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Hardness of Potable Water in Southwestern Skane

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PREFACE

Water resource systems have been an important part of resource and environment related research at IIASA since its inception. As demands for water increase relative to supply, the intensity and efficiency of water resource management must be developed further. This in turn requires an increase in the degree of detail and sophistication of the analysis, including economic, social and environmental evaluation of water resource development alternatives aided by application of mathematical modeling techniques, to generate inputs for planning, design, and operational decisions.

This paper is a contribution to the study of water resources management problems in Southwestern Skåne, Sweden, carried out by the Resources and Environment Area (REN) of IIASA in collaboration with the Department of Water Resources Engineering of the Lund Institute of Technology/University of Lund (LTH), Sweden. The study was initiated and pursued with the support of the Swedish National Environment Board, whose encouragement and financial assistance is gratefully acknowledged. The methodological work implemented within the framework of this study was generously supported by a grant from the Stiftung Volkswagenwerk, Hannover, Federal Republic of Germany.

This paper is concerned with water hardness in the municipal water supply systems. After a general overview of the health aspects of water hardness, this issue is discussed in the specific context of Southwestern Skåne.

Janusz Kindler
Chairman
Resources & Environment Area

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HARDNESS OF POTABLE WATER IN SOUTHWESTERN SKÅNE

INTRODUCTION

Water quality problems have been incorporated into water resources systems as an integral part. Therefore regional water management has to take into account not only quantitative changes, but also qualitative ones that will occur or are foreseen to occur. This holds true also for the region of Southwestern Skåne (Sweden), where water hardness can be substantially affected by the withdrawal of water from the Bolmen Lake.

Different water resources contribute to covering the demands in Southwestern Skåne (Sweden) - both surface water and groundwater. The Vomb Lake and Alnarp aquifer are the main water resources for the southern part of the area, while the Ring Lake and several local groundwater resources are basic for the northern part. The development of the water resources system will include the Bolmen Lake Scheme, which will be able to cover all the demands of the region. There is, however, a substantial difference in the hardness of water of these resources. The sources now available supply water of high or medium hardness: even the surface water of lakes has a relatively high degree of hardness. Water from the Bolmen Lake, on the other hand, is very soft.

The solution of problems related to integration of water resources in a regional water resources system is thus complicated by the changes in water hardness.

BASIC WATER CHEMISTRY INFORMATION

Hard water is under some conditions apt to form solid incrustations in pipes. When changes in the hardness of the water, its acidity and alkalinity take place, some dissolving tendencies may occur.

The equilibrium between the Ca^{++}(aq) ions and CO_3^{--}(aq) ions in water can be characterized by the saturation index of Langlier (1946), that was derived on the basis of the equation

$$C_aCO_3(s) + H^+ = Ca^{++} + HCO_3^-$$

From this equation, pH_s is derived, i.e. the pH value at which the calcium and the alkalinity are in equilibrium with $CaCO_3(s)$. The saturation index S then measures the "distance" in pH from this state

$$S = pH_a - pH_s$$

where pH_a is the measured pH of the water. For S > C the water will have the tendency to form solid incrustations of $CaCO_3$.

Flentje (1961) found empirically that the saturation index is also an indicator of corrosion conditions in pipes. Estimation of the saturation index is simplified by using Figure 1.

The raw water from the Bolmen Lake, for instance, has a mean value of hardness expressed as the calcium content Ca^{++} 8.9 mg/l with pH_a = 6.7 (mean values of the observations 1971-73 - see Table 1). This point (6.7; 8.9) is in Figure 1 in the soluble region of the diagram. The pH value corresponding to the level of 8.9 can be read from the diagram moving horizontally along the pH ordinate until the boundary level is reached and pH_s = 9.2. The Langlier index S = 6.7 - 9.2 = -2.5. Therefore this water will be very corrosive to iron pipes. The water at the tunnel intake has lower pH_a = 5.0 than the Langlier index, which at S = 5 - 9.2 = -4.2 indicates even higher corrosivity of this water.

HEALTH ASPECTS OF WATER HARDNESS

Since 1957, when Kobayashi (1957) published his report in which the geographical relationship between chemical properties of the river water and the death rate from apoplexy was shown, the relationship of health to drinking water has been studied more intensively. The relationship between water hardness and cardiovascular disease has been especially thoroughly investigated.

Figure 1. Determination of saturation index (15°C).

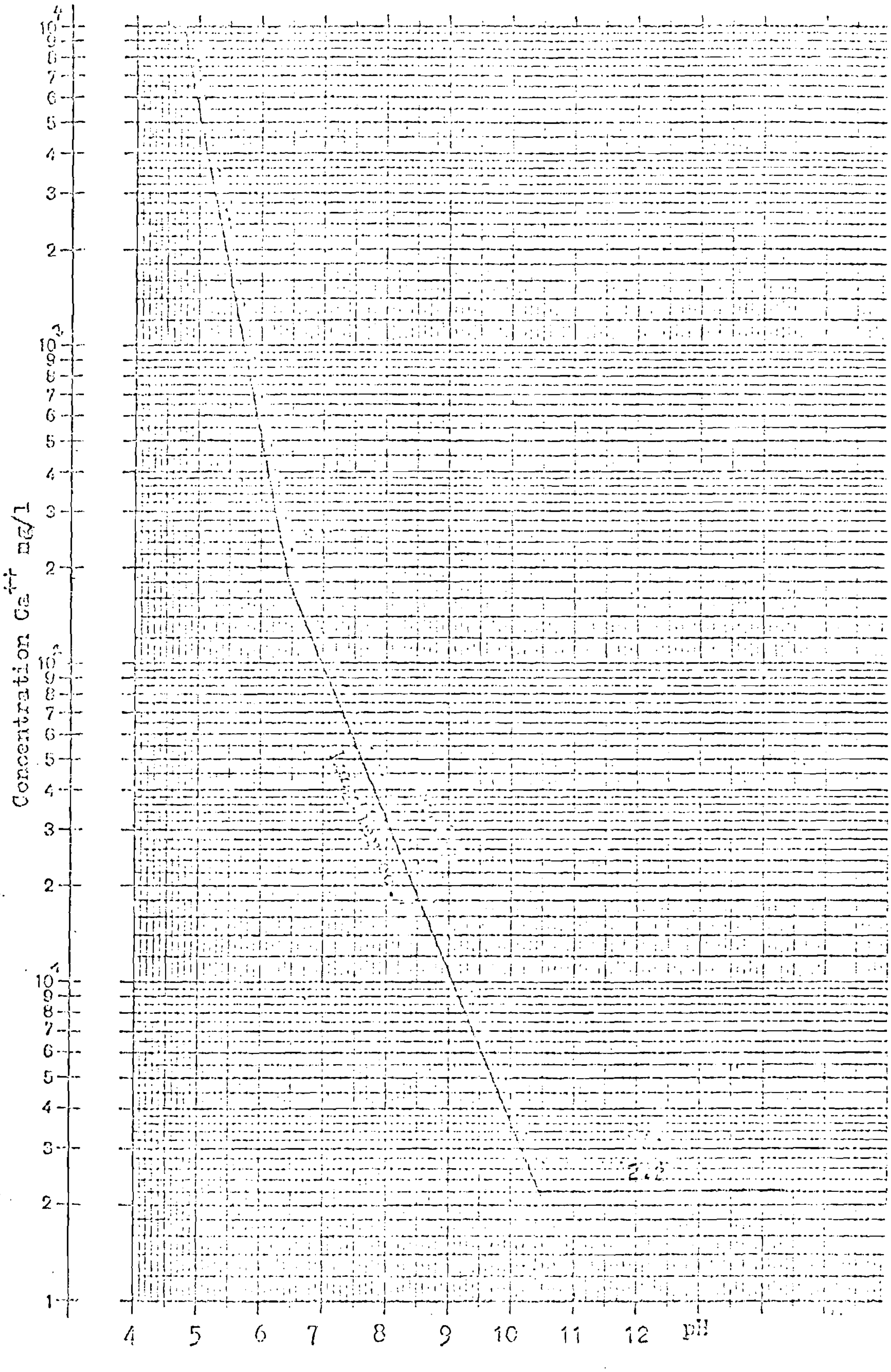

Table 1. Quality of the Bolmen Lake raw water.

Date	T °C	pH	HCO_3^- mg/l	Ca^{++} mg/l
1971				
26/3	4,0	6,3	4,5	7,0
29/3	4,0	6,3	6,1	13,0
30/3	4,0	6,3	6,1	11,5
27/4	9,0	6,4	6,1	9,6
4/5	9,0	6,7	4,6	11,0
5/5	9,0	6,8	6,1	13,0
6/5	10,0	6,7	4,6	11,0
12/5	15,0	6,9	4,6	8,0
13/5	15,0	6,9	4,6	8,0
14/5	15,5	6,8	4,6	8,0
17/5	16,0	7,2	4,6	8,0
19/5	16,0	8,2	4,6	8,0
25/5	13,0	6,9	4,6	11,5
26/5	13,0	7,2	4,6	8,0
27/5	12,0	6,9	4,6	8,0
4/6	20,0	6,7		6,7
7/6	20,5	6,7	4,6	8,0
8/6	20,0	6,9	4,6	7,7
9/6	18,5	6,7	4,6	8,0
11/6	17,0	6,7	4,5	8,0
11/6	17,0	6,5		7,0
14/6	16,0	6,9		9,1
14/6	16,0	7,1	4,6	8,3
15/6	16,0	7,1	5,4	7,8
16/6	15,0	6,9	4,6	7,5
17/6	14,5	6,9	4,6	8,0
18,6	14,0	6,9	4,6	7,8
23/6	16,0	6,9	4,6	7,5
29/6	16,0	7,1	4,6	8,0
30/6	16,0	7,0	4,6	7,5
1/7	17,0	7,1	4,6	7,5
2/7	18,0	7,0	4,6	8,0
19/7	16,6	6,4		6,3
26/7	18,4	6,5		6,7
9/8	20,0	6,7		9,4
11/8	17,0	6,9	5,4	8,0
11/8	17,0	6,9		4,6
21/9	14,0	6,7		6,6
20/10	-	6,4		6,8
26/10	9,0	6,6		11,2
1/11	8,0	6,5	4,6	11,0
2/11	-	6,8		11,0
3/11	9,0	6,6	6,1	8,0
3/11	9,0	6,6	5,4	8,3
5/11	9,0	6,7	4,6	7,5
17/11	5,0	6,5	5,4	8,8
17/11	5,0			7,5
18/11	5,0	6,7	4,6	10,5
19/11	3,0	6,4	4,6	10,0
14/12	3,0	6,7	4,6	9,0
15/12	3,0	6,6	4,6	9,0
16/12	3,0	6,8	5,4	9,5
20/12	4,0	6,7	4,6	9,0
21/12	4,0	6,8	5,4	10,0
21/12	4,0	6,7		10,5
22/12	4,0	6,8	4,6	9,5

Date	T °C	pH	HCO_3^- mg/l	Ca^{++} mg/l
1972				
18/1	2,0	6,7	6,1	9,5
19/1	2,0	6,8		5,0
19/1	2,0	6,7	5,4	9,3
20/1	2,0	6,7	5,4	9,5
21/1	2,0	6,7	6,1	8,5
25/1	2,0	6,7	6,1	10,5
25/1	2,0	6,9		9,5
26/1	2,0	6,7	6,9	9,0
2/2	2,0	6,7	5,4	9,0
2/2	2,0	7,1		7,3
3/2	2,0	6,8	7,7	10,0
4/2	2,0	6,8	6,9	9,5
8/2	2,0	6,6	6,8	8,5
9/2	2,0	6,9	6,1	9,8
9/2	2,0	6,4		8,5
10/2	2,0	6,8	7,7	9,8
15/2	2,0	6,7		8,8
15/2	2,0	6,7	6,1	10,0
16/2	2,0	6,7	6,1	9,8
17/2	2,0	6,8	5,4	10,0
24/2	2,5	6,8	6,1	9,5
29/2	2,5	6,9	6,1	10,0
1/3	-	6,5		10,5
2/3	2,5	6,8	6,1	10,0
6/3	2,5	6,9	6,1	10,0
7/3	2,5	6,85	6,1	10,0
8/3	2,5	6,8	6,9	10,0
9/3	2,5	6,9	6,9	10,5
13/3	3,0	6,7	6,1	2,0
14/3	3,0	6,85	6,1	10,5
14/3	3,0	6,3		10,5
28/3	3,5	6,1		9,0
25/4	8,0	6,5	4,6	10,0
26/4	8,5	6,65	6,1	8,5
26/4	8,5	6,5		7,8
27/4	8,5	6,8	5,4	9,5
3/5	9,5	6,6		8,0
3/5	9,5	6,6	4,6	9,5
4/5	11,0	6,75	6,1	8,0
5/5	11,0	6,75	6,1	9,5
9/5	14,0	6,8	6,1	9,5
9/5	14,0	6,6		7,5
10/5	14,0	6,8	6,1	9,5
17/5	13,0	6,6	6,1	10,0
17/5	13,0	6,4		6,5
18/5	13,0	6,9	6,1	10,0
19/5	12,0	6,8	6,1	10,5
24/5	13,0	6,8	6,1	10,0
24/5	13,0	6,6		7,3
25/5	13,0	6,8	6,1	8,0
30/5	12,0	6,9	6,9	8,5
31/5	13,0	6,8	6,1	9,5
31/5	13,0	6,1		9,0
1/6	12,0	6,85	5,4	8,0
7/6	15,0	6,85	4,6	10,0
7/6	15,0	6,5		9,0
8/6	16,0	6,95	5,4	10,5
13/6	16,0	6,9	6,1	9,0
14/6	15,0	6,95	6,9	8,5
15/6	17,0	6,8	6,1	9,5
16/6	17,0	6,85	5,4	10,0
20/6	17,0	7,0	6,1	8,0
21/6	17,0	6,8	6,1	9,5
22/6	17,0	6,9	6,1	9,5
27/6	19,0	6,9	6,1	7,5
28/6	20,0	7,0	5,4	9,5
28/6	20,0	6,3		8,5
29/6	20,0	7,0	4,6	8,0
30/6	21,0	6,7	5,4	8,5

Table 1. Quality of the Bolmen Lake raw water (cont.).

Date	T °C	pH	HCO_3^- mg/l	Ca^{2+} mg/l
1972				
26/7	22,0	6,7	5,4	9,0
26/7	22,0	6,9		7,3
27/7	22,0	6,7	6,1	8,0
2/8	20,0	6,7	6,1	9,5
3/8	21,0	6,8	6,1	10,0
3/8	21,0	7,1		7,0
4/8	20,0	6,7	6,1	9,5
8/8	20,0	6,9	6,1	10,5
9/8	20,0	6,9	5,4	10,5
9/8	20,0	6,7		7,3
10/8	20,0	6,9	6,1	8,0
16/8	19,0	6,8	5,4	8,3
16/8	19,0	6,4		7,9
19/8	18,0	6,7	6,1	8,8
23/8	18,0	7,1		7,0
23/8	18,0	6,7	6,1	8,3
24/8	18,0	6,7	6,9	9,0
5/9	17,0	6,8	6,1	8,8
6/9	17,0	6,9	6,1	9,0
7/9	17,0	6,8	6,1	9,0
8/9	17,0	6,8	6,1	8,8
28/9	11,5	6,6	5,4	10,0
3/10	10,5	6,9	5,4	9,5
4/10	10,5	6,6	6,1	9,5
5/10	10,5	6,7	6,1	9,5
6/10	10,5	6,7	5,4	9,5
11/10	11,0	6,7	6,1	9,5
12/10	11,0	6,7	6,1	9,5
13/10	11,0	6,8	6,1	9,5
17/10	8,5	6,6	6,1	8,5
18/10	8,5	6,6	6,1	8,5
25/10	7,0	6,7	6,1	9,5
26/10	7,0	6,8	6,1	8,0
27/10	7,0	6,8	6,1	9,0
1/11	8,5	6,7	6,1	9,0
2/11	8,5	6,8	6,1	9,0
7/11	8,0	6,8	6,1	9,0
8/11	8,0	6,9	6,1	8,3
9/11	8,0	6,8	6,1	9,0
10/11	8,0	6,9	6,1	9,0
15/11	5,0	6,8	6,1	9,5
16/11	5,0	6,8	6,1	10,0
21/11	3,2	6,8	5,4	10,0
22/11	4,0	6,8	6,1	9,5
23/11	4,0	6,7	5,4	8,5
28/11	5,0	6,9	6,1	9,5
5/12	5,5	6,9	6,1	8,8
6/12	5,5	6,8	6,1	8,0
12/12	5,5	7,0	6,1	9,8
13/12	5,0	7,1		7,8
13/12	5,0	6,9	5,4	9,5
14/12	5,5	6,9	5,4	9,0
19/12	6,0	6,6		9,4
19/12	6,0	6,7	5,4	8,8
20/12	6,0	6,8	5,4	8,0
21/12	5,0	6,9	5,4	8,5
22/12	4,5	6,9	5,4	9,5

Date	T °C	pH	HCO_3^- mg/l	Ca^{2+} mg/l
1973				
9/1	3,0	7,1	6,1	9,5
19/1	3,0	7,1		7,8
12/1	3,0	6,8	6,1	9,0
16/1	3,0	6,9	5,4	9,0
17/1	3,0	7,2	6,1	9,0
17/1				10,3
18/1	3,0	7,1	6,1	9,0
23/1	3,0	6,8	4,6	9,0
23/1	3,0	5,6		7,4
25/1	3,0	6,7	6,1	9,0
25/1				7,4
30/1	3,0	6,8	5,4	9,0
31/1	3,0	6,8	5,4	9,0
31/1	3,0	6,2		7,1
1/2	3,0	6,7	5,4	9,0
6/2	3,0	6,7	5,6	9,0
13/2	3,0	6,7	4,6	9,0
14/2	3,0	6,6	4,6	9,0
14/2	3,0	6,7		7,1
15/2	3,0	6,7	5,4	9,5
21/2	3,0	6,6	4,6	9,5
22/2	3,5	6,5	4,6	9,5
23/2	3,5	6,5	5,4	9,5
28/2	3,0			7,1
8/3	3,5	6,5	3,8	9,0
8/3	3,0			7,1
14/3	4,0	7,3		7,1
14/3	4,0	6,8	5,4	10,0
15/3	4,0	6,8	5,4	10,0
16/3	4,0	6,9	5,4	10,0
20/3	4,0	6,8	5,4	10,0
21/3	4,5	6,9	5,4	10,0
21/3	5,0			7,6
22/3	5,0	6,9	5,4	10,5
23/3	5,0	6,9	4,6	10,0

The first study of this kind was probably done by Schroeder (1960), stating that areas with hard drinking water supplies exhibited statistically a significantly lower than average rate of death by cardiovascular diseases, whereas areas with soft water had a higher rate.

Over the next two decades, a series of studies of this kind followed. The investigations of the health aspects of water hardness in both these studies and present research can be divided into two main groups, i.e.:

(1) In the first group, the authors of the studies tried to find out whether this relationship is statistically significant and researched the degree of this significance;

(2) In the second group, the possible causes of this relationship were investigated together with the possible mechanism of water hardness influence.

Statistical Approach

The study by Schroeder (1966) may be counted among those of the first group. He reviewed the correlation with more recent mortality rates, and a relatively high negative correlation between water hardness and cardiovascular disease was found (coefficient of correlation of death rates for cardiovascular disease for white males aged 45 to 64 years was $r = -0.411$).

This correlation was confirmed by Morris, Crawford and Heady (1962) in England and by Biorck, Boström and Widstrom (1965) in Sweden. In more recent studies Shaper, Clayton and Morris (1974) and Shaper (1975) have shown that the coefficient of correlation for population aged 45-64 years was as high as -0.71 for an area covering 61 more populous boroughs in England and Wales. Hudson and Gilcreac (1976) analyzed drinking water hardness and cardiovascular disease mortality data from about one hundred cities in the U.S.A. and likewise found the above-mentioned negative correlation.

As e.g. Bierenbaum (1976) stated, however, some exceptions to this overall negative correlation were found in the cases of the neighboring cities of Kansas City, Kansas and Kansas City, Missouri. The water of Kansas City, Missouri was softened to about half that of Kansas City, Kansas. According to most of the previous correlation analyses, the rate of cardiovascular disease mortality should have been higher in Missouri, where soft water prevailed; instead, it was significantly lower there. This exception is nonetheless not statistically significant, dealing as it did with only two element samples.

Therefore the study by Masironi, Pisa and Clayton(1979), based on the assumption that the negative association between water hardness and cardiovascular disease (i.e., the harder the water the lower the mortality rate from cardiovascular disease) is more evident in studies covering large geographical areas with a sufficiently high population. The WHO Myocardial Infarction Community Registers in seventeen European towns and cities were used to ascertain whether the negative relationship between the hardness of drinking water and cardiovascular disease applies in Europe, too. The overall negative correlation concerning this relationship was found; some exceptions, however, were discovered, namely the two cities of Göteborg (referred to in the study as Gothenburg) in Sweden and Tampere in Finland. The water supplies in these two cities have almost the same level of hardness (45 resp 62 mg/l $CaCO_3$, which indicates soft water), but the myocardial rate of heart disease was more than twice as high in Tampere as in Götheborg (13.3 resp 5.5).

In Australia, Meyers (1975) compared the death rates for cardiovascular disease in Brisbane and Melbourne, finding it higher in Brisbane although that city had hard drinking water (142 mg/l $CaCO_3$) and Melbourne had soft water (13 mg/l $CaCO_3$). In both cities, however, the death rate is stated to be relatively high.

These opposing indices require a more thorough investigation of the problem. Some authors have therefore concentrated their attention to possible causes of this relationship.

Causal Approach

The second group of investigations of the water hardness and cardiovascular disease relationship attempts to find the water factor in combination with other risk factors of cardiovascular disease (toxic metals, obesity, smoking habits, blood pressure level, etc.) and the influence of water hardness on human tissues and intestines.

The paper presented by Masironi (1973) at the 9th International Congress of Nutrition held in Mexico from September 3-9, 1972, can be considered as the first summarizing paper taking the causal approach. This paper reviews the relationship between trace elements and cardiovascular disease. Some elements (e.g. Zn, Cu, Cr, F, Mn, Si, V) seem to exert beneficial influences on the cardiocirculatory functions, while others like cadmium, cobalt and lead (Cd, Co, Pb) may have detrimental effects. The association between soft water and higher cardiovascular death rate may be due to the fact that soft waters lack the beneficial elements present in hard water, or that they extract harmful elements from pipes.

A very important contribution in this second group of studies was the paper by Neri et al. (1975), presented at the Annual Conference of AWWA on June 18, 1974. Analyzing data from 575 Canadian communities, they not only investigated geographical correlations, but also extended their studies to tissue analyses of the heart muscle of persons dying from myocardial infarction and incidents. In this way they were able to determine which elements really differ in healthy and in ill subjects. They concluded that magnesium appears to be the element most probably responsible for associations between cardiovascular mortality and water hardness.

One possible explanation of the correlation between water hardness and cardiovascular disease is the fact that soft water tends to pick up elements from the distribution systems, in contrast to hard water, which loses elements.

Similar results were presented by Sharrett (1977), who stated that hard water can contribute significantly to daily magnesium intake. Residents of hard water areas may have raised magnesium levels in coronary arteries, bone and myocardial tissue. Soft water combined with lead plumbing may cause elevation of lead levels in the body and in blood.

That magnesium is the main source of differences between soft and hard water areas is suspected by the Chipperfields (1979). Two areas (Burnley and Hull in Ontario, Canada) were compared, and it was found that calcium concentration was little higher in the hearts of those dying from cardiovascular diseases than in those who were not suffering from such diseases. Therefore it is probably not the calcium content of hard water that causes the water effect in cardiovascular mortality. On the other hand, the low magnesium content of soft drinking water might be associated with low myocardial magnesium concentrations found in those dying from cardiovascular disease. This suggested that an intracellular deficit of magnesium might be the important factor in increase of the cardiovascular death rate.

Other authors, however, are not convinced of the efficacy of magnesium in protecting against cardiovascular disease. If all studies agreed that a simple increase in ingested magnesium or calcium helped prevent cardiovascular disease, then it would be an easy matter to add calcium or magnesium to the water supply. Bierenbaum (1976) reviewed the references concerning this question and listed the different attitudes. The key to this problem is probably in analysis of the metabolic role of bulk and trace elements in the process.

Some part of this question was answered by Ingols and Craft (1976), who evaluated the protective action of the calcium and magnesium ions against the passage of metallic ions from food or water thorugh the intestinal wall to the vascular system.

Conclusion and Discussion

On the basis of the studies cited and in accordance with the main recommendation of the Advisory Panel of the Committee on Medical Aspects of Food Policy on Diet in Relation to Cardiovascular and Cerebrovascular Disease (1974), the following conclusions were reached:

1) Differences in the concentration of dissolved substances in the water supply as an essential constituent of the diet, affect the amount in the diet of these substances. Individuals who live in an area where the water supply is soft may receive from food cooked in or otherwise treated with water, and from drinking water, appreciably less calcium (and less of other metals, e.g. magnesium but not lead) than those who live in a hard water area.

2) During the past two decades, investigators in several countries have observed a negative association between the hardness of the domestic water supply and the local death rate for cardiovascular disease.

3) The bulk constituents of hard water exhibit a protective effect. The cause of this effect may be a lowered intestinal absorption of toxic trace metals.

4) Trace elements or components present in soft water could have a harmful effect on health and cardiovascular disease death rates. For example, lead and cadmium, which have toxic health effects, could be leached from the water supply system.

5) Compounds and trace elements often associated with hard water might provide a protective effect against cardiovascular disease. Their absence could constitute a dietary deficiency and thus weaken the population, thus rendering it more susceptible to cardiovascular disease.

WATER RESOURCES OF SOUTHWESTERN SKÅNE

The available information concerning water hardness of various water resources in Southwestern Skåne differs according to the time and duration of measurement and according to the type of resource, i.e. whether surface or underground water is being measured. Therefore the form of data used in this study corresponds to this available information. The final presentation, however, will enable us to compare the resources and evaluate the final water hardness after the mixing of different resources.

Input Information on Hardness of Water

The main water resources at present are the Ring Lake water, treated by infiltration together with several local ground water resources in the northern part of the area, and the Vomb Lake and Alnarp Aquifer in the southern part of the area. In the future, the system is to be expanded through the Bolmen Lake Scheme.

The Ring Lake system can be characterized by the following data on water hardness:

Piped water after treatment has a total hardness of 67 mg/l Ca^{++}. Total hardness of the water of the Rönne River immediately downstream of the Ring Lake (according to measurement on October 1, 1967) was 53 mg/l Ca^{++}. These data were supplemented by measurements made in 1978 (de Maré, 1980), and the result of measurement after treatment in the Ring plant can be characterized by the mean value of water hardness 65 mg/l Ca^{++}, with minimum value 56 mg/l and maximum value 72 mg/l.

Water in the water supply system has a higher level of hardness due to infiltration and mixing with underground water. When water is infiltrated at Helsingborg and mixed with water from Råån and groundwater from rock ground in an approximate proportion of 11.0: 1.5: 0.9, then the resulting hardness of water pumped to the water supply system has the value of 81 mg/l Ca^{++} with maximum values of 83 mg/l and minimum values of 79 mg/l.

This water can be characterized as hard water. If the value pH = 7.9 is considered (as proposed by VBB, 1972), then the resulting value of the Langlier index will be 0.7, indicating a slight possibility of $CaCO_3$ precipitation. In the study (VBB, 1972) of mixing water from the Ring Lake with water from the Bolmen scheme, the value of 53 mg/l Ca^{++} was obtained for the Ring Lake water, according to the projected treatment of this water. Thus the Langlier index will be +0.1, indicating intermediate water without corrosion or coating of pipes.

Water from the Vomb Lake and the Alnarp Aquifer is very hard. Since it is not softened, the values of hardness from raw water and treated water do not differ substantially. The mean value for the period of measurement (1970-78) was 94.8 mg/l Ca^{++} for the Vomb raw water and 94.5 mg/l for the Vomb treated water respectively, with minimum annual value of 91 mg/l for both. For the Alnarp Aquifer, the mean value was 118.0 for raw water and 117.9 for treated water respectively, with an annual maximum value of 122 and 124 mg/l and annual minimum values of 112 and 111 mg/l for raw and treated water respectively.

Ground water resources in the Kävlinge River basin having capacity greater than 500 m^3/day had a mean weighted value of water hardness 106 mg/l Ca^{++} with maximum value at 150 mg/l and minimum value at 90 mg/l.

The mean pH value for this resource is 7.5. The Langlier index will therefore be +0.3 for the Vomb Lake, +0.5 for the Alnarp Aquifer, and +0.4 for the ground resources in the Kävlinge River basin indicating the $CaCO_3$ precipitation tendency.

The water hardness of the Bolmen Lake was measured after 1966 and in the period 1971-73. The mean value for the period 1971-73 was 8.9 mg/l Ca^{++}, with a maximum of 13.0 and a minimum value of 4.6 mg/l (the value 2.0 from March 13, 1972 is probably a measurement error, as on March 9, 1972 and March 14, 1972, the value 10.5 was recorded.

The mean value of pH was 6.72, with the maximum value at 7.3 and the minimum at 6.0 (values 5.6 and 8.2 were statistical outlyers and were considered as errors of measurement).

For the mean value of pH = 6.7 and hardness 8.9 mg/l Ca^{++}, the Langlier index will be 6.7 - 9.2 = -2.5. This is an index of very soft and corrosive water. The resulting conclusion stemming from this investigation was to treat water for drinking purposes in two stages. The first stage would involve alkalization by lime to values of pH 8.0 to 8.5 and change in hardness of 16 mg/l Ca^{++} (see Table 2); in the second stage, water would be mixed with other water resources in a water resources system in Southwestern Skåne.

Table 2. Capacity of Water Resources.

Resource	Present Capacity m3/s	Possible Enlargement m3/s
Ring Lake	1.13	
Vomb Lake	1.50	
Alnarp	0.31	0.5 - 0.8
Bolmen Lake	0.0	6.0

Water Quality Standards and Water Hardness

The water hardness can be judged from the standpoint of water quality standards. However, in Sweden there is no state standard of this kind. In 1969 a proposal for judging water quality was published, and although it was never officially approved, it has been used in practice. In 1980, a group investigated the EPA standards with the aim of arriving at Swedish standards that can be officially approved. These standards are categorized according to the purpose of water use, i.e.:

a) Outdoor swimming, natural waters

b) Drinking water supply system

c) Fishing water

d) General status

Hardness of water can affect the content of heavy metals (lead, cadmium) in tap water. This fact was not considered in the water standards discussed above; they could therefore not be used in judging hardness of water in the Southwestern Skåne area.

Dissolving Scale Deposits after Changes in Water Hardness

In the Skåne area, the expansion of the water supply system by water from the Bolmen Scheme may occasion a change in water hardness to lower values. This change may be considered purposeful for some parts of the existing system, as the scale dissolving tendency may be forecasted.

If such dissolving occurs, it will generally be very slow at first. The rate depends in the first place on the pH and CO_2 content of the water. Water in contact with air readily absorbs CO_2 gas, which under certain conditions converts to a weak carbonic acid.

$$CO_2 + H_2O \rightarrow H_2CO_3$$

This weak acid can dissolve calcium carbonate to form soluble calcium bicarbonate:

$$CaCO_3 + H_2CO_3 \rightarrow Ca^{++} + 2HCO_3^-$$

After water treatment, the content of CO_2 will be limited, and if such a reaction occurs, it will diminish along the water mains. For this and other reasons (Uhlig ,1971), the process of dissolving would be very uneven. Some parts would be left without any appreciable change, whereas in other parts, corrosion would occur. Dissolution of previously deposited scale by a change in water characteristics can result in a porous or sloughing scale deposit, which, as reported by Cowan and Weintritt (1976), can also foster localized corrosion.

After aggregation of the Bolmen Scheme into a water resources system with the existing resources, therefore, the water properties should be such as to reach an equilibrium or near equilibrium conditions. This can be achieved through chemical stabilization, namely by adjustment of the pH value, Ca^{++} and/or alkalinity of water to its $CaCO_3$ saturation equilibrium. The stabilized water then neither dissolves nor precipitates $CaCO_3$. Equilibrium conditions are defined by Langlier index or by precitable lime. It is obvious that higher values of the Langlier index (L.I.) indicate a greater tendency to corrosion (L.I. < 0) or scale forming (L.I. > 0). Quantitative evaluation is, however, very difficult (Fair, Geyer, Okun, 1968). One reason lies in the fact that the quantitative evaluation is dependent on conditions near the investigated surface, that can differ from the mean conditions. The practical solution of this problem lies in a design that would secure equilibrium conditions in the whole system, including water from the Bolmen Scheme.

Qualitative Impact of Mixing Different Water Resources

The possible problems associated with mixing waters from different resources have been studied by Vattenbyggnadsbyran (VBB) using Sydvatten's order as a basis. The result of VBB's study (VBB, 1972) has been compared with the methods used in this study, with the accent on the possible health consequences. The main focus of VBB's study was the problem of corrosiveness of the mixed waters as compared with the original unmixed waters. The health problems may be affected by the water corrosiveness; the relationship, however, is not a straightforward one. The quality of water from the Bolmen Lake was considered in these calculations according to figures in Table 3 following.

Table 3. Quality of the Bolmen Water Considered in Mixing.

	Before Alkalinization	After Alkalinization with Lime
pH value	6.5	8.0 to 8.5
Calcium Ca g/m^3	15	16
Precitable lime calculated as Ca g/m^3	-3	-1
Bicarbonates, HCO_3^-	5	9
Free carbon acid as CO_2	3	< 1
Agressive acids calculated as CO_2 in g/m^3	3	1

SOURCE: VBB, 1972.

The negative values of precitable lime indicate that this water has the ability to dissolve $CaCO_3$.

Table 3 makes apparent the relatively low content of bicarbonates and a relative lack of calcium. The pH values are intended to be raised to values 8.0 to 8.5. The results of the calculations made by VBB show that despite the alkalinization to high values of pH, water is still aggressive, due mainly to low content of calcium and bicarbonates. In order to arrive at equilibrium conditions (with Ca^{++} content at 16 g/m^3), the pH values had to be raised up to approximately 9.5. According to EPA standards, water of such high alkalinity cannot be distributed by the water supply system; therefore the maximum possible value of pH for normal and extra class V2/V3-EPA is 8.5.

According to the present stage of the planning process, all water coming from the Bolmen Scheme will be treated in the treatment station located near the Ring Lake outflow and then mixed with treated waters from the Ring Lake. This plan is supported by the present high aggressivity of the Bolmen waters and by the prediction of even higher values of untreated water aggressivity of these waters in the future. By recent measurements and their evaluation by VBB it was found that the increases in the acidity of the Bolmen waters are most probably due to acid rains. This fact must be taken into consideration in the analysis of the extent to which water treatment is necessary.

In judging the quality of water, not only the aggressivity, but also the content of bicarbonates was taken into account. Therefore the mixing of all water from the Bolmen Scheme with the waters from the Ring Lake was considered.

The values of the saturation index in Table 4 below were calculated using the temperature 10°C, as the same value was used in other calculations by VBB. Therefore the values from Figure 1 (which is based on values for 15°C) could not be used, and an approximative method of calculation proposed by Cowan and Weintritt (1976) was applied. The first column of Table 4, which corresponds to the last column of Table 3, shows the data for the alkalinized Bolmen Lake water. The last column of Table shows the data for the Ring Lake water (according to the VBB study). When these data are compared with those on page 11, the only difference observable is in the Langlier index, as the value 0.1 was calculated for 15°C and the value in Table 4 was determined for 10°C.

The body of Table 4, with the exception of the last three rows, is based on data from the VBB study (VBB, 1972). In the last row but one, Ca^{++} content was calculated proportional to the degree of mixing and the corresponding Langlier index is in the last row.

Using either the precitable lime or the saturation index as the indicator, it is apparent that the corrosiveness of the mixed water, without hardening processes, is even higher than that of the individual resources. This can be deduced from the relatively low content of bicarbonates that can otherwise form a buffer for determination of the pH value. VBB used a model for calculating the pH values, on the basis of bicarbonates (VBB, 1972), that is not linear in pH values. For instance, the linear combination of pH values for the case of 10% waters from the Ring Lake and 90% from the Bolmen Lake will be 0.1 x 7.9 + 0.9 x 8.5 = 8.44, not 8.2.

The solution to possible water corrosiveness and health problems is given in the last two rows of Table 3, using the water hardening processes that can increase the water hardness to 35 mg/l Ca^{++} (de Maré, 1980). Then none of the combinations of mixed waters will demonstrate aggressiveness.

Table 4. Water Hardness and pH under Different Mixing Proportions.

Ring Lake %	0	5	10	15	20	25	30	50	75	100
Bolmen Lake %	100	95	90	85	80	75	70	50	25	0
pH value	8.5	8.3	8.2	8.1	8.1	8.0	8.0	8.0	7.9	7.9
Ca mg/l	16	18	20	22	23	25	27	35	44	53
Precitable lime calculated as Ca mg/l	-1	-1	-1	-1	-1	-1	-1	-1	-1	<1
Bicarbonates HCO_3^- mg/l	9	13	18	22	26	31	35	53	75	97
Free carbon acid as CO_2 mg/l	<1	<1	<1	<1	<1	<1	<1	1	2	2
Aggressive acids calculated as CO_2 mg/l	1	1	1	1	1	1	1	1	<1	<1
Saturation index	-0.4	-0.4	-0.5	-0.5	-0.5	-0.5	-0.5	-0.3	-0.2	0.0
With water hardening processes										
Ca mg/l	35	36	37	38	39	40	40	44	49	53
Saturation index	+ 0.2	+ 0.1	+ 0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Such a solution would be important from the standpoints of both engineering and health. The analyses and investigations mentioned above indicate that noncorrosive water is relatively safer and may diminish the risk of cardiovascular diseases.

SUMMARY

In this paper, the possible effects of the change in water hardness in the Southwestern Skåne as the result of integration of the Bolmen Scheme into the water resources system have been studied. Criteria from the standpoints of both health and engineering were applied: the health criterion was represented by the relation of water hardness to the rate of cardiovascular diseases, the engineering by the tendency of

the water to dissolve or to form the scale deposits, or by the aggressivity and corrosiveness of the water. As the standard of measurement in the first case, the attack rate of cardiovascular disease per 1000 people was applied; in the second case, the Langlier saturation index and precitable lime deficit were used. Some investigations indicate that both these indicators have a negative correlation, i.e., the increase in Langlier index corresponds to a decrease in the attack rate.

Both perspectives, however--and especially that of health--were investigated on the basis of the latest information from the information banks throughout the world to which IIASA has direct or indirect access.

Both a) the results of the investigation on the water quality of individual water resources and the quality of the mixed waters, and b) tendencies toward a decrease of pH (and a consequent increase in acidity) in the Bolmen Lake, would seem to recommend a system of structural and nonstructural measures to oppose these tendencies and effects. Such a system would entail the alkalinization of the Bolmen Lake water, together with application of water hardening processes and mixing of the resulting water after treatment with the water from the Ring Lake in order to achieve water that will not be aggressive and corrosive. Water treated in this manner would probably be more acceptable from the standpoint of health as well, particularly with regard to the rate of cardiovascular disease. Alkalinization and mixing with Ring Lake water alone are not sufficient to cancel the aggressivity of the water; this has been proved by the calculations of VBB on the basis of precitable lime deficit and once more in this study using the Langlier saturation index.

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