of lime delivered to Brookings.

b - Price quoted by PPG Industries of Minneapolis, Minnesota.

The procedure followed can be found in Class 1, Case 2 of Section 57. The calculation was made using 90 percent pure chemical lime and 98 percent pure soda ash. It was desired that the effluent have 35 mg/l of calcium hardness and 45 mg/l of magnesium hardness.

Sample Calculations for Determining Carbon Dioxide Costs for Recarbonation

The theoretical amount of carbon dioxide required per million gallons of water treated is 3.7 pounds per mg/l of alkalinity, expressed as $CaCO_3$. It is generally necessary to add an additional 25 percent to this amount making the total about five pounds of carbon dioxide needed per million gallons per mg/l of alkalinity present in the effluent. Natural gas when burned yields 110 pounds of carbon dioxide per 1,000 cubic feet of gas (29).

Permutit (28-53) shows that when the calcium hardness is reduced to 35 mg/l and the magnesium noncarbonate hardness is reduced to 45 mg/l the alkalinity present in the effluent is 56 mg/l.

56 mg/l of alkalinity x 5 lbs of CO_2/mil gal/mg/l of alkalinity yields 280 lbs of carbon dioxide needed.

$$\frac{280 \text{ lbs of } CO_2 \quad \times \quad 1{,}000}{110 \text{ lbs of } CO_2/1{,}000 \text{ cu ft of gas}} = 2{,}550 \text{ cu ft of gas needed}$$

By calculating the cost of natural gas based on the minimum rate of 8.0 cents per 100 cubic feet the cost per million gallons of water treated can be determined.

$$\frac{2{,}550 \text{ cu ft of gas}}{100 \text{ cu ft}} \times 0.08 \text{ cents/100 cu ft} = \$2.04\text{/mil gal}$$

The cost of recarbonation for Brookings water softened to five grains per gallon of hardness by the lime-soda ash method of softening would be $2.04 per million gallons of water treated.