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SOAP USAGE AND WATER HARDNESS

BY

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Soap Usage and Water Hardness

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THE economic significance of this study lies in the monetary saving found to be obtainable through the use of soft water, in its convenience utility which reaches beyond any monetary gain, yet is of importance to the user, and in the effect that the findings may have on the soap industry, on the household water softener industry, on the construction of municipal water softening plants, on real estate values and community growth.

Water of a certain quality may possess both the economic characteristics of utility and scarcity and consequently have value; while water, as such, without regard to quality, may be of little use as well as abundant and consequently of little or no value. The primary purpose here is to measure the value of water quality, with respect to its effect on soap consumption in the home.

. To obtain information concerning this problem, market surveys of retail soap sales have been made in Chicago Heights, Bloomington and Champaign-Urbana, Ill., and Superior, Wis. These cities are comparable in size and are supplied with different types of water, including naturally soft, municipally softened, medium hard and very hard waters.

Soaps and soap products of all kinds sold at retail in the various cities have been included in the data. Commercial laundries have not been included in the study, because most of the commercial laundry work in Chicago Heights goes out of town, while most of the laundries in Champaign-Urbana have water softeners. Industrial use of soap has not been included, because the extent and type of industrial development varies materially from city to city. Some industries use large amounts of soap, while others use practically none.

Personal Interview Method Used to Collect Data

The personal interview method has been used to collect all data on soap sales, because a high percentage of returns is considered essential to the success of the study. The retail survey has proved to be the only practicable means of getting enough data on soap used in the home to be significant.

The original data obtained by the surveys, if used without correction, would not give accurate results. Corrections have been made, therefore, for such inaccuracies as incompleteness of data, the sale of soap to the surrounding trade territory, the use of water from water softeners and cisterns in hard water cities and differences between the type of water used in a city and in its surrounding trade territory.

The most important source of error is the trade territory supplied by the various cities[9]. Reilly's Law of retail gravitation seems to offer the best solution for this problem. According to that law, "Two cities attract retail trade from any. intermediate city or town in the vicinity of the breaking point, approximately in direct proportion to the population of the two cities and in inverse proportion to the square of the distance from these two cities to the intermediate town"[8].

Results of Field Survey

The data obtained from the field surveys have been summarized in Table 1. Table 2 presents the refined data in comparable form after corrections have been made for the various sources of error mentioned above.

Table I. Total Soap Sales in the Four Cities

City	Annual Soap Sales, Pounds	Annual Soap Sales, Dollars
Superior, Wis.	1,530,314	$196,133
Bloomington, Ill.	1,517,658	215,528
Champaign-Urbana, Ill.	2,093,881	307,732
Chicago Heights, Ill.	1,009,503	159,910

Superior, Wis., uses 29.2 pounds, or $3.75 worth, of soap per capita annually. Even with its relatively very soft water, 45 p.p.m. (parts per million) hardness, a considerable quantity of soap is required to remove dirt and grease. Water alone will not do the work. If it were possible for a city to obtain a water supply of zero hardness, it would still use almost as much soap as does Superior, Wis.[22]

Taking Superior as a base for comparison, it may be seen from the data presented in Table 2 that the excess soap consumption for Bloomington is 2.9 pounds per capita per annum. The cost of this excess is 73 cents. The annual per capita excess for Champaign-Urbana is 10.66 pounds, or $2.18. Chicago Heights, with its water supply of 555 p.p.m. hardness, uses annually 16.55 pounds, or $3.75 worth, more soap per capita than does Superior.

Table 2. Per Capita Soap Consumption with Different Types of Water

City	Total Hardness of Water Supply, p.p.m.	Annual per Capita Soap Consumption Pounds	Annual Cost of Soap per Capita, Dollars
Superior, Wis.	45	29.23	$3.75
Bloomington, Ill.	70	32.13	4.48
Champaign-Urbana, Ill.	298	39.89	5.93
Chicago Heights, Ill.	555	45.78	7.50

The excess soap usage for Bloomington, Champaign-Urbana and Chicago Heights, expressed in percentage of total soap consumption for each city, is 9 per cent, 26.7 per cent and 36 per cent respectively. This excess, expressed in terms of value percentage, amounts to 16.5 per cent, 36.8 per cent and 50 per cent for the various cities in the order named. The greater percentage excess in value than by weight seems to be due primarily to the use of more expensive soaps and soap compounds in cities supplied with hard water.

The significance of the excess soap requirements of hard water may be brought out more clearly by stating the total excess for each city. For Bloomington, with her present water supply of 70 p.p.m. hardness, the total annual excess soap requirement is 40.4 tons, or $22,942. Champaign-Urbana with her water of medium hardness, is using annually 216.6 tons, or $88,713 worth, of soap

more than would be required with water like that of the Superior supply. Chicago Heights, with a population of little more than half that of Champaign-Urbana, but having water almost twice as hard, uses 184./ tons, or $83,689 worth, more soap annually than would be necessary with soft water. It is calculated from the data at hand that Bloomington's excess soap usage, before she obtained her present supply of relatively soft water, must have been approximately 323 tons, or $162,000 annually.

Cost of Soft Water

In those sections of the country where relatively hard water prevails, there are various possible ways of obtaining soft water. Which of these devices, or what combination of them, can best solve the problem of scarcity of the quality of softness in water under a given set of conditions follows the principle of relative costs. In other words, in order to be able to draw conclusions concerning the economy of soft water, it is necessary to know the cost of obtaining it, as well as the advantages derived from it.

Not all of the various methods of obtaining soft water are available to any of the four trading centers considered. Superior has no interest in a better water supply than she now has, but the other three cities have possibilities of economies by one or more methods. Costs of obtaining soft water for Bloomington by various methods are presented in Table 3. Like information is given for Champaign-Urbana in Table 4 and for Chicago Heights in Table 5.

It will be noted by reference to Tables 3, 4 and 5, that cistern water is the most expensive in every case, with regard to both total investment and annual cost. Practically the entire cost of cistern water consists of interest and depreciation. Operating expense is so small that it has not been included in the data.

Household water softeners cost one-half as much as cisterns, but in the case of the former, there is an additional operating cost which consists primarily of chemicals, which brings the annual cost up to more nearly that of cistern water. This method of obtaining soft water rates second highest in total investment and annual cost for all three cities.

A municipal water softener furnishes the most economical method of obtaining soft water for Chicago Heights and Champaign-Urbana. This method has the advantage over all others with respect to both investment and annual costs.

Net Gain From Improved Water Supply

Bloomington's soft water supply has made possible a saving in soap by those families formerly using hard water. Soft water supplies for Champaign-Urbana and Chicago Heights would make possible similar savings in soap for residents of those cities now using hard water. If the entire population used hard water, the soft water supply would produce the total soap savings and net gains indicated in Table 6. That table also shows the per capita net gain produced by soft water for those individuals formerly using hard water in the various cities.

That part of the population using water from cisterns and water softeners is now saving soap but at a cost that is greater than the value of the soap saved. A municipal water softener can save those people future operating expense and upkeep. The original investment in cisterns and household water softeners, however, can not be retrieved.

A municipal water softening plant that could save the residents of Champaign-Urbana who now use cisterns $4.52 per capita, as compared to the $2.18 soap saving to those using hard water. Thus the saving to the 1,900 families, 6,728 individuals, using cisterns would be $15,-743 more than indicated in the figures of soap saving. Users of water softeners would save $4.37 per capita, or $2.19 more than the soap saving of those who use hard water. This group of 575 families, or 2,036 individuals, would save $4,459 more than the soap saving for the same group without water softeners. Thus a municipal water softener would save $20,202 in addition to the annual soap saving of $88,713 indicated in Table 6, or a total of $108,913. The cost of this saving is $38,-000, leaving a total net gain of $70,915 annually. Slight additional savings of this nature would apply to Bloomington and Chicago Heights but not enough to make any great difference in the figures as presented in Tables 3 and 5. This is because of the greater soap saving in the harder water cities.

Table 3. Cost of Obtaining Soft Water for Bloomington, Illinois, by the Various Methods Available

Method	Total Investment	Total Annual Cost	Annual per Capita Cost
Soap[1]		$22,942	$ .73
Soap[3]		162,300	5.19
Cisterns	$3,379,600	337.960[5]	10.93
Househ'd water softeners	1,689,800	295,315	9.56
Storage basin[3]	1,191,808	112,197	3.59
Muni. water softener[4]	26,635	10,417	.33
Stor. has. & soft., com..	1,218,442	122,614	3.92

[1] Excess with water of 70 p.p.m. hardness.
[2] Calculated excess with water of 800 p.p.m. hardness.
[3] For obtaining water of 250 p.p.m. hardness.
[4] For reducing hardness from 250 p.p.m. to 75 p.p.m. hardness. The additional cost of reducing hardness from 75 p.p.m. to 45 p.p.m. would be $1,488 per annum, or 4.7 cents per capita annually.
[5] Annual cost for cisterns includes interest at 6% and depreciation at 4%.

Table 4. Cost of Obtaining Soft Water for Champaign-Urbana, Illinois, by the Various Methods Available

Method	Total Investment	Total Annual Cost	Annual per Capita Cost
Soap		$88,713	$2.18
Cisterns	$3,774,000	377,400[1]	11.30
Household water softeners ..	1,887,000	259,462	7.77
Municipal water softener . .	250,000-300,000	38,000	.93

[1]Annual cost for cisterns includes interest at 6% and depreciation at 4%.

Table 5. Cost of Obtaining Soft Water for Chicago Heights, Illinois, by the Various Methods Available

Method	Total Investment	Total Annual Cost	Annual per Capita Cost
Soap		$83,689	$3.75
Cisterns	$2,022,800	202,280[1]	9.06
Household water softeners..	1.011,400	176,995	7.93
Lake Mich. water supply...	1,816,000	171.907	7.70
Municipal water softener ...	150,000	58.225	2.61

[1]Annual cost for cistern; includes interest at 6% and depreciation at 4%.

Table 6. Net Gains from Soft Water. Soap Consumption of Superior, Wisconsin, Taken as Base

City	Total Annual Cost of Soft Water	Soap Saved by Soft Water	Total Annual Net Gain	Annual per Capita Net Gain
Bloomington, Ill.....	$122,614[1]	$162,300	$39,686	$1.37
Champaign-Urbana, Ill	38,000	88,713	50,713	1.25
Chicago Heights, Ill.....	58,225	83,689	25,464	1.14

[1]Calculated from former supply of hard water.

Summary and Conclusions

It is evident from data presented that the part of the family budget devoted to cleanliness is materially affected by hardness of water. That effect is felt to the extent of $88,700 per annum by the population of Champaign-Urbana, while a like burden on the householders of Chicago Heights is only $5,000 less. In other words,

Table 7. Total Excess Soap Usage Due to Hardness of Water. Superior Soap Consumption Used as a Base for Comparison.

City.	Population	Total hardness of water supply p. p. m.	Total excess per day Pounds.	Dollars.
Superior, Wis.	36,113	45	Base	Base
Bloomington, Ill.	31,279[a]	70	221	62.85
Champaign-Urbana, Ill.	40,636[a]	298	1187	243.02
Chicago, Ill.	22,321	555	1012	229.29

			Total excess per year Tons.	Dollars.
Superior. Wis.	36,113	45	Base	Base
Bloomington, Ill.	31,279[a]	70	40.4	22,942
Champaign-Urbana. Ill.	40,636[a]	298	216.6	88,713
Chicago Heights, Ill.	22,321	555	184.7	83,689

a. Including non-resident student population.

the per capita excess soap usage for Chicago Heights is almost twice that for Champaign-Urbana, while a similar relation exists between the hardness of the water supplies of the two communities. Thus, the household soap bill increases as the hardness of the water with which soap is used increases.

Data Show Costs of Obtaining Soft Water

Since soap serves a useful purposes, the effect of hard water upon its increased usage is of comparatively little economic significance, apart from a consideration of how that usage may be reduced and how much such reduction may cost. Data presented in Tables 3, 4 and 5 show the costs of obtaining soft water by various methods. Comparisons of those costs are presented to show the relative efficiency of the various methods and the net gain obtainable by the use of the most efficient method. Bloomington's improved water supply is reducing the household soap bill $162,300 annually. This reduction is obtained by an expenditure of $119,617 annually, thus leaving a net gain of $42,683. Although the saving in the household soap bill that could be obtained by Champaign-Urbana would amount to little more than half that for Bloomington, due to the difference in hardness of water, the cost of a soft water supply would be only approximately one-third that of the Bloomington supply. Thus the net gain for Champaign-Urbana in soap economy for home use would amount to over $50,000 annually.

Worthy of mention as of economic importance is the minimum convenience value of soft water to a large number of individuals, as measured by the highest cost method in use for obtaining soft water. Many people in Champaign-Urbana pay as high as $11.30 per capita. if not more, for rain water. Economy of soap can offset only $2.18 of this total cost. Another dollar might be accounted for in other savings, such as reduced plumbing repair bills, but, pending some measurement, only a guess as to their saving can be suggested. The remaining $8, more or less, evidently brings greater satisfaction to the purchasers of the convenience utility of soft water than in any alternative economic good it might buy. Just what is the maximum that any individual might be willing to pay for soft water rather than be without it is indeterminable. That problem lies in the realm of subjective utility rather than of objective economic value. It may be considered, however, that any more efficient method of obtaining soft water will leave a consumer's surplus at least as great as the difference between the cost by that method and the cost of cistern water.

Municipal Plant Offers Greatest Economy

From comparative costs of obtaining soft water by the various possible methods, it appears that the municipal water softening plant offers the greatest economy, provided a water supply of sufficient quantity is available. Even the more expensive methods of obtaining a municipal supply of soft water, by the soft water storage basin and the long distance conveyance of soft water, appear to be more economical than either the private cistern or household water softener.

From the data presented it seems safe to generalize that almost any city, supplied with surface water requiring filtration and containing enough mineral matter to be at all noticeable, can well afford water softening. A similar generalization concerning cities supplied with ground water would hardly be safe, because of local factors of water supply and construction costs that might enter in. The following equation will show the degree of hardness necessary in any particular water supply in order that the economy in soap obtainable by soft water may pay for the cost of softening:

$$X = \frac{C - 75d + 75F}{F - d}$$

X = hardness of water supply in p.p.m., the softening of which will be paid for in soap economy alone.
75 = demonstrated attainable hardness of water in p.p.m. from municipal water softening plants.
F = soap waste per capita per year per p.p.m. hardness.*
C = capital overhead charges, including superintendence, per capita per year.
D = cost of chemicals per capita per year per p.p.m. hardness.

This equation applied to data for Champaign-Urbana shows that even if their water supply tested only 145 ppm. hardness, a municipal water softener that would soften the water to 75 p.p.m. would save enough in soap for home use alone to pay for itself. The economy point of hardness for the Chicago Heights supply would be 200 ppm., while for Bloomington, with its higher cost plant, it would be approximately 600 p.p.m.

Those Affected by Findings

Any attempt to evaluate the findings of this investigation must take the form of estimations of its effects upon certain economic groups. If the interest expressed in the outcome during its preparation can be accepted as an indication of those that may be affected by the results, there must be included soap manufacturers, water supply experts, public officials, manufacturers of household water softeners and private citizens. Although the chief interest has been shown through the hard water sections of the country, the extent of that interest has been indicated by letters from all parts of the United States and from foreign countries.

Effects Upon Soap Industry

The chief interest of the soap industry in the study lies in the influence the data presented may have on the development of soft water projects for city water supply and on the use of household water softeners.. It is

hardly to be expected that any economic fact presented to the public will be acted upon immediately by any large portion of the group or groups it may concern. While the soap industry serves the whole country, hard water affects only certain sections. Even a widespread movement to obtain soft water would affect soap sales only in those sections.

It seems doubtful whether the use of soft water will increase any more rapidly than the total population of the country increases. If that is true, soap production will not decrease. The effect will be simply to retard the growth of that industry below the increase it would enjoy with a continuation of the present rate of growth of that portion of the population using hard water.

Manufacturers of household water softeners are not likely to find their sales in general greatly affected by the facts here presented. Their market is probably so far from saturation that the publicity given the value of soft water through the installation of municipal water softening plants in the larger towns and cities may increase the demand for home softeners in other cities.

Influence on Installation of Municipal Softeners

Perhaps the greatest economic importance of this study will be found in its influence on the installation of municipal water sotteners. Many cities have been seeking accurate economic facts concerning the problem of water hardness, especially facts that affect the average citizen directly. Making known the fact that soap saved by soft water in the home will more than pay for softening the entire city supply, will in all probability hasten the gradually growing movement toward municipal water softening.

Two Facts Deserving of Mention

Of economic significance, apart from their connection with the present problem, are two facts that seem deserving of brief mention. The first is that Reilly's "Law" of retail gravitation has been tested by actual field survey and confirmed in so far as the data obtained may be considered a confirmation. The book expounding that law was published shortly after the present investigation was begun and had not had time to be subjected to test by other workers. No data available or method proposed seemed to present as scientific and accurate a solution to the problem of trading area as did this law of retail gravitation. Since it was new, however, it seemed advisable to test it in the territory covered by the data with which it was to be used.

The second fact of importance, apart from its direct connection with this study, is that the quantitative data showing the per capita domestic consumption of soap are the first data on that point that have ever been presented, in so far as it has been possible to determine. These data furnish the starting point for the main problem of the thesis, the economic effects of quality of water, with special reference to soap consumption in the home.

This is an abstract of a thesis submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Economics in the Graduate School of the University of Illinois, *1933*. For their assistance and guidance, acknowledgment is hereby given to the following professors of the Graduate School of the University of Illinois: A. M. Buswell, Professor of Chemistry, Chiet, State Water Survey Division, who suggested the problem; N. A. Weston; M. H. Hunter, under whose supervision the work has been done; Paul D. Converse; M. J. Wasserman and H. M. Gray; and to C. P. Hoover, Chemist in Charge of Water Purification, Columbus, Ohio.

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*F = O.8c at 425 p.p.m. Add 0.01c for every decrease in hardness at 25 p.p.m. Subtract 0.01c for every increase in hardness of 25 p.p.m.