REHABILITATION OF SANDSTONE WELLS

By

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The multiple problems involving the rehabilitation of sandstone wells in northern Illinois should be approached in the same manner as any other engineering project. Accurate, factual data should be obtained on the existing condition of the well, as well as on the past performance, before attempting to estimate the possible future benefits of repair and the methods of obtaining these benefits. Because it is not economically possible actually to view these wells as one would a building, our own imagination shrouds the problem in mystery. The unseen provokes the unknown. However, there are many methods of inferring indisputable facts concerning the unseen and the supposedly unknown.

The location of a well is of prime importance to the existing and future scheme of any water supply system. It is sometimes desirable to recapitulate and reconsider in order to determine the advantages or disadvantages of the present location of a well. Since the cost of rehabilitation may be quite high it has on some occasions been found more economical to drill a new well. On other occasions it has been found desirable to obtain better quality water. In some cases it may be wise to reserve the existing well for standby service. Serious consideration should be given to the local rate of water level recession and the possible future life of the well supply even with the best of repair and maintenance.

Such considerations as the area to be served (residential, manufacturing or commercial), the trend of the water demand, the present and future size of distribution systems, the present or future type of treatment, the question of obtaining surface water, the desirability of a concentrated or of a segregated well field—all of these are first to be considered.

The constantly increasing demand for ground water in this Chicago area has resulted in an irregular but unquestioned recession in water levels over the general area since 1890. Since the rate of recession is not always constant and is often too slow to be noted over a short period of time, it is necessary to consult long-time records available for the general area. Every effort should be made to check the available records for accuracy, since very often false and misleading data may be obtained from an air line of unknown length or from a well in which a false head is maintained above the pump bowls. These records must be interpreted with due respect to the past, the present and the expected future demand for water in the surrounding as well as in the immediate vicinity.

Size of Well

Assuming the well under consideration to be in the desired location, the diameter of the existing bore is next to be considered. Many wells penetrating the deep sandstones were drilled
many years ago and the diameters throughout their entire depth are now too small when considered in terms of present-day desired capacities. Observations indicate that many of these old wells, while penetrating the sandstone formations, had a bore diameter ranging from 8 to 12 in. at the top, and finishing 4 to 5 in. at the bottom. These wells apparently produced sufficient water in their day. However, increased demand and recession of water levels have necessitated larger pumps and deeper settings of pumping equipment. Wells of larger bore are therefore required, not only in the area of deep pump setting, but are also desirable through the aquifers. However, the cost of increasing the diameter of the bore in an old well is often greater than the cost of an entirely new well. Thus, the picture is now revised. A well must be developed to meet certain capacity requirements and to provide for efficient pumping equipment. A discussion by A. O. Fabrin [W.W. & Sew., 91: 371 (1944)] on the subject of well diameter and pump size provokes some thought.

Depth of Well

The history of deep wells in the area under discussion brings forth some interesting observations. The first few deep well contractors to operate in this area were oil field men from the East who were accustomed to drilling deep wells, and so the natural inclination, by virtue of heredity in this business, was to drill them of similar diameter and depth. Procedures in oil well drilling were such as to produce wells of relatively low capacity for a valuable product. In contrast, water well drilling serves the end of producing a low dollar value product at high capacities. The depths of these wells were often excessive insofar as quality and quantity and source of water "were concerned. A few consequences resulting from drilling wells of excessive depth include high chloride content, high temperatures and a tendency for some of the formations to be of a thieving nature, thus creating excessive depths to water for both the static and the pumping heads.

In Chicago and the surrounding area, observations have led us to believe that wells drilled through the Galesville sandstone will generally produce the largest desirable quantity of usable water for many industrial purposes, although not always adaptable to human consumption.

Rehabilitation

Regarding the rehabilitation of a Galesville well, if the location is appropriate and if the diameter of the bore is of sufficient size, the problem will be that of increasing the production. During the life of most sandstone wells, all water-bearing formations have been open and the waters at one time may have moved through the well from one formation to another, and at a later period of time the reverse procedure may have taken place. The extent and time of this exchange of waters has depended (1) on the relative static heads of the aquifers, (2) on the dynamic heads prevalent during pumping, and (3) on the relative abilities of the various aquifers to give and take water. Other controlling factors include the pumpage in the immediate and surrounding area and the resultant recession of static heads of these various aquifers.

By virtue of some of these movements, chemical reactions have altered the producing characteristics of these aquifers. For example, limestone wa-
ter, having its iron oxidized by exposure to air and transferred to the higher producing sandstone formation of lower static head, would tend to reduce the sandstone porosity particularly at the surface of the sandstone, which acts as a filter for the water entering the formation.

In another example, suggested many years ago by Leverett in 1897 and Slichter in 1910, a deposit is formed on the well wall in the sandstone area. Slichter stated, "For some reason the water-bearing sandstone has become 'clogged' in the neighborhood of the wells so that the sandstone is not able to transmit as much water as formerly. This is a common experience with such wells, especially when operated under high drawdown. The writer believes that this clogging is due to the liberation of CO, by the reduction in pressure. It is not believed that it is due to mechanical clogging alone." This may be explained by considering that the sandstone water, as it enters the well bore during withdrawal at high rates, undergoes a very large drop in internal pressure. This results in a strong tendency to shift the natural chemical solubility equilibrium, resulting in a small but accumulating deposit of limestone on the surface of the sandstone on the wall of the well bore. This deposition reduces the porosity and the capacity to yield water. Such deposits are primarily on the surface and must be removed to increase the porosity and to permit a greater rate of entrance of the water.

The most common method of removing this deposit is by shooting the sandstone in the producing zone into the well with nitroglycerine, thereby crumbling the surface area. A predetermined indication of the most favorable shooting area in the sandstone is most helpful. This information can be obtained by a geophysical survey. Such a survey includes the electric logging of the well. By correlation with the original log, considerable valuable data may be obtained. There are many modifications of the electric logging work, and as many of these modifications as practical should be made in order to obtain a complete picture of the well in question. When the areas of most probable high permeability are located, shots of approximately 100 to 600 lb. may be exploded opposite these areas in the well bore. It may be necessary to use two or three such shots in order to obtain the best results, and an indication of these results can be judged, to some extent, by the amount of coarse sandstone bailed out of the well. No method, however, can replace the production test to indicate the final effectiveness of the rehabilitation.

It is not unusual to find that the original production capacity can be reclaimed. To substantiate this last statement, a well in the Elgin area was drilled in 1938 to a depth of 1,222 ft. This well penetrated the Galesville sandstone and was found on completion to have a 48-hour tested capacity of 1,250 gpm., with a 160-ft. drawdown from a 123-ft. static level (or a specific capacity of 7.8 gpm. per ft.). Six years later, in 1944, before rehabilitation, this well produced, on test, 540 gpm., with a 93-ft. drawdown from a 143-ft. static level (or a specific capacity of 5.8 gpm. per ft.). After rehabilitation following the above-mentioned procedure, the well was tested to produce 540 gpm., with a 65-ft. drawdown from the same 143-ft. static level (or a specific capacity of 8.3 gpm. per ft.). This represents an increase of 30 per cent for specific capacity.
Eleven cubic yards of sandstone was bailed out. It should be noted that the dynamic or pumping level did not reach the original pumping level for the same rate.

Other rehabilitation projects with more phenomenal success have been recorded but complete data before and after are not available for presentation here.

Rehabilitation of a well to increase its capacity does not refer to a rise in static level but rather to a rise in pumping level with the same or greater rate of withdrawal. Of course small changes in static level may be observed as the result of resting the well during rehabilitation. Rehabilitation increases the ability of an aquifer or, by a combination of circumstances, the ability of a well to produce more water per foot of drawdown. Rehabilitation may and has raised or lowered the static level of the water in some wells. In each case, this can be explained by the fact that the "giving" or the "taking" aquifer in the well has been affected to give or take more water respectively.

In a few fortunate cases of rehabilitation the ability of a sandstone to give water has been increased and, as a result, the crevices in other aquifers in the well have been more readily replenished during idle periods. During pumping periods, these crevices or storage reservoirs feed water into the well at a high rate for prolonged periods with less drawdown than that necessary to extract the water from the original sandstone source itself.

In addition, much has been said and much more can be said concerning the interference by pumping other wells in the area of immediate and prolonged influence. It is not the purpose of the author to discuss the hydraulics and mathematics involved in such studies.

It is enough to say that it requires but little imagination to picture the effect of two people rather than one with straws in the same soda glass.

A word of caution regarding the shooting of a well: If liner casings are adjacent to the area to be shot, or a long string of casing is in the hole, then such casings must be removed before any heavy shooting is effected; otherwise, this casing will collapse and much added expense will be incurred.

Other methods of rehabilitation include under-reaming and acidizing. Under-reaming is not as effective as shooting and does not have the support of the drillers, nor the romance with which shooting is blessed. Acidizing is handicapped with the problem of applying the acid in high concentration at the desired point in the well without filling the whole well with acid. Nor does it increase the diameter of the hole. Only one record is available of a sandstone well in the Cook County area having been acidized. The data in this case are not sufficient to condemn or recommend the procedure.

Salt water, when found to be entering the well in objectionable quantities, can be reduced by plugging off the lower part of the well, if this has been found to be the source. Most of these operations have been successful, but several failures are on record. One of these failures has been attributed to excessive shooting in the lower part of the well, which prevented any possibility of obtaining a tight seal at the proper depth.

In many wells it is desirable to "cement in" the upper top casing in order to exclude surface water or poor quality water and hydrogen sulfide from the well. This procedure also has a distinct advantage in preventing any possible future corrosion from the outside
of the casing. The more successful applications involve the introduction of cement grout to the lower end of the casing and forcing it upward around the outside to fill the annular space to the surface.

The approach of the rehabilitation period is usually first noted by lower pumping levels and reduced capacity. Careful and regular water level readings, plus observations of flow meter charts, will usually give much advance notice of the impending failure. The air test line for determining water levels is, to the water works superintendent, what the patient's pulse is to the doctor, because it is an indication of a strong or a weakening condition. The flow meter yields data of distinct aid to the air line indications, and often a few watt meter readings may pin repair indications directly to pump trouble or to well trouble. On many occasions a chemical analysis of the water will assist in the determination of the water source or change in source. In some cases rehabilitation requires only a deeper pump setting to meet the receding water level in the vicinity.

Rehabilitation of Limestone Wells

There are areas outside of Chicago where sizeable quantities of water are being obtained from the first limestone. These areas lie south, southwest and west of the city. The quality of this limestone water is not always the best for the purpose for which it is used. However, chemical treatment can and has been successfully applied. This upper limestone water has the great desirable feature of being cold water (51-53°F.).

Water in limestone is present by virtue of creviced areas or reef areas (State Geological Survey Bulletin 65). The former are simply chains of breaks or cracks or fissures in the limestone. These fissures may be vertical weathered crevices or, as generally found in the lower part of the limestone, they may be horizontal crevices or solution channels in the formation. There is some evidence to show that both types of crevices are often fed locally or at some distant point by rainfall and infiltration. The reef areas are systems of honey-combed rock and the sources of stored water are the same as those for the creviced areas.

The rehabilitation of a limestone well is often successfully accomplished with the use of acid. Hydrochloric acid of a strength of 15 or 30 per cent, inhibited to prevent corrosion and with the addition of other ingredients to keep the dissolved iron salts in suspension, is introduced into the well under pressure. This acid has a tendency to dissolve the more soluble portion of the clays that have clogged the inter-joining creviced areas. Upon clearing these crevices, substantial increases in well capacities have been noted. Several failures of this treatment are on record and it should be proper to obtain experienced authentic advice on this type of rehabilitation.

There is also some question still concerning the proportion of the effect of some of the successful applications that should be attributed to the cleaning of the pump by the acid. Here again, a good production test, properly interpreted before treatment, will yield pertinent information.

Economics

The rehabilitation of a well seems to go hand in hand with the rehabilitation of the well pump. There is perhaps as much widespread cost to such operations as there ever has been. However, it is not unusual to find that
repairs to pump and to the casing and well will amount to $10,000 to $20,000. Oftentimes repairs to pump may involve a complete new unit either to replace poor operation efficiency, to eliminate corrosion or to fit the existing hole size at a lower setting.

Serious consideration should be given to replacing an inefficient pump with one of modern efficiency and of size and design to meet the demand requirements. This consideration should also go hand in hand with the question of "rehabilitation or new well." If corrosion is experienced there should be no hesitancy to ask for assistance. Answers are not always readily available but if they are apparent, there should be no excuse to ignore any opportunity to make use of them. If it appears necessary to substitute cast-iron bowls with bronze at a 100 per cent additional cost per bowl, the increased lifetime of the pump will warrant the added investment. Unless operation and repair expenditures are made on a fly-by-night basis, there should also be no hesitancy to provide protective coating for column pipe when water of high mineral content is used.

The total cost of securing and maintaining a well supply should be considered along with any disadvantages of poor water quality and compared with the cost of water from other sources. This provides a common dollar-and-cents basis on which to proceed with an efficient program. The initial cost of installation or rehabilitation, when prorated on a basis of dollars per million gallons, is often a very small percentage of the cost of pumping and treatment per million gallons of delivered water.

Summary

No rehabilitation job should be started without preliminary planning in a sound engineering manner using basic indisputable facts. The facts are not always available but much can be learned: (1) by a thorough, well-performed and interpreted production test to learn of the present character of the well and pump; (2) by chemical analysis of the water to assist in interpreting the data; (3) by an assembly of the past history of the well and of the water levels with reference to past and expected recession, the water demands and the construction of the well; (4) by geophysical logging of the well to determine unknown factors such as casing and liners, size of hole, lost tools, bridging, past shooting and creviced areas; (5) by assembling the facts concerning future demand and quality and correlating with the facts concerning the future underground water resources of the area; and (6) after rehabilitation by a thorough production test to indicate the effectiveness of the rehabilitation and to be available for reference when the next rehabilitation job becomes necessary.

All wells should be equipped with an air line, a sampling tap on the discharge line, and in many cases a flow meter. In all wells, the pumping rate, pumpage, static levels, pumping levels and chemical analysis of the water should be checked at specified intervals.
DISCUSSION— Carl Duy
Engr., Water Works, Aurora, Ill.

The writer would like to discuss Mr. Millis' paper strictly from an operator's viewpoint.

The operators of all water systems deriving water from wells can make a worth-while contribution to their operating statement by taking their wells more seriously and giving more daily attention to their productive possibilities. It is the writer's belief that, if there is no information available on the wells, every effort should be made at the first opportunity to make such investigations and tests as are necessary to determine the depth, the diameter and the amount of casing installed in each well. Once this information is obtained the capacity, drawdown and power cost tests should be made a part of the permanent record and the tests should be conducted semi-monthly.

The tests for pumping levels should be conducted by means of air-line and air-pressure gages. These should be periodically checked with electrodes to prevent the occurrence of false readings on the operating levels and capacities. It is also essential to have complete data and factory tests on the pumps so that if deficiencies exist they can be properly located. The matter of time is an important consideration of these tests. They should be taken over a period of at least 5 to 8 hours. Shorter periods may yield erroneous capacity figures, as some wells will pump down and reduce their specific capacity after a greater period of operation.

It is also important to have a record of the recovery period, as well as regular temperature readings of the water. If temperature readings are available, any change taking place will quickly indicate water coming in from a new source or formation. In addition the water should be tested for any change in its chemical qualities at least as often as once a year. This information is useful to consumers in any installations that may be contemplated for domestic or industrial purposes.

At the present time Lake Michigan water should not be considered by municipalities as far from the lake as Elgin, Aurora and Joliet, as the cost of transmission of water would be very high. Due to capital charges the cost of water delivered would be much in excess of the present cost. Possibly some time in the future the density of population between the corporate limits of the city of Chicago and Aurora, Elgin and Joliet will create a demand for water which would warrant capital charges in keeping with a project of this nature.

There are many wells in the northern part of Illinois of a size that it would not be advisable to rehabilitate. Wells constructed during the last twenty years are in practically all cases much larger in diameter both at top and bottom than wells constructed at an earlier date.

There is considerable difference of opinion relative to the depth that a well should be drilled in the northern part of Illinois. Some are of the opinion that there is very little water below the Galesville member of the Dresbach system. Others believe that there is considerable water in the Mt. Simon sandstone, the lower member of the Dres-
bach system. Water obtained from the lower member is considerably higher in temperature and it is believed that this formation has a high yield.

Shooting the well is the most common means of increasing the specific capacity. As Millis stated, it is very important that the present casing installed in the well should be properly located before shooting so that there will be no danger of collapsing the casing. In shooting the well it is advisable to place several explosives at different levels throughout the water-bearing sandstones instead of using one or two heavy shots.

There are very few, if any, cases on record where acidizing has increased the productive capacity of a sandstone well, although there are many cases where a substantial increase in production capacity has been obtained by acidizing a Niagaran limestone or gravel wall well.

The making of a geophysical survey prior to rehabilitating a well has considerable merit, although the data obtained cannot be considered 100 per cent accurate.

At the completion of the rehabilitating of a well or wells, very lengthy tests should be conducted on the well. The adjacent ones should also be tested to see what effect the rehabilitated well had on the older ones, especially if a great amount of shooting was done in the rehabilitation. These data are very important for the operating records.

In any rehabilitating work contemplated, the following items should be given careful consideration before the project is let:
  1. Age of the well.
  2. The average life of casing in wells constructed in vicinity of well to be rehabilitated.
  3. Original production capacity.
  4. Present production capacity.
  5. Previous shooting of well, if done.
  7. Estimated cost of new well.

DISCUSSION—Edward Wilson
Engr., Corn Products Refining Co., Argo, Ill.

Mr. Millis' statement, "The unseen provokes the unknown," is interesting, for the more experience I have with deep wells and underground water flow, the more I think of those lines by Robert Owen, "All things I thought I knew but now confess, the more I know I know, I know the less." Working with underground water is like playing golf; just about the time you think you are getting good, you go out and shoot the worst game of the season. The same is true of wells; about the time one thinks he knows something about them, the unexpected shows up and he wonders if he knows anything about them.

At the Argo Plant of the Corn Products Refining Company, in what is called the "old well system," there are eight wells drilled to a depth of about 1,800 ft., with diameters of 16 in. at the top and 8 in. at the bottom. These wells were pumped by means of a shaft and tunnel system 360 ft. under the ground. That is, the water in the well flowed by gravity through the underground pipe to an ordinary centrifugal
pump, in a pump room at the bottom of the shaft, which delivered the water to the surface.

In 1933, a rehabilitation program was started and after cleaning and shooting a number of the wells, there was an increase of about 15 ft. in the pumping water level, or a static level of around 308 ft., pumping 2 mgd.

There was then a rapid drop in water level and by 1940 it was down to 350 ft. for a flow of 2 mgd. By 1941 it was no longer possible to obtain a flow of 2 mgd.

The next rehabilitation plan called for some new wells with individual deep well pumps, for the old wells were too small in diameter to take deep well pumps.

The first of the four new wells, which was ready for operation in August 1942, was drilled to a depth of 1,540 ft. (just below the Galesville sandstone). It was 26 in. in diameter at the surface and 17 in. in diameter at the bottom, cased and concreted 500 ft. down from the surface. The tops of the pump bowls were set at 500 ft., and the pump designed to deliver 1,000 gpm.

Before starting this well the water stood at 340 ft. and after pumping 1,000 gpm. it dropped to 441 ft. The old well system flow dropped to 500-000 gpd., so a total of approximately 2 mgd. was obtained from the ground.

The starting of the second well in 1943 brought the end of the old well system—it was dry. There were also indications that the 500-ft. pump setting should be lowered. The pumping water level of the second well was as low as 469 ft., while the water level in the first well dropped 28 ft. for an increased total flow from the ground of 650,000 gpd.

Accordingly, the next two well pumps were set at 600 ft. and the first two well pumps were changed to 600 ft. Table 1 shows the water levels at the time each well was first put into operation. (All measurements are from the ground surface.) As can be seen from the table, there was a drop of 74 ft. in the static water level from August 1942 to January 1945.

<table>
<thead>
<tr>
<th>Well No.</th>
<th>Date</th>
<th>Water Level Before Starting Pump—ft.</th>
<th>Water Level While Pumping 1,000 gpm.—ft.</th>
<th>Total Flow From Ground—mgd.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Aug. 1942</td>
<td>340</td>
<td>441</td>
<td>2.0</td>
</tr>
<tr>
<td>2</td>
<td>June 1943</td>
<td>350</td>
<td>463</td>
<td>2.4</td>
</tr>
<tr>
<td>3</td>
<td>June 1944</td>
<td>380</td>
<td>480</td>
<td>2.5</td>
</tr>
<tr>
<td>4</td>
<td>Jan. 1945</td>
<td>414</td>
<td>*</td>
<td></td>
</tr>
</tbody>
</table>

* Test not run on this well.

Mr. Millis states: "The quality of the water should be considered." This is very true, and when quality is considered it may be better to use some source of supply other than deep wells. The chemical analysis of a deep well cannot be accurately determined until the well is complete and in operation. For example, an analysis of the water from the first three wells at the Argo Plant checked very closely but the fourth well showed a wide variation, even though all the wells were located on an area of approximately 75 acres. The analyses are shown in Table 2.

<table>
<thead>
<tr>
<th>First Three Wells</th>
<th>Fourth Well</th>
</tr>
</thead>
<tbody>
<tr>
<td>ppm.</td>
<td>ppm.</td>
</tr>
<tr>
<td>Total Hardness</td>
<td>308</td>
</tr>
<tr>
<td>Calcium Hardness</td>
<td>205</td>
</tr>
<tr>
<td>Magnesium Hardness</td>
<td>103</td>
</tr>
<tr>
<td>Sulfate</td>
<td>222</td>
</tr>
<tr>
<td>Chlorides</td>
<td>154</td>
</tr>
<tr>
<td>Total Dissolved Solids Temperature</td>
<td>684</td>
</tr>
<tr>
<td></td>
<td>60⁰</td>
</tr>
</tbody>
</table>
The No. 4 well presented a new problem and it was decided to rehabilitate it so the water could be used. It was analyzed somewhat as follows:

1. The higher chloride content led to the belief that the water was coming from the lower strata or from Mt. Simon sandstone.

2. The high dissolved solids content and the lower temperature indicated that the water was coming from the upper or limestone strata.

3. One of the old wells, located 30 ft. away from Well No. 4, went down to a depth of 1,866 ft. and was not cased in the upper strata. Was the water from this well getting into Well No. 4? To check this, salt was added to the old well while Well No. 4 was running and in less than five minutes there was a definite increase in the chloride content in the water from the new well.

It is planned to fill up the old well to the bottom of the new well and put a concrete plug in the old well approximately 500 ft. below the ground surface, thereby keeping the undesired water from getting into Well No. 4.

All of the wells are equipped with air lines, discharge pressure gages, recording flow meters and indicating amperemeters on the motors. These are read daily when a well is in operation. This equipment not only tells the story of what each well is doing, but it also indicates the pump performance. The amperemeter plays an important part in deep well pump operations. One day, as the discharge valves on one of the well pumps was being throttled, the amperemeter started swinging, instead of going lower, as it usually does when the load decreases. This indicated that the shaft had stretched, causing the pump impellers to rub on the pump bowls. The impellers and shaft were raised by means of the lateral adjusting screws, and the amperemeter immediately came back to its normal position. Later, when this pump was pulled, score marks showed where the impellers had been rubbing. If this rubbing had continued, the pump would have been ruined in a very short time.