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SOME FEATURES OF IOWA GROUND WATERS, II.

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About two years ago the writer read before this body a paper, under the above title, giving a general statement of his work on the quality of Iowa well waters. The accumulating experience of the past two years seems to justify at this time a statement of some additional facts that seem important and which may be of interest to the Iowa Academy of Science.

The analytical work on which the author has been engaged is now practically discontinued, not completed since the field seems almost without limit, and at present the results are being put in form for publication. During the course of the work there have been accumulated about four hundred analyses of the waters of wells of importance. These wells are fairly distributed throughout the state, and there are representatives in almost every county in the state. A total of about one thousand analysis and nearly as many descriptions of wells have been at hand to give good opportunity for generalizations on the subject under discussion. It is proposed in this communication to confine attention to three topics, the availability of ground water in this state, the present and probable future development of this resource, and the softening of hard water for industrial uses.

Certain physical features of the surface of the state of Iowa which contribute to decrease the importance of its surface waters as compared with other states are almost too obvious to require statement.

This is a state of comparatively level surface; that is, the differences of elevations above sea-level are small. Taken in detail its surface is gently undulating. There are no mountains, and scarcely anything worthy of the name hills. Ninety-five per cent of the surface is tillable and nearly the whole of it is under cultivation. There is thus very little wild land or forest area as compared with eastern states, to serve as collecting ground for lakes and rivers of good water. The soil is very deep and generally very fine and porous. Under it are the comparatively porous loess and the sand and gravel of the drift. The drift covers nearly the whole state and is very deep, over most of its surface. Though the state has an annual rainfall of nearly thirty-five inches, these conditions contribute to make the run-off small and the amount of water taken up by the ground very large. Owing to the deep drift covering the rock strata, the scarcity of outcrops and the generally unbroken surface of the land, perennial springs that might feed the streams during dry weather are comparatively rare. Without this source of supply, without forest areas to hold the water back, and with the porous soil to take up nearly the whole of the rainfall of the drier months it follows that many of the small interior rivers of the state contract to insignificance during the dry periods, usually of the summer and early fall. At all times and specially during the dry seasons their waters are subject to pollution by the surface drainage, sewerage of towns and commercial concerns along their courses. Owing to the large percentage of plowed land, the fine soil and clays, their waters are very turbid most of the year. In short, such streams as we who cast the fly find in Michigan and Colorado, with their strong currents of pure, clear water, derived from springs and forest covered sand layers, or from melting snow above the habitations of men, are unknown in Iowa. According to present sanitary standards there is no river in Iowa or on its border whose natural waters may be used the year through as the source of municipal supplies. The situation is likely to become worse rather than better as the population becomes more dense and the industrial interests expand and multiply. Unless some practicable plan of filtration adapted to the smaller places is devised it seems probable that rivers as the source of such supplies will continue to be of secondary importance.

Iowa is a state having few lakes of consequence. The only ones of importance form a group near the northern border of the state and well to the west. They are far removed from centers of population, they are fed by small streams, are shallow and they cannot be considered suitable the year around for town supplies. The same physical features that cause insufficient and poor river water also make large reservoirs or artificial lakes of good water practically unobtainable.

It is an interesting and important fact that the most of the conditions that contribute to make the rivers of smaller importance are the ones that increase the ground water resources and its easy availability. The level surface, the porous soil and drift, the large percentage of cultivated land increase the percentage of water absorbed. The deep soil and subsoil, the sand and gravel of the drift afford it storage. This filtered and stored water is in most regions easily reached by the bored well or the sand point. In very many areas the sand and gravel layers lie in basins or troughs and in such regions flowing wells are secured. In some regions such water-bearing layers are struck high in the drift, but a very large number of wells go to the rock and derive their water from gravel layers just above it.

The level nature of the land may also account for the fact that for the most part Iowa rivers and streams have low velocities of flow and meander through wide level valleys, instead of flowing with high velocity between ranges of hills as in more rugged countries. In such valley-plains of rivers, water supplies can be secured from the so-called "under-flow." In the southwestern part of the state where there are many such streams this source seems to be the best and the most generally resorted to for town water systems. Good examples are Atlantic, Red Oak, Elliott and Griswold on the Nishabotany. Such waters have the advantage that they contain about the same amount or very little more mineral matter than the waters of the rivers themselves.

There remains to be mentioned the unparalleled source of well water in the northeastern part of the state,—the sand-stone layers of the Cambrian and Ordovinchian systems, known as the St. Peter, New Richmond, Jordan and Dresbach. This magnificent source is too well known to require further mention. It may be of interest to note, however, that in at fewest five of the most favorably located counties this source is untouched; and in several others one finds only one or two wells to each county.

Such are the well water resources of the state. To what extent are they being used or to what extent are the people dependent upon them? That well waters have up to this time held the most important place appears strikingly from a study of the municipal water systems of the state. The following figures are from the Underwriters' Hand-book of Iowa, in which are given all the towns of the state with their populations and their means of fire protection. The populations are taken from the last census, though the edition of the book is for 1907.

In going over the list the following facts appear. There are 324 cities and towns having water systems, including stand-pipes, street mains and fire taps. Towns having systems for fire protection only are not included. Of this number six have as their sources of supply lakes, or natural or artificial ponds; twenty-four have water from rivers, and 294 get their water from wells. It appears further that the urban population in towns having water systems are supplied as follows:

From lakes and ponds	21,000
From rivers	341,000
From wells	534,000

It follows that well water supplies about 60 per cent of the dwellers in such towns But, this is only a part of the truth. The inhabitants of such towns are a comparatively small minority as compared with the whole population of the state. There are many large towns without water systems. The people of these towns and the whole rural population are dependent upon wells of one sort or another. Taking this fact into account it follows that about 84 per cent of the whole population are dependent upon ground water.

There is much reason to expect a greater proportionate development in the use of ground water, and water from deeper sources. Though there are many towns of 150 to 300 inhabitants that have water systems, there are also many of 500 to 2,000 people that are yet without such systems. They will be forced to provide such supplies in the near future. The indications are that many towns have installed water systems more or less temporary and to meet the then existing needs, whether this temporary character was intentional or not. There is observable a very general tendency to extend well systems and to put down deeper wells as the towns have grown. It is interesting also to note the tendency to provide unfailing water supplies on the farms. Iowa is getting to be a state of very large live stock interests. Stock must have water, and something better than the shallow well, located very likely in some draw, only a few feet deep and provided it may be with only a hand pump, has become a necessity. The result is that farm wells 100 to 500 and even 1,000 feet in depth are becoming very numerous, and it is very probable that with the increasing need of plenty of good water, and also the increasing wealth of farmers in Iowa such farm wells will become very general.

In the former paper referred to, mention was made of the corrosion of well casings by hard waters. Several instances are on record where casings or parts of them have been taken out of the wells and found full of holes due to pitting. There is evidence that this is very general in wells having hard waters, and though no very accurate data have been collected the probability is that ordinary iron tubing in wells having quite hard water will be eaten through in from five to ten years. The following is an interesting example in a well in the southern part of the state and in a particular locality where the upper water is very highly mineralized. The well was drilled in 1904 to a depth of 2,054 feet. The following are four analyses of its water made at intervals of about one year.

Date of Analysis.	Total Solids.
Sept. 18, 1905	1,228
Sept. 9, 1906	1,637
Nov. 26, 1907	1,930
Sept. 9, 1908	2,594

The content of mineral matter has steadily increased during the four years, and it seems very likely that this is due to the gradual deterioration of the casing due to corrosion.

The want of efficiency and durability in the casings is one of the chief weak points in the deep well as a source of water supply. Not only do casings rust through, but in many instances they do not reach sufficient depths to shut out hard water and to prevent caving of shale. The town of Grinnell has lost one well and the capacity of another in quality and quantity has been greatly diminished by the caving of shale at the depth of about 1,700 feet or just above the St. Peter. At the present time well number (4) is being drilled and has reached a depth of 1,850 feet. The plans and contract regarding casing are so unusual, and are likely to be of such importance that a mention of them seems desirable.

As is well known cast iron far excels wrought iron in its resistance to the corrosive action of air and water. Of course, the mild steel which has so largely replaced wrought tubing on account of its cheapness is still far inferior to wrought iron in durability. Having had experience with both soft steel and wrought iron tubing the Grinnell authorities contracted for a casing of cast iron in well number (4) to reach to a depth of 1,700 feet. If this experiment succeeds it ought to be of much interest from both the practical and scientific standpoints. There are few if any deep wells near the center of the state from which the waters above the great sandstone layers are entirely excluded. No one now certainly knows what these sandstones are capable of yielding in this region in either the quality or the quantity of water. In the Grinnell wells as they have hitherto been cased, very considerable quantities of hard water have been received from the limestone layers below the casings at depths from 1,200 to 1,600 feet. If the water supply of the new well should prove abundant and should have a mineral content anywhere near as low as the water from the same strata fifty miles to the northeast, it ought to encourage more deep wells in this region, and even the extension of the region of artesian wells farther to the south and west. In any event the successful putting down of this casing will demonstrate the practicability of cast iron for this purpose, and the opportunity of thus very greatly increasing the durability of the casing and the life of the deep well.

Iowa waters from whatever source are notably harder than those from corresponding sources in the states farther east. The waters of Lake Michigan and of the great lakes generally contain about 130 parts of solid matter per million; lakes and rivers farther to the east contain smaller amounts, even to less than half as much. On the other hand the softest of Iowa river, lake and well waters contain about twice that amount; that is, about 260 parts per million. There are few well waters of this degree of freedom from mineral matter. Excepting a few wells the great majority vary from 350 to 10,000 parts. On Iowa standards a town with a supply of water containing 500 parts of solids per million may consider itself fortunate in this respect; 700 parts may be considered fair, and 1,000 parts or even more, tolerable. For boilers and most industrial purposes none of these could be considered very good.

One railroad in the state has classified its waters according to standards as follows: less than 134 parts, of incrusting solids, very good; 200 parts, good; 300 parts, fair; 450 parts, poor; 600 parts, bad; over 700 parts, very bad. According to this standard and its own analyses of waters along its lines no water can be considered very good; only eight of its waters are good; thirty-seven are fair, and eighty-eight are poor to very bad. If the 123 waters of this road may be taken as representative and the standard quoted as valid, then about two-thirds of the Iowa waters are poor to very bad for boiler use. The case is really worse. Railroads care little about the sanitary condition of their boiler waters, and they take them from rivers, ponds and slough wells by preference because they are softer than the waters from deeper wells such as supply cities. Of city supplies probably far more than two-thirds are really poor to very bad for boilers.

That hard waters form boiler scale and are very likely to be corrosive are facts too well known by this body to require discussion; also, that scale decreases the efficiency of the boiler, and corrosion means early and frequent repair and short life of the boiler.

Many means have been devised with the object of avoiding these difficulties. From the standpoint of the chemist there is only one right way, if the water is to be used at all and is not bad beyond possibilities of treatment. Since this method has now been introduced on a very large scale in this state by one of the largest corporations and has proved very successful, at any rate a brief statement for record seems desirable. But first as to palliatives and quack remedies.

If one wishes to avoid the difficulties attending the use of a hard water for boilers or other industrial purpose, the most obvious thing to do is to soften it, if this is practicable. There is nothing new in the idea of softening water; the chemistry of it has been known for a long time, but there are new developments in methods and the scale on which it may be carried on, at any rate in this state, where on account of the hardness of the waters it should be a matter of very great industrial importance. In order to make more clear the scientific character and efficiency of the method I have mentioned it may be well to describe briefly two palliative methods as carried out on a small scale.

One method is by use of the pre-heater, the source of heat being usually exhaust steam. It is a matter of economy to feed the boiler with heated water, and the heating causes the precipitation and settling out of a considerable portion of the calcium carbonate. Sometimes a boiler compound or an alkali is added to the heater, thus removing a portion of the permanent hardness. The method is good so far as it goes, but the apparatus is usually too small to allow proper settling, it is troublesome to manage and its efficiency is farther restricted by the want of knowledge and care of the individual engineer.

Perhaps the most generally used and the worst method is that of using alkalies and so-called "boiler compounds" for the precipitation of the solid matter in the boiler. This makes the sludge where it will do the most harm. It may cause foaming, it necessitates frequent cleaning, it may settle in a compact mass when the boiler is out of use and cause overheating of the covered plates and even explosion when the fires are again started. As a rule in practice the nature and amount of the boiler compound bear little relation to the work to be done, the compound of unknown composition being added from time to time without much regard to the mineral content of the water or the amount of water used. The treatment is likely to be only partial, or the compound is likely to accumulate and cause trouble.

The number of boiler compounds on the market is very large and for them their venders claim almost miraculous properties, and they sell them at exorbitant prices. A few days ago there came into my hands a boiler compound used in a Grinnell power plant. So far as could be discovered it contained only sodium hydroxide, about 18 per cent, and a very little coloring matter that may have been due to the action of the strong alkali upon the barrel. It was bought by the barrel at eight cents a pound, or about $42.00 a barrel. It was actually worth, barrel and freight included, about $5.00. The man who bought this compound is one of unusual intelligence and business ability. In fact, the appeal of the boiler compound to the trade may be likened in many respects to that of the patent medicine, and mystery seems to be the controlling factor. Now, as a matter of fact there are only a few practically useful chemicals for softening water, and they are all perfectly well known as is also their action. There is no necessarily efficient nostrum applicable in all cases. Any peculiar, secret and patented combination ought to be treated as a fraud, and the engineer who applies to a chemist for advice should be plainly told this fact.

The chief substances in water that make boiler scale are calcium and magnesium in association usually with carbonic and sulfuric acid ions. The scale consists mainly of calcium and magnesium carbonates, hydroxides and calcium sulfate. The chief agents of corrosion are free carbonic acid, and other acids that may be set free by the hydrolysis of salts at the high temperature of the water. The problem is, therefore, to remove calcium and magnesium (secondarily aluminium and iron), and carbonic acid ions, to leave the water neutral or slightly alkaline, with the introduction of the minimum of soluble material.

First of all one must have an accurate mineral analysis of the water to be softened. The volume of the water must be measured and the chemicals must be calculated to meet the given case and the amount used weighed. Though there is no logical procedure applicable to all waters, effectiveness and cheapness both considered, it is generally better to use only lime if the calcium and magnesium ions do not exceed in equivalence the carbonic acid ion, HCO^3; otherwise a mixture of lime and soda ash serves the purpose best. The absolute amounts depend, of course, upon the quantities of substances to be removed, and their relative amounts must be varied according to the infinitely varying proportions of the ions, Ca, Mg, HCO^3 and SO_4. Every water must have its own proportions precisely adapted to its mineral content. The chief reactions in such water softening are represented by the following equations:

1. $Ca(HCO_3)_2 + Ca(OH)_2 = 2CaCO_3 + 2H_2O$.
2. $Mg(HCO_3)_2 + 2Ca(OH)_2 = 2CaCO_3 + Mg(OH)_2 + H_2O$.
3. $MgSO_4 + Ca(OH)_2 = Mg(OH)_2 + CaSO_4$.
4. $CaSO_4 + Na_2CO_3 = CaCO_3 + CaSO_4$.

Equations (1) and (2) show the removal of calcium and magnesium carbonates, or "temporary hardness." When the water contains sulfates of these elements, that is, is "permanently hard," sodium carbonate is also used, and removes calcium sulfate already present or formed as in (3) by the reaction expressed in (4).

The chemical scheme that I have outlined is the one that is being used by the railroads of Iowa so far as they have taken up the enterprise. The present situation is indicated by the following points from the correspondence with the chief chemists, or engineers of tests as they are in some cases called. Mr. M. H. Wickhorst of the Burlington road writes that they have installed three large plants which are giving very satisfactory results. Mr. Geo. D. Prentiss of the C., M. & St. P. states that his road has attained excellent results at Sioux City and in another plant across the river in South Dakota. Mr. F. O. Bunnell states that the Rock Island could scarcely maintain its present schedule in some regions without the softening plants, and that their system of softening would probably soon be extended to Iowa.

To the Chicago & North-western railroad, however, is due the credit of the widest application of water softening on a large scale. The information at hand comes from Mr. Geo. M. Davidson, engineer of tests for many years, through correspondence and a paper on the North-western softening system, published in the Western Railroad Club.

This road has in successful operation forty-one softening plants, of which twenty-two are in Iowa. With three exceptions these plants have a capacity of 240,000 gallons a day. The chemical process has already been essentially described. Only a few of the prominent mechanical features and the results can be given.

The apparatus is comparatively simple and is constructed in the shops belonging to the road. The essential vessels, excluding the storage tanks for the hard and for the softened water are, a small tank to hold the mixture of milk of lime and sodium carbonate, the mixing tank provided with stirring blades, and two settling tanks. The hard water receives the softening solution just before it reaches the measuring apparatus, which consists of a two-compartment tilting box, each compartment holding 100 gallons. The tilting vessel operates two pumps whose cylinders supply the softening solution and the length of the stroke can be regulated to supply the desired volume. The weight of water in the tilting vessel is also the source of power to operate the stirring blades and they are reversed with every change of position. From the mixing vessel the water goes to the settling tanks of which there are two, each having a capacity of 77,000 gallons. From them the clear water is pumped to the storage tank for use.

The effectiveness of the process may be illustrated by the results attained by three plants, at Council Bluffs, Denison and West Side. The average of the incrusting solids of the untreated waters is 644 parts per million, and of the treated waters seventy-four parts. About four grains per gallon or seventy parts per million of incrusting solids marks the usual efficiency without much regard to the character of the water originally. This amount is regarded as practically harmless.

The results of the use of this softened water in railroad engines have been very gratifying. The first effect in boilers that have used hard waters is to cause leakage owing to the loosening of old scale. If the tubes are then re-rolled there is very little farther trouble, and the general results is that boiler repair and time lost by engines in the repair shop are reduced to a small fraction of what they were when untreated water was used.

The cost of treatment varies greatly with the degree of hardness of the water. Fair boiler waters cost about one cent per 1.000 gallons. From this minimum the cost increases to ten cents, with the average about three cents per 1,000 gallons.

All waters cannot be made good boiler waters by softening. Very hard waters are likely to contain already some sodium sulfate. To remove calcium sulfate by the method described means necessarily an increase of sodium sulfate. If the total quantity present exceeds about 600 parts per million, the result is foaming in the boiler.

Iowa waters are hard and trouble with them in boilers and in other industrial uses is well-nigh universal. The trouble will not disappear of itself, but will become more acute as the industries of the state increase. I deem it worth while to call the attention of men of science to this most scientific remedy which has been proved wholly practicable on a large scale. It ought to be as practicable for a large stationary power plant or a manufacturing concern as for a railroad. In every town of considerable size there are numerous power plants, often laundries, tanneries and the like, and it would seem reasonable for them to unite in the erection of a softening plant for their common use if the method of solving their difficulties regarding water were made clear.