A SEMINAR ON

# Ground Water Hydrology, Water Well Construction and Maintenance

SEPTEMBER 19 & 20, 1977

*Sponsored by*
*Capital Area Ground Water Conservation Commission*
*Department of Civil Engineering, Louisiana State University*
*Consulting Engineers Council of Louisiana, Inc.*
*Louisiana Engineering Society*
*Louisiana Tech University, Water Resources Center*
*Louisiana Water Resources Research Institute*
*Louisiana Water Well Association*
*Louisiana Department of Transportation and Development,*
*Office of Public Works*
*U. S. Geological Survey, Water Resources Division*

# WELL HYDRAULICS

by David L. Kill*

## Definition of Terms

Static or Standing Water Level ( SWL )

Pumping Water Level ( PWL )

Drawdown ( s )

Well Capacity or Yield ( Q )

Specific Capacity ( Q/s )

Well Efficiency ( Q/s actual / Q/s theoretical )

## Calculation of Well Efficiency

$Q/s \text{ theo} = \frac{T}{2000}$ for artesian aquifer

$Q/s \text{ theo} = \frac{T}{1500}$ for water table aquifer

T = Transmissibility ( gpd/ft ) = m P

m = Aquifer Thickness ( ft )

P = Aquifer Permeability ( $gpd/ft^2$ )

## Importance of Well Efficiency

Lower Pumping Levels - increased pumping cost

Limited Yield - restricted available drawdown

## Causes of Well Inefficiency

Poor Gravel Pack and Placement

- Size
- Uniformity
- Well Rounded
- Placement

* Regional Manager, Johnson Division UOP, Inc. St. Paul, MN 55165

Poor Intake Device

- Open Area
- Slot Size and Configuration
- Length
- Setting

Lack of Well Development

- Purpose
- Benefit
- Methods

# WATER-WELL DRILLING AND TESTING, OUTLINE OF PRINCIPLES AND PROCEDURES

by J. E. Rogers and G. T. Cardwell

I. Site selection.

A. Site information.

1. Site within a well field.

a. Records of existing wells.

b. Interpolation for new sites.

c. Using old records for offset wells.

2. Extension of a well field.

a. Records of existing wells.

b. Extrapolation of data to adjacent areas.

3. Exploring for new well fields. (In instances 1 and 2, above, if records are not available, then work in or near a well field becomes of an exploratory nature.)

a. Published records and maps of various areas (Alexandria well field example).

b. Records of oil company wildcat wells.

c. Prior development pertinent to the area under consideration.

d. Procedures followed in Louisiana Office of Public Works test-drilling program.

(1) Review reports and data in U.S. Geological Survey files.

(2) Obtain electrical logs of nearby oil and gas wells.

(3) Check for information available from other (unscheduled) wells in area.

(4) Select sites and assign priority. (Sites near proposed pipelines generally have a high priority.)

II. What is needed at a test site (before construction of a production well).

A. Test hole to log formations and collect sand samples. (Good sand samples are essential.)

B. Electrical log desirable to determine precise sand depths and thicknesses and to determine if the aquifers contain freshwater.

C. Sieve analyses of sand samples.

D. Small-diameter test well or drill-stem test. (To facilitate development of test well, test hole should be minimum size required for electrical log or minimum size required for size of proposed test string.)

1. Sample aquifer to determine water quality and suitability of water for use (also treatment requirements).

2. Obtain water-level and yield information. (A short pumping test may suffice. Where quantity is the principal concern, a larger diameter well, and possibly observation wells, for better quantitative information, may be required.)

III. Drilling production well.

A. Conventional rotary method. (Mud cake must be removed from the sand face. Collapse of the sand around the screen is essential for successful development of the well.)

B. Reverse-rotary drilling. (Avoids mud-cake problems. Deep water levels may require excessive supply of water to maintain hydrostatic head in the well to prevent collapse of the sand beds.)

C. Underreaming and gravel packing. (May be used either with conventional or reverse rotary. Increases effective diameter of the well and allows use of larger screen openings to give more open area per foot of screen.)

D. Organic "muds".--Sometimes are used instead of native clays or commercial muds. Breakdown of the organic material generally greatly reduces development time.

IV. Test pumping the well.--Until the well is test pumped, the optimum pumping rate can be only roughly estimated. (The well should be tested at "full" capacity when feasible.)

A. Types of tests and data obtained.

1. Pumping test to determine (or confirm) hydraulic data for aquifer.

2. Step-drawdown test to determine optimum pumping rate.

3. Specific-capacity test (can be determined from 1 and 2, above). An initial specific-capacity measurement is essential for judging changes in well performance with time.

V. Problems encountered in well drilling that affect well installation, development, or yield.

A. Mud or mud-filtrate loss that allows material to penetrate a sand to the extent that development procedures are not effective.

B. Caving during underreaming may seal off producing strata.

C. Crooked or out-of-plumb hole.

D. Incomplete development.

E. Multiscreen wells.

1. Each screen may not develop fully (all or most of water may be coming from one interval).

2. Mixing of unlike waters from different sands may result in chemical reactions that could plug a screen or the gravel pack.

F. Improper sizing of screen, which allows sand production. (May be caused by poor sand samples.)

G. Improper sizing (or emplacement) of gravel pack, which allows sand production or allows sand to invade gravel pack and reduce yield.

H. Installation of well in a limited aquifer (water level does not recover to, or near, static level within the "normal" recovery period).

Statistics on test holes drilled by the Louisiana Office of Public Works and the U.S. Geological Survey (through December 31, 1976):

1,207 test holes (902,000 feet of test hole drilled).

1,372 temporary (test) wells or permanent observation wells (installed 778,591 feet of wells).

# CHAPTER II. REGULATIONS AND STANDARDS FOR WATER-WELL CONSTRUCTION

by Darrel Primeaux*




*Chief, Water Resources Section, Louisiana Department of Transportation and Development, Office of Public Works.

# WELL DESIGN & CONSTRUCTION SPECIFICATIONS, A CONTRACTOR'S VIEWPOINT

by R. M. Holt*

I wish to take this opportunity to thank the Louisiana Water Well Association for inviting me to represent them on this program, and I wish to congratulate the sponsoring organizations and their program committee on putting together this very fine seminar. The title of my paper "Well Design & Construction Specifications, A Contractor's Viewpoint" was selected by this program committee and is an excellent topic. I am taking the liberty of expanding on this subject, however, to include not only the technical specifications but also the entire contract documents. This is a subject which needs to be examined and reviewed in a constructive manner in order to assure all parties, the purchaser, the consulting engineer, and the contractor, that the contract documents will provide the best end result for the purchaser at a competitive price at which the contractor can be assured of a reasonable profit.

My comments will be directed primarily toward the consulting engineer writing specifications for municipal wells and I sincerely

*District Manager, Layne Louisiana Company, Lake Charles, Louisiana.

hope that this paper will be received in the manner in which it is offered--as constructive criticism. For the most part, the consultant does a very commendable job. The specifications are attractively bound and some even use different colored paper for different sections which is very beneficial to the bidder. The plans also are very professional and represent a lot of work by the draftsman and the engineer in the design and checking of these drawings. All too frequently there are unnecessary contradictions between the various parts of the contract documents and these contradictions, for the most part, could be eliminated or substantially reduced if the engineer would take sufficient time to proof read the technical specifications together with the special conditions, the drawings and the proposal form.

The tendency of the engineer is to develop one set of standard specifications which he can use on all different types of wells. There is nothing wrong with this approach but, so often, the plans will show one size well and the specifications another. It can be very confusing. I was looking at some specifications recently which covered all possible conditions--gravel wall or straight rotary--casing sizes from 4" to 36"--clay-base mud or organic mud, etc. These specifications covered three different contracts---the well, the distribution system and a tank. There were special conditions for each contract, and the special conditions applying to the water well were tied in to those of the other contracts. As I say, they covered all possible electives in the drilling of the well, but were so confusing that you really couldn't be sure you had touched all the bases in putting your bid together unless you read the entire set of specifications. I was surprised, after reading through these specifications, that neither the depth of the well nor the length of the casing and screen was ever mentioned--not even on the proposal form or the special conditions. It was only shown on the drawings.

There are three major portions of the contract documents which I feel need to be discussed at this time. The Proposal Form, the General Conditions and the Technical Specifications.

The Proposal Form is quite frequently designed without any apparent regard for the procedure which the bidder follows in preparing his bid. We prefer to see a Lump Sum Proposal Form with one lump sum price for the well, pump, foundation, valves, everything, then adjustment prices which will apply for more or less test drilling, more or less casing, more or less screen, and more or less pump setting. These are the only bid items which are apt to change. Many engineers, however, use a unit price proposal form which has a unit price for the test hole, the outer casing, the inner casing, the screen, and a lump sum price for the pump and a lump sum price for one or two other categories. The sum of all these extended prices constitutes the base bid. This creates a very awkward situation because in order to make a balanced bid you need to distribute part of your mobilization and other fixed costs to each of these categories, but this results in excessively high unit prices for those items which are apt to vary. The tendency on such unit price proposal forms is to throw in a majority of the mobilization and fixed costs into one of the lump sum bid items in order to keep the adjustment prices within reasonable limits. In the preparation of a bid, we take the cost of materials, labor, third party services and add a margin of profit to arrive at a base bid. On unit price proposal forms, we then have to turn around and break out a portion of the labor, materials and third party services applicable to each bid item, which results in a lot of extra work and really serves no useful purpose.

Finally, the unit price proposal form can become very cumbersome when more than one well is provided for or when there are alternates for different size wells or different pumping conditions or options for a standby engine and gear drive, or for one or more water samples.

In regards to the General Conditions, one of the most objectionable inequities in any contract is liquidated damages. I have talked to a number of engineers regarding this matter and some feel that this is the only way that a purchaser can be protected against a long drawn-out construction period, which is perhaps true, but by the same token it is more frequently used against a contractor without regard for true justice. A few years ago we were exposed to more than the average amount of liquidated damages, some of which were justifiable, but some of which were definitely not. In one particular instance, during a period when delivery on all manufactured material was running from 4 to 6 months, the consulting engineer changed the specifications on some electrical starting equipment after the original order had gone in some three months earlier. The change order resulted in an additional five months delay in receiving the merchandise, yet he would not agree to an extension of contract time. This incident cost us several thousand dollars and the municipality involved said they had to go along with the recommendations of the engineer. My parent company elected not to take this matter to court and as a result Layne Louisiana Company had to eat these charges. To this day, I have never forgiven that consulting engineer.

In another instance a municipality was facing an emergency condition due to a lack of water. They told their consulting engineer to make every effort to get the new well specifications on the market so they could take bids at the council meeting the next Tuesday night. I was at this council meeting when they were faced with this impending emergency and I recommended to the council and the engineer that inasmuch as time was so vital, that they should inject a clause in the contract to not just penalize the contractor $50 per day for failure to complete the job on time, but to give him a bonus of $50 per day for each day that he completed the project ahead of schedule. They were afraid it might make the well cost a few hundred dollars more than they planned to spend, which made me question their sincerity about the emergency. This is an example of how the matter of liquidated damages is used against the contractor and not for the benefit of the customer. Why should the contractor take all the gamble? I feel that the bonus method is certainly the most equitable approach, but in lieu of this, I sincerely believe that it should be incumbent upon the municipality to prove that they have suffered monetary loss or damage. For instance, if they had gone to the bank and borrowed money that they were continueing to pay interest on even though the contractor was late in completing the work, I think they are certainly entitled to liquidated damages. Similarly, when the contractor is late in completing a project and the municipality is required to pay additional consulting fees on a per diem basis, this, too, should be cause for renumeration. But there again, these damages should be substantiated and be the basis of any claim for compensation.

The Technical Specifications are the real meat of the contract documents. They explain in detail just what is to be provided for under the contract---sizes and materials of construction, procedures, required production, guarantees, etc.

The specifications may require that a test hole be drilled to contract depth and sand samples taken at 10-foot intervals.

If the proposed well is to be 900' deep, why take sand samples from the shallower sands. Quite often, time and money are wasted catching and analysing sand samples that are not going to be used in the completion of the permanent well.

Occasionally the specifications will require the taking of one or more water samples from the test hole where chemical quality is questionable. This is sound engineering practice, because occasionally wells are completed in aquifers which produce less than satisfactory water quality. Water sampling requires the completion and development of a small diameter temporary well. There is a very great amount of risk involved in this water sampling. Occasionally you have a hard time making the packer above the screen hold particularly in loose unconsolidated shallow sands which necessitates rereaming down to the aquifer to provide a new packer seat. There is even greater risk in getting the pipe and screen stuck. The risk of getting stuck increases with depth. In deep exploratory test hole where two or more water samples are to be taken, we like to see two holes drilled. The first one primarily to be used for collecting sand samples and electric logging. This information is then used as the basis for selecting the points at which water samples are to be taken in the second hole. This way you are taking a water sample from an undisturbed sand section as you drill on down.

On the other hand, if you attempt to take the water samples from the original pilot hole, the deeper water samples are going to be increasingly difficult to obtain because you have had those deeper sands mudded off for weeks or even months before you finish sampling all the aquifers to be tested.

The technical specifications in recent years, to a large extent, have called for the use of a continuous slot or close rodded type well screen. I prefer to call it simply rod-base screen. For certain applications this is an excellent type of screen construction, however, one of the biggest faults is its collapse strength. This factor is often overlooked in writing water well specifications. Layne Louisiana Company is hesitant to use the rod base screen in a deep hole even though we have perhaps installed this type of screen deeper than any other water well driller in the country. On two different occasions we have installed rod base screen at a depth of approximately 5000'. But these were gravel wall wells. We would not like to install a rod base screen in a straight rotary type well at this depth, or even 1000', due to its low collapse strength. Specifications generally will call for a rod base screen which will provide a certain entrance velocity but only rarely will they specify the extra heavy or double extra heavy. Even this terminology is meaningless because there is no standard among screen manufacturers. We recently were awarded a job and proposed to use the extra heavy screen manufactured by the ABC Company, but this manufacturer claimed that his extra heavy 10" screen only had a collapse strength of 240 lbs. I went to another manufacturer who said their extra heavy screen is rated for 470 lbs. Inasmuch as I had told ABC I wanted to use their screen, I asked them for a requote on a screen that would give me something in excess of 400 lbs. collapse strength, and he had to decline to quote because he said he couldn't get heavy enough wire to meet these conditions. I point this out to emphasize that the industry sorely needs to establish certain minimum standards for the standard weight, extra heavy rod base screens.

Speaking of rod base screen, in recent years there has been a trend toward specifying an entrance velocity of 1/10 foot per second when selecting the slot opening of the well screen. This is a design criteria I have never been able to accept. In theory, and this is strictly theory---94% of the production is derived from the upper 25% of the well screen and the bottom 50% of the screen accounts for less than 1% of the production.(1) These calculations were made for me by one of the design engineers at our pump factory, Layne & Bowler, Inc., in Memphis. This is purely theoretical and is based on the percentage of production passing through the screen but does not give the percentage of flow through the aquifer. The flow velocity in the aquifer is uniform but the

(1) Based on 100' of 12" screen with .030 opening.

flow velocities through the screen is not. The transition from uniform velocity distribution is made in the gravel pack area around the screen and these calculations give me sufficient cause to question the practical aspects of selecting the slot opening of a screen on the basis of entrance velocity.

There is only one criteria to use in the selection of the slot opening, that being the grain size of the water bearing sand--regardless of the diameter or length of the screen, the design capacity of the well, or the type of construction, whether it be gravel wall or naturally developed. We prefer to run our own sand analysis. Not only does this save considerable time, but it is much too critical a detail to be left to a third party.

The engineer, whether it be the private consultant writing municipal specifications or the industrial engineer, sometimes is guilty of overengineering a project. We recently completed a well in New Orleans which required that the well casing be galvanized then given an external coat of primer, two coats of semi-plasticized enamel, wrapped with Fiberglass then another coat of enamel, then wrapped with tar impregnated felt and finally coated with Kraft paper. This is really great but this pipe was plain end and had to be welded into the hole. This welding no doubt burned off the internal coating of zinc and though the external joint was coated with a quick dry epoxy after being welded this is certainly the weakest point in the string and they should have gone one step further and specified threaded connections. Furthermore, I recommended to the customer they use schedule 40 casing but they preferred to stay with the lighter weight schedule 30.

Another example of overengineering is one local engineer who always specifies the casing shall be welded by "certified welders." The first time we encountered this we interpreted it to mean "qualified" welders. After reaming the test hole, we were ready to run casing and the engineer asked for the welders certification papers. To make a long story short, we ended up spending about $2,000.00 before we got two welders certified plus losing three days rig time circulating to keep the hole open. This was totally unnecessary. Water well casing need not be welded as though it was a code pressure vessel. Hopefully, it made the engineer feel important, but it cost this contractor a bundle of money.

Similarly, a set of short coupled fire pump specifications called for a type 316 stainless steel lineshaft. We suggested a type 303 stainless which was our factory standard in the 300 series of stainless steels and was offered at a reduced price. The customer declined the substitution, but when a stainless steel suction strainer was recommended, they said "No, we'll stay with the epoxy coated galvanized iron strainer." Again--overengineering.

I just mentioned jobs that are over engineered but this applied primarily to materials of construction. However, there is also another area where we have found jobs that were over engineered, where the engineer makes all the decisions and requires the contractor to guarantee the results. In one specific job which comes to mind, a test hole had previously been drilled at the proposed site and the electric log run, sand samples were taken and analyzed which gave the engineer all the information he needed to write his specifications. He specified the casing sizes and setting depth, the screen size and length, the slot opening, gravel size, gravel uniformity coefficient, diameter of the underreamed hole, the method and extent of development and the pump setting, and then required that the contractor guarantee the well to produce 600 GPM at a specified minimum draw-down. Now, this may not seem to be all that demanding on the contractor in view of the information which had been previously obtained from the test hole. But, in this particular case, this was a small diameter well with 55' of 5" screen. After moving on the job, we took our own sand samples, ran our own sieve analysis, and with a plot of this sand analysis and a plot of the analysis of the well gravel which we proposed to use, we recommended to the engineer that the screen should have a .030 slot opening. The engineer overruled us and told us that we should use a .012 slot opening. We, of course, explained that we could never meet his specific capacity guarantee with this fine screen and he referred us to the specifications where there was a paragraph that said "If the contractor has attempted to properly develop the well according to these specifications and this development is satisfactory to the engineer, payment for the well shall be made at full price regardless of well yield, drawdown or efficiency." This paragraph got us off the hook, but gentlemen, it is certainly a glaring example of the engineer over exercising his role in designing and supervising the construction of a water well. Now, to make this matter even worse, as I mentioned they were shooting for 600 GPM but they required that the well be test pumped at one and one-helf times this desired rate. Now, when you produce a well at 900 GPM that only has 55' of 5" screen with a .012 slot opening, you are looking at an entrance velocity of 5 times the recommended .10 feet/second and this excessive rate of production will cause a good well to make sand. As it turned out on this job, we were not able to produce the well at the 900 GPM, in fact we could not produce 600 GPM even with the pump set down to the top of the inner casing. Don't allow your client to dictate design conditions to you that cannot be achieved within the limits of sound engineering practice.

Specifications often require that the water produced must meet the standards of the U. S. Public Health Service. No water well contractor should knowingly agree to any such requirement, and surely neither the engineer nor the purchaser can reasonably expect the contractor to guarantee chemical quality. Nonetheless, this requirement is included in many specifications.

If the purchaser or engineer has reason to believe that water with objectionable chemical characteristics may be produced from the new well, they should certainly make provisions for the taking of a water sample from the test hole. Test hole samples can be quite expensive to obtain, but they are the only means by which chemical quality can be determined before the completion of the permanent well.

I have several recommendations to suggest regarding water well specifications.

(a) The inner casing should lap up inside the outer casing a distance of 60 feet where the well depth permits. This precludes the production of water up between the inner and outer casings and makes unnecessary a lead or other type seal between the casings.

(b) The top of the screen should begin at a point approximately two to five feet below the bottom of the surface casing in a gravel wall well. This insures that the screen is surrounded by a uniformly thick gravel envelope. If the top of the screen is immediately below the casing, the underreamer may not be fully opened, and hence there is only a very thin gravel wall at that point.

(c) The diameter of the underreamed hole should be 16" greater than the diameter of the screen. Some specifications require only 6" greater diameter and I've seen some that require as much as 40" greater diameter. The thin gravel envelope around the screen does not provide sufficient filtering and leaves no room for error in centering the screen in the underreamed hole. The overly thick gravel pack, however, makes development of the well almost impossible because you cannot penetrate the gravel to remove the fine material and mud from the face of the underreamed hole.

I would also like to recommend that a section be included in your specifications to provide for a television inspection of the completed well to be run prior to the installation of the permanent pump. There are many advantages to such a survey. First, it verifies the location and length of the inner casings and screen sections. I recently witnessed a couple of TV surveys which proved the well log to be in error. As you might suspect, there was less screen than we expected to find in the well. Secondly, it will prove the well screen to be open all the way to the total depth. I don't mean the camera survey can determine if the well screen is or is not thoroughly developed, but it will show if the screen is collapsed. And a television inspection will show if there is any junk left in the hole. We recently surveyed a well in Lake Charles and found a chain tong had been dropped in the well. I was surprised and a little embarrased when we found it, but the industrial engineer on the job said that though he had forgotten it was there he did remember when it was dropped. This TV survey is recorded on tape and can be played back at any time. Such a survey can be made for $1,000 to $1,500 depending on well depth.

In closing, I want to mention briefly the pump specifications which are consistently much better prepared than the well specifications. I noticed in preparing this paper one set of specifications where the design conditions were 150 GPM @190 feet total head but the pump was set at 280 feet. I don't think there is any danger of the pump breaking suction.

There are a couple of construction features which are often overlooked in pump specifications. One is the requirement of bowl wear rings. They are standard construction for the better quality pump, but on the economy line of pumps they are only furnished when specifically ordered.

It should be noted that for most pump manufacturers the standard weight of discharge column pipe 6" or smaller is Schedule 40 pipe and for column pipe larger than 6" the standard is Schedule 30. Don't accept anything less. We've pulled some pumps with column pipe that was 1/4" or less and you can't even unscrew it without mashing it.

SOME ASPECTS OF THE DEVELOPMENT AND COMPLETION OF WATER WELLS IN UNCONSOLIDATED AQUIFERS

by D. D. Smith*

The development phase of water well construction is so closely aligned to the methodology utilized in drilling, casing and screening the bore hole, as to be virtually dictated by the prior activities. In order to devise an intelligent approach to development, a thorough knowledge of the lithology of the formation(s) penetrated, the method and material used for drilling the hole and the specifications of pipe, screens, gravel and etc. are all of vital interest.

Virtually all methods of drilling disturb the original condition of the formational material which a bore hole has penetrated. The intrusion could be expected to reduce the permeability and as a consequence, lower potential yield and decrease the specific capacity. Understanding the hydrologic properties of a rock or soil material will aid the developer in comprehension of the nature of the damage inflicted and the effects of remedial measures.

## Background

Previous presentations at this Seminar have defined and provided a conceptual relationship for the various hydrologic terminology which depicts the occurrence and movement of underground water as it is controlled by the laws of physics.

*D. D. Smith, Geologist, High Plains Underground Water Conservation District No. 1, Lubbock, Texas.

Indulging in a mathematical exercise will demonstrate that increasing the diameter of a well bore has little effect upon the potential yield of a well. For example, increasing the diameter from one foot to two feet will theoretically increase the yield by 10 percent and increasing the well bore to four feet would improve the yield only 21 percent more than the one foot well. While increasing the diameter of the bore has little theoretical effect on yield, it does decrease the velocity with which water passes through formational material adjacent to the well casing. Doubling the diameter will decrease the velocity by one-half. Where fine sand or silt is present in the formation, it may prove desirable to reduce velocity. Laboratory experimentation indicates water with a velocity of 0.1 ft/sec. to 0.25 ft/sec. will just perceptibly lift sand in the 0.25 mm to 0.50 mm diameter range while a velocity of 0.06 ft/sec. will just lift material in the silt and clay range.

The above discussion is intended to serve as an introduction to the subject of development of a newly drilled and cased bore hole. It is apparent that development activities do not have to extend a large radial distance from the well bore to intercept most of the inherent potential of the aquifer. Enhancement of the original potential is a subject more properly addressed in the design and construction phase.

## THE DEVELOPMENT PHASE OF WATER WELL CONSTRUCTION

The development phase of new water well construction consists of mechanical activities designed to correct the damage which may have occurred during the drilling phase, the abstraction of some of the finer formational material to produce a more uniform envelope around the well, and additionally, development should grade the formational material around the screen in such a way as to assure a stabilized condition. Development may be attempted by a variety of procedures including pumping, backwashing, surging, the injection of compressed air, and high velocity jetting.

Pumping and Backwashing

Within the High Plains of Texas, pumping — over-pumping and backwashing have been the most common methods of well development. Pumping - as implied - consists simply of installing the production pump and commencing operations. In practice, better results are normally achieved when the power unit can be operated through a wide speed range. Initial operation is commonly at low rpm's and the speed is increased in small increments as the produced water becomes clear. This procedure is continued until the speed capability of the power unit is reached, or the pumping level in the well reaches the pump setting.

Over pumping proceeds in virtually the same manner as pumping with the exception that a test pump is normally utilized and the capability of the pump and/or power unit is larger than the anticipated permanent installation. It also has the added advantage of being able to test the production potential of the new well and, with the results of such tests, aid in the selection of an efficient pumping plant.

Backwashing of a well consists of any of several methods in well development which are designed to create agitation of the formational material opposite the screen area. One of the methods consists of operating a pump without a foot valve at high rates coupled with intermittent stops. Such actions are designed to create rapid changes in pressure heads by alternately causing large draw-down and then allowing the water in the pump column to fall back. Severe agitation can be achieved when the aquifer is relatively thin and the depth to static water level is large.

Backwashing can also be accomplished with a bailer. A common method consists of rapidly dumping large quantities of water into the well and then bailing out the hole with a bailer. An alternate method would be to place pipe in the well and force water under pressure into the cased bore hole. An outlet pipe and valve may be added so that the well could be hydraulically flushed at intervals.

Surging

Surging of the water within a well has long been utilized as an effective method in development. Cable-tool drillers have been using simply constructed "swabs" or using a heavy bailer to create surges since early time. The methodology has been adapted to rotary rigs with equally good results.

In theory, a piston or cylinder type devise is plunged up and down in the cased well creating a surging effect in the formational material which tends to draw in the fines. The "surge plunger" should be loose fitting to the screen and may be of the solid type whereby force is exerted on both the up and downward strokes, or it may be valved so the force is large on the up-stroke and lesser on the down-stroke to create continuous agitation

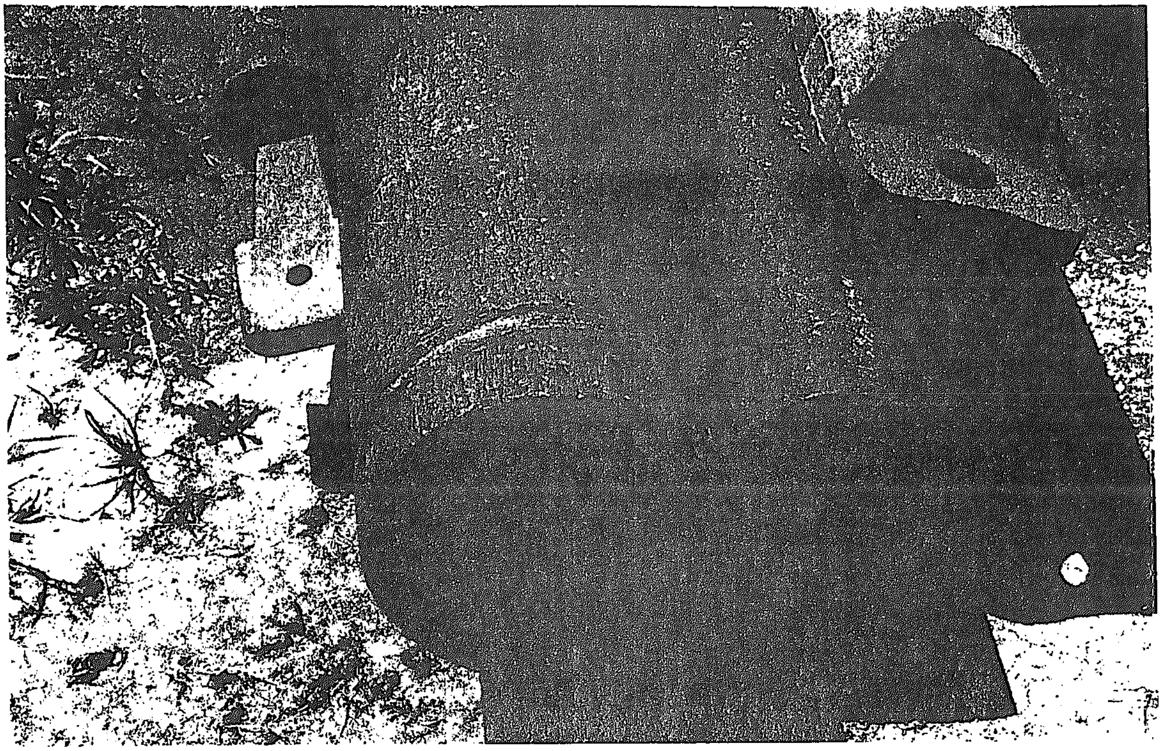

Figure 1. Dart valve and flat-valve bailers.

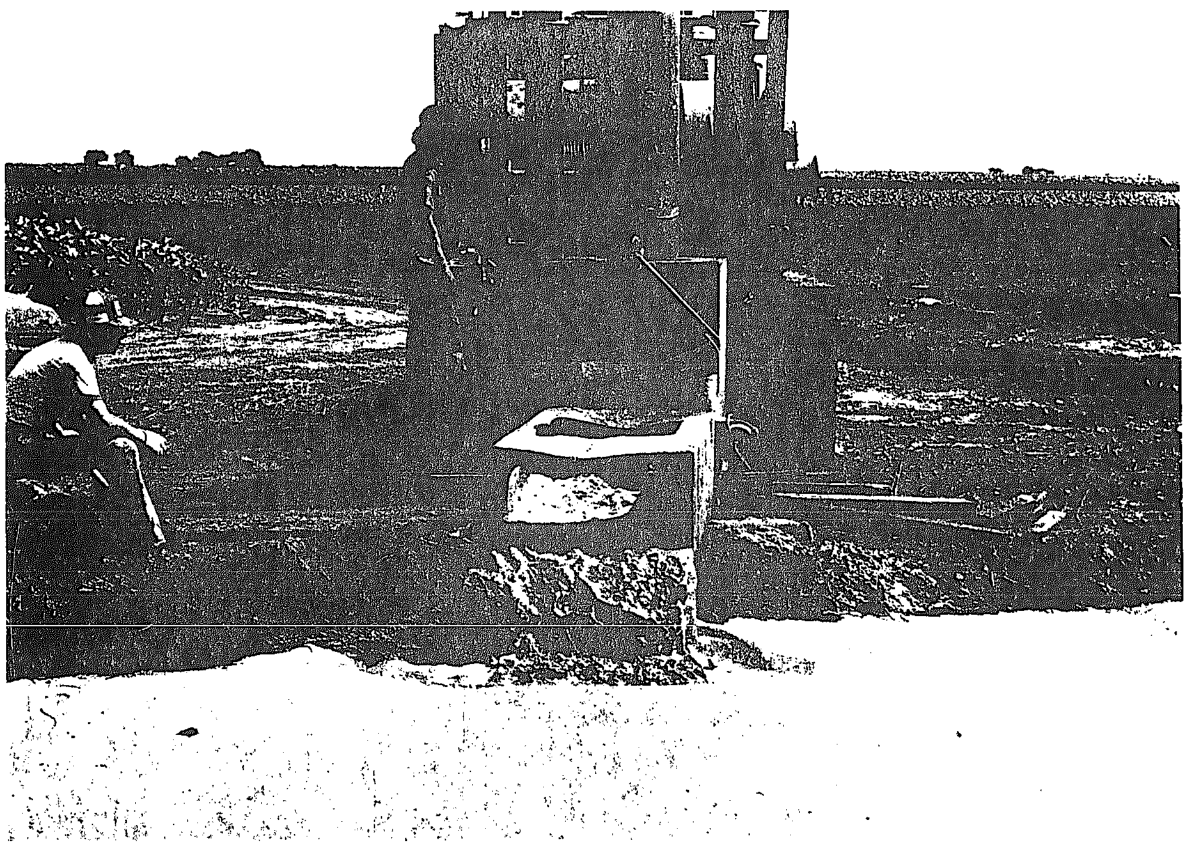

Figure 2. Two hundred gallon bailer being used to develop an irrigation well.

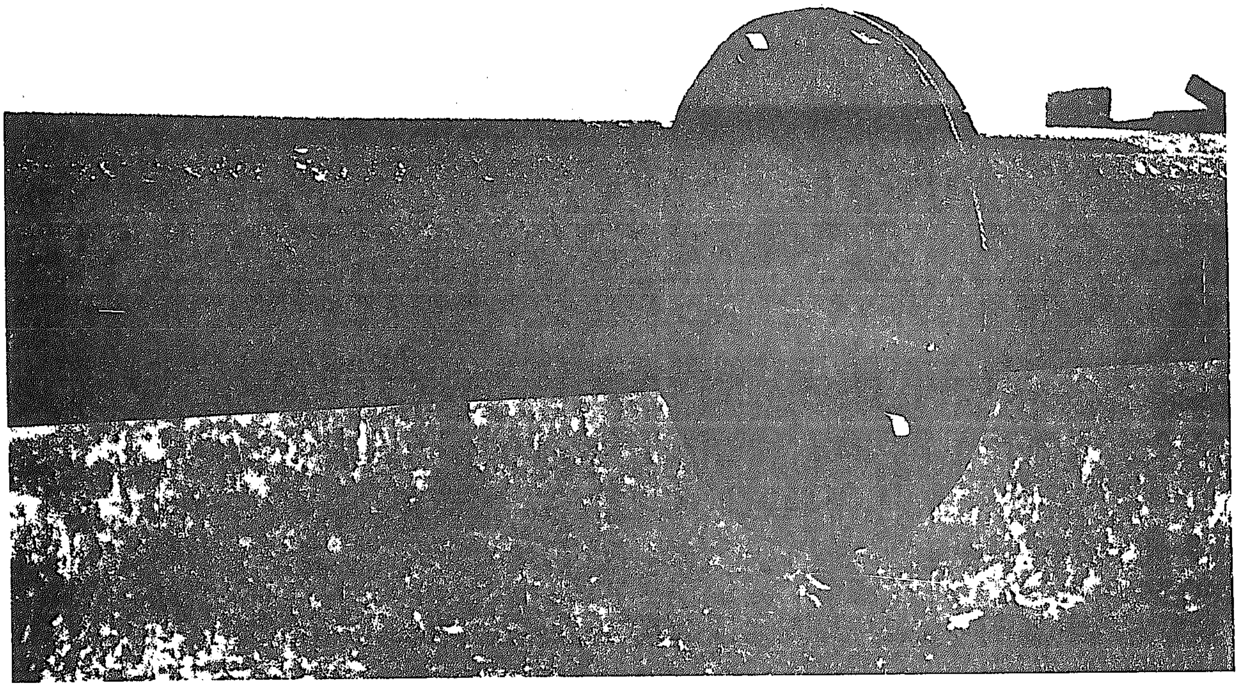

Figure 3. Surge block fabricated on heavy bailer.

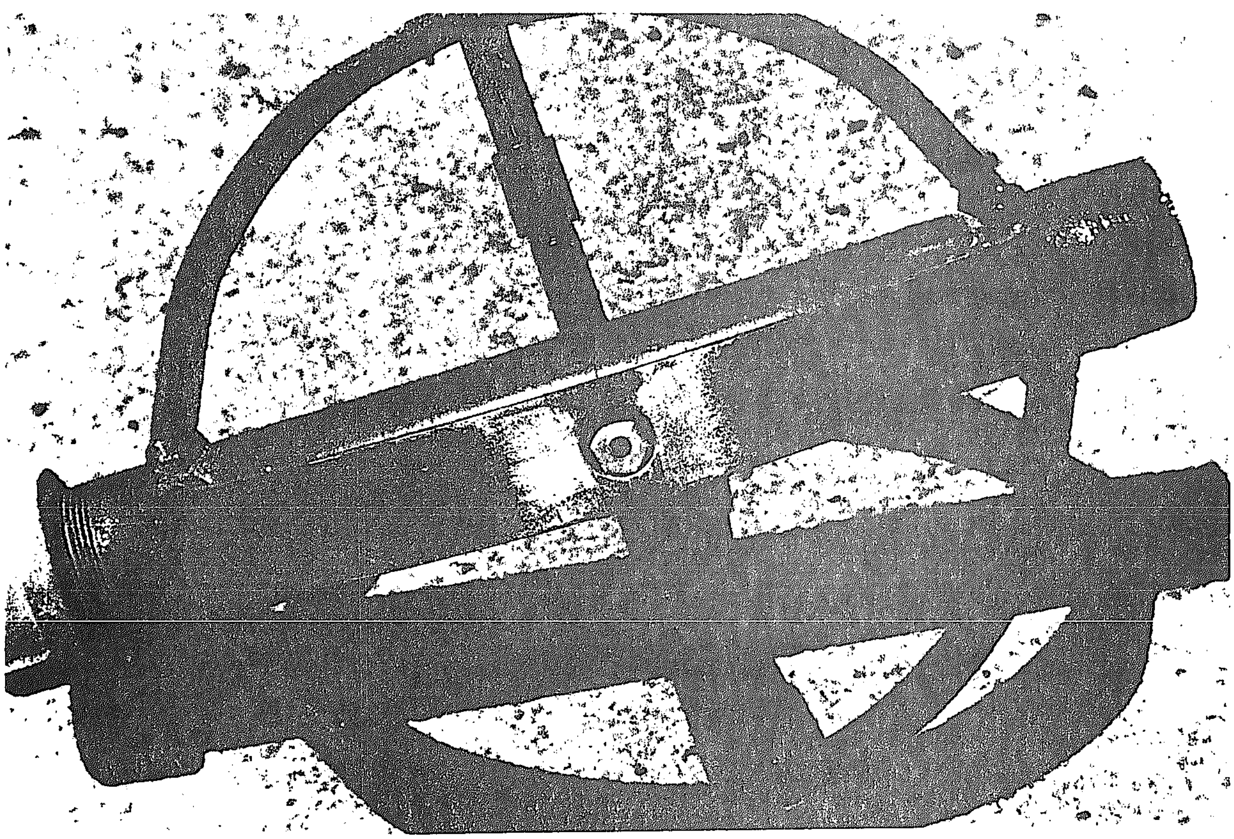

Figure 4. Shop built jetting tool designed for use inside 14-inch screen.

with over-all movement into the well. Care must be exercised to thoroughly bail the well at regular intervals to prevent excessive development of the upper portion of the screened area because the lower portion is continuously blocked off by the accumulation of indrawn sands.

A method for surging with compressed air has been developed and has proven effective in may applications. The equipment requirements, plus the necessity that at least 60 percent of the well depth be within the saturated portion of the aquifer, preclude widespread use of the method in many areas. The principal involved is a combination "pump and then surge" operation. The release of large volumes of injected air creates substantial surging and pumping is accomplished in the same way as an ordinary air lift.

## High Velocity Jetting

High velocity jetting operates in principal very similar to the previously described backwashing under pressure. It differs in that the force is concentrated in a small area by jetting the high velocity water through a nozzle arrangement which may be raised or lowered in the well to effectively work over the entire screened area.

The equipment required for high velocity jetting include a nozzle arrangement on a jetting tool just slightly smaller than the inside diameter of the screen, a high pressure pump with hose and connections to fit a string of drop pipe, and wherever possible a pump or air lift to remove slightly more water from the well than the volume introduced by the jetting stream.

The force introduced into the formational material will disturb the finer portions and the turbulence will normally carry the fines along the path of least resistance back inside the screen at points above and below the working interval. Where the open area of a screen is small, or an artificial gravel pack of substantial thickness has been placed, the effectiveness of high velocity jetting will be diminished. The limitations of the high pressure pump are probably the controlling factor in creating the velocity necessary to achieve success in the more difficult environs.

## CONCLUDING DEVELOPMENT

After practicing development work on a new well installation for a period of time, it would be normal that the question "When to stop?" should arise. Obviously, construction engineered constraints, the intended use of the well, the extent to which the well will be pumped and other economic considerations may all exert legitimate limitations upon the degree of perfection attained.

The ideal well might be one which yields all of the water desired with no drawdown and completely free of particulate matter. Since the well owner will occasionally settle for less, some practical criteria for the industry have been addressed by the National Water Well Association.

Under contract with the U. S. Environmental Protection Agency, the NWWA has recently completed the Manual of Water Well Construction Practices. In establishing limits for the sand content allowable within the various water useage categories, the publication suggests that where "the nature of the water-bearing formations and the overlying strata ---" are such that the well life will not be shortened by abstraction of limited amounts of material, flood type irrigation water may contain 15 ppm, sprinkler irrigation and industrial evaporative cooling be limited to 10 ppm, other industries along with municipal and private water supply wells contain less than 5 ppm while well water used in the food processing industry should be less than 1 ppm. While the quantity of sand allowable in various categories is obviously highly variable, it should be noted that the removal of particulate matter in even such small quantities as has been suggested above can, through time, create substantial voids. For example, assume a water well pumping 1 million gpd with sand content of 15 ppm, is in operation 200 days per year: If the median size of the sand grains was 0.1 $mm^3$, after the first year of pumpage a cavity of 0.3 $m^3$ (10.5 $ft^3$) could be present and after 20 years of operation the potential cavity could be 6 $m^3$. The point and emphasis is that pumpage of even minute amounts of the formational material has the potential to shorten well life substantially.

In the water well construction industry as in most other skilled trades, practitioners do have a tendency, over time, to acquire expertise in some particular development technique and attempt to utilize it exclusively. When the variability of the lithology of an alluvial formation from one site to another is introduced as a factor to be dealt with in the construction and development of water wells in unconsolidated aquifers, the need to provide alternative methods becomes obvious.

The development phase of water well construction employs many scientific tools and sophisticated mechanical devises to accomplish it's objectives. However, in the final analysis, development remains more akin to artistic endeavor than the ABC's of science.

# REFERENCE BIBLIOGRAPHY


American Water Works Association, 1958. "AWWA Standard for Deep Wells," New York.

Anon, 1966. "Ground Water and Wells," Johnson Division, UOP Inc., Saint Paul, Minnesota.

Anon, 1975. "The Principles and Practical Methods of Developing Water Wells," Johnson Division, UOP Inc., Bulletin No. 1033, St. Paul, Minnesota.

Lohman, S. W., 1972. "Ground-Water Hydraulics," U. S. Geological Survey Professional Paper 708.

U. S. Environmental Protection Agency, 1975. "Manual of Water Well Construction Practices," EPA-570/9-75-001.

Walton, William C., 1970. "Groundwater Resource Evaluation": New York, McGraw-Hill Book Co., 664 p.

# WELL MAINTENANCE

by Mark E. Walton*



*Nuclear Staff Assistant, Power Plant Engineering and Design, Gulf States Utilities Company, Baton Rouge, Louisiana 70821.

# WELL REDEVELOPMENT

By Tyler E. Gass*

Energy curtailment and regional reductions of the water table have made it extremely important that water wells be maintained so that they operate at maximum efficiency. Proper redevelopment of a well can increase well productivity, minimize energy requirements and costs for pumping, and reduce excessive drawdown of the water table in the vicinity of a well. Most wells which are producing at 50 percent or better of original design capacity can be restored to produce up to 95 percent of their original capacity when the well is properly redeveloped. There are a great number of factors that could make it necessary to redevelop a well. This paper will deal with only the most common causes of reduced well yield that result in a need for redevelopment. The procedures for well treatment described are accurate, but presented in a general manner because most water well contractors devise ingenious adaptations of treatment methods to meet the specific situations most frequently encountered in the region of the country in which they operate.

## Incrustation

Incrustation, the most common cause of decrease in the specific capacity of a well, results from increasing resistance to the flow of water into a well. This occurs when the well screen or casing perforations, and the formations around the well become clogged by deposition of material

---

*Director of Technical Services, National Water Well Association, Worthington, Ohio, 43085.

in, on, and around the screen or casing openings and the voids of the aquifer. Incrustation can be the result of one or a combination of conditions descriptively subdivided into chemical, bacteriological, and mechanical causes.

The chemistry of the ground water is the most important factor affecting the potential for incrustation. The dissolved minerals and gases in ground water are present in a rather delicately balanced condition. When ground water is no longer in chemical equilibrium with the subsurface environment, the dissolved minerals begin to precipitate. The chemical equilibrium of ground water is frequently disrupted by a reduction in head or pressure resulting from drawdown around a pumping well. Carbon dioxide is released from solution because of the pressure reduction. This carbon dioxide imbalance forces minerals dissolved in the water to precipitate and form an insoluble scale.

The formation of calcium carbonate and calcium bicarbonate is a classic example of what occurs:

$$\underset{\text{Calcium bicarbonate}}{Ca(HCO_3)_2} \xrightarrow{\text{reduced pressure}} \underset{\text{carbon dioxide}}{CO_2} + \underset{\text{calcium carbonate}}{CaCo_3} + \underset{\text{water}}{H_2O}$$

Magnesium bicarbonate changes to magnesium carbonate in the same manner as calcium bicarbonate when carbon dioxide is relaesed.

Precipitation of iron occurs when iron in its reduced state comes in contact with oxygen, converting the soluble ferrous iron into insoluble ferric iron.

$$4\ Fe\ (HCO_3)_2 + O_2 + 2H_2O \longrightarrow 4\ FE\ (OH)_3 + 8CO_2$$

The precipitation of manganese ions occur in a manner similar to that of iron ions.

Sufficient quantities of oxygen for the oxidation of reduced iron and manganese become available in and around the cone of depression. Air enters the voids of the cone of depression and oxidizes the iron in the film of water adhering to individual grains of the aquifer. If pumping is started and stopped intermittently, a coating of iron oxide can build up, progressively clogging the void space in part of the formation. This type of incrustation reduces storage capacity and permeability in the vicinity of the well and results in an enlargement of the cone of depression, and reduced pumping efficiency.

Bacteriological incrustation is commonly caused by iron bacteria. These are filamentous organisms which develop thread-like slime growths. Iron bacteria oxidize dissolved iron (and manganese) and accumulate large amounts of ferric hydroxide in a slime. The resulting precipitation of iron and bacteriological slime can plug openings in the well casing, screen and in the pores of the formation surrounding the well bore.

Iron bacteria and plugging caused by it are generally found:

(a) In shallow waters, probably because the bacteria are aerobic;

(b) In waters at temperatures of 65° F or less;

(c) In high iron and manganese water (1 ppm iron or more is necessary to sustain growth).

(d) In waters with less than 1,000 ppm total dissolved solids.

Iron bacteria problems are usually not capable of being solved permanently. Periodic maintenance will thus be required to keep the well performing as designed.

Mechanical plugging caused by silt, clay and fine sand does not occur as often as chemical or biological incrustation. It typically occurs when a well has been improperly designed or constructed, or where the waterbearing formation contains an abnormal amount of these fine materials. Fine material which is pulled into the well openings, becomes lodged in pore spaces in the vicinity of the well when it is being pumped.

When problems of incrustation are recognized and acted upon early most wells can be redeveloped successfully. If structural failure or ground water depletion of the aquifer does not occur a well that is properly maintained can operate indefinitely.

## Methods of Well Redevelopment

The most common method of redeveloping wells which have been plugged by chemical precipitation is with some type of acid treatment.

Muriatic acid (another name for hydrochloric acid) is one of the most commonly used acids for removing mineral scale. It is commercially prepared for well redevelopment use in the form of a clear to yellowish solution of hydrogen chloride gas dissolved in water. It is produced in varying strengths which are identified by degrees baumé. Eighteen baumé (which is 28 percent) muriatic acid is most frequently used to treat wells with incrustation problems.

Muriatic acid is usually introduced into the well through a small diameter plastic or black iron pipe (Figure 1). The quantity of muriatic acid used should be equal to the volume of water in the screen plus 50 percent. This quantity will provide enough acid to fill the screen, with sufficient additional acid to maintain adequate strength as the chemical reacts with incrusting material in the screen and surrounding formation.

"If the screen is more than 5 feet long, enough acid should be added to fill the lower 5 feet of screen. Then the pipe should be raised, and the next 5 feet of screen filled with acid, continuing in this way until the entire screen is filled" (Schafer, 1974).

Following the placing of the muriatic acid in the screen, enough water should be poured into the well to displace the acid and force it into the formation. If possible, some type of mechanical agitation, such as surging or jetting should be employed while the acid is in the well to promote the dissolution and break-up of the incrusting deposits and to improve overall efficiency of the treatment process. Agitation should proceed for 1-2 hours, increasing in intensity with time. When the chemical reaction is completed the spent acid and debris should be pumped to waste.

Muriatic acid is an extremely effective well cleaner, but it does have disadvantages. It is very dangerous to handle because it is corrosive to flesh and gives off toxic fumes. The acid also has a very corrosive effect on many types of well casing, screens and pump components. The corrosion resistance of materials to muriatic acid is listed in decreasing order below:

Types 316 and 304 stainless steel
Silicon manganese bronze (Everdur)
Silicon red brass (Red Brass)
Fiberglass
Plastic
Amoco Iron
Low carbon steel

Sulfamic acid is a dry, white, granular material which becomes a strong acid when mixed in water. Sulfamic acid can be mixed with water at the surface and then placed in the well following the same procedure used for muriatic acid. Ten gallons of water can be used to dissolve 14 to 20 pounds of granular sulfanic acid. The actual amount that will dissolve depends on water temperature. It is possible to dump the dry granular material directly into the well. However, it then becomes necessary to completely saturate the entire column of standing water in the well with the material. This results in a great amount of waste. Like muriatic acid it is necessary to agitate the solution once it has been placed in the well.

U O P Johnson has overcome the problem of directly using dry sulfamic acid by developing a product known as Nu-Well. Nu-Well comes in the form of a pellet that consists partially of sulfamic acid. The pellets are heavier than water so they fall to the bottom of the well screen before dissolving.

While sulfamic acid works very well on carbonate incrustation it only partly dissolves iron oxide scale. The effectiveness of dissolving iron scale deposits is increased by adding sodium chloride (salt) to the acid. About 50 pounds of salt should be used for every 100 pounds of granular sulfamic acid.

Sulfamic acid is safer to use than muriatic acid because in a dry form it does not give off toxic fumes and will not irritate dry skin. If spilled, it can be cleaned up easily. It is also less likely to corrode pump parts, casing or screens. However, it does require a longer contact time than muriatic acid. It is recommended that it be allowed to stand overnight in a well for optimum performance.

Hydroxyacetic acid is frequently used on wells with iron incrustation and iron bacteria. It is a liquid organic acid, generally available commercially in 70 percent concentrations. Even though it is in liquid form, it is relatively non-corrosive and will not give off toxic fumes.

Hydroxyacetic acid is an excellent bactericide in addition to its ability to dissolve mineral scale. This accounts for its popularity for wells plagued by iron bacteria and iron incrustation. It provides one-step removal of iron scale and bacteria.

This type of acid is also a chelating or sequestering agent. This means hydroxyacetic acid has the ability to dissolve and then keep metal ions in solution. This prevents re-precipitation of scale as the acid is spent.

Hydroxyacetic acid is placed in a well and agitated in the same manner as muriatic acid. One gallon of 70 percent hydroxyacetic acid should be used for every 10 or 15 gallons of water that is standing in the well screen plus an additional 50 percent so that it can remove scale beyond the well bore (Table 1)

Because it is not as potent as muriatic acid or sulfamic acid, hydroxyacetic acid requires a longer contact time than either of the other two. This contact time can be reduced by mixing small quantities of either sulfamic or muriatic acid with hydroxyacetic acid.

It is useful to keep the following concepts in mind when redeveloping a well with any type acid:

(1) The rate at which an acid removes scale is related to its pH. The lower the pH the faster it works.

(2) Always wear goggles and water-proof gloves when working with acid.

(3) Always slowly pour acid into water. NEVER pour water into acid.

(4) Work with acid only in well-ventilated spaces.

(5) After using an acid in a well make certain it has all been pumped out.

The clogging of a well screen and the adjacent formation due to iron bacteria is partly caused by the slimy organic material produced by the bacteria and the iron deposits associated with the organism. These deposits may combine with scale minerals such as calcium carbonate.

Optimum treatment must, therefore, involve a bactericide to eliminate the iron bacteria and a strong acid to dissolve mineral scale. The use of hydroxyacetic acid has already been discussed for this purpose, but some water well contractors prefer other methods.

One 3-step treatment method consists of an initial shock chlorination followed by acidization and finally another shock chlorination.

During shock chlorination a quantity of chlorine compound is placed in the well sufficient to raise the residual chlorine concentration to as high as 500 ppm. The chlorine is then agitated so that it is forced out into the water bearing formation. The second step is acidization with muriatic or sulfamic acid. The third step is the additional shock chlorination.

Whether shock chlorinating or using standard chlorination procedures, the contractor should introduce the chlorine solution into the well through a small-diameter plastic pipe. The pipe must be positioned in the well so that the concentrated chlorine solution does not impinge directly upon any part of the pump, well casing or well screen. The chlorine should then be forced out into the water-bearing formation, using 50 to 100 times the volume of standing water in the well. It may be necessary to repeat the 3-step treatment 3 to 4 times in a well undergoing redevelopment for iron bacteria incrustation, since repitition increases the chance that the chemical will be flushed through every part of the formation in the vicinity of the well that may be plugged by the growth of slime-producing bacteria.

Potassium permanganate is a strong oxidizing agent that can also be used to treat bacteriological incrustation. It consists of a dry purplish-colored crystal that should be dissolved in a sufficient volume of water to fill the screen, plus a volume 50 percent greater than the screen. Once the solution has been prepared, it is placed in the well in a manner similar to chlorine and agitated.

Sequestering or dispersing agents react with clay and silt particles in a manner that causes each of the particles to repel one another, or "disperse." Such agents increase the mobility of sand, silt and clay particles, making it easier to remove them from a well when water is pumped.

Sodium phosphate is the most commonly used sequestering agents. It is a white, free-flowing dry material which usually comes in two forms: (1) Glassy phosphates (Calgon, Polyphos, etc.) which belongs to the family of sodium hexametaphosphate; and (2) Crystalline phosphate such as sodium tripolyphosphate, sodium acid pyrophosphate (SAP) and tetra sodium pyrophosphate. The crystalline prosphates, although not as popular as glassy phosphates, are equally effective as sequestering agents.

Polyphosphates should be mixed with water at the surface, because dry polyphosphate placed in a well sinks to the bottom without dissolving. Fifteen to 30 pounds of material should be used for every 100 gallons of water in the well. The solution can be made by placing the polyphosphate in a wire or burlap basket and then suspending it in a tank of water. After the polyphosphate solution has been prepared, it can perhaps be best emplaced in the well by jetting. If a jetting tool is not used, the solution should be vigorously agitated in the well to loosen and disperse silt and clay particles.

If slime-producing bacteria are also a problem in the well, a small amount of calcium hypochlorite can be used to kill the organisms. About one pound of calcium hypochlorite should be used for each 100 gallons of water in the well.

Surfactants, or wetting agents, are chemicals that lower the surface tension of water, thereby permitting the water to more readily flow into pores, cracks and crevices. Wetting agents are typically found in detergents to assist in removing soil from clothing. The sufractants chosen must have low sudsing properties so that they do not prohibit the agitation necessary for proper well redevelopment. The surfactants should also be of the non-ionic type, because use of the non-ionic type of surfactant prevents chemical reaction that may cause insoluble precipitates to form.

Surfactants are inexpensive to use because of the low concentration required - about 250-500 ppm. They can enhance the dispersing efficiency of the polyphosphates for the removal of silt and clay. Likewise, acidizing is more effective when a surfactant is used in conjunction with the acid. This is because the surfactant enables the acid solution to soak into all of the pores and cracks in the incrusing deposit, increasing the total areal contact between acid and incrustation and thereby speeding the rate of removal of incrustation (Schafer, 1974).

Explosives have been used to redevelop wells in sandstone aquifers that have been clogged by chemical or mechanical incrustation. Explosives have also been used to stop sand-pumping of sandstone wells, where weakly cemented sandstone crumbles off the borehole wall as the well is being pumped. In some cases, shooting will knock down all of the looser material, leaving only the more solid sandstone exposed in the well.

Dynamite is the preferred explosive for shooting wells because it is less hazardous and more easily handled than nitroglycerin. Drillers prefer 60 to 100 percent gelatin dynamite for well redevelopment, with the majority of contractors using 60 percent. Charges of 100 to 500 pounds are generally used, the size varying with the hardness of the rock to be broken and the depth at which the charge is to detonated. Drillers frequently argue about the size of shot to use, which is not all that surprising when one considers the different varieties of hydrogeologic conditions under which explosives are used.

Each individual shot should be detonated opposite a productive zone. The proper positioning of the shot, therefore, requires an accurate knowledge of the depths of the most productive formations. This means that before redevelopment commences, well logs should be carefully examined. It may even be worthwhile to run additional borehole logs.

A description of the setting of charges should be presented by an expert, and therefore will not be discussed in this paper. However, certain safety precautions are worthy of note. Explosives and caps must be transported seperately. All explosives and caps should be removed from the well site each day when work is finished.

Sonic well cleaning is a method of treatment that can be used to successfully rehabilitate wells that are plagued by mechanical, or chemical incrustation or a combination of the two. Sonic well cleaning works by the coordinated timing of a mild harmonic frequency of shock waves, and a pulsating, horizontally-directed gas jet. The shock waves gently loosen incrusted mineral scales, and clay, silt and sand. The gas jets fluid back and forth through the perforations at a high velocity to deep-clean producing aquifers.

The sonic well cleaning process utilizes a polyethylene clad piano wire, which contains two materials: a high velocity, 30,000 fps sound wave material, whose energy is carefully released in a manner that sets up a gentle harmonic vibration along the casing wall; and capsules of barium peroxide, which creates the jetting action.

Water well contractors who have used sonic well cleaning techniques report that they have had excellent results in redeveloping wells where other methods of redevelopment were unsuccessful.

No matter what causes the yield of a well to decline, it is always easier to redevelop the well if the problem is diagnosed early and if treatment is applied before the well deteriorates to a point at which its yield is 50 percent below its original specific capacity.

It is essential that the well owner keep good records of the well's performance so that changes in specific capacity will not go undetected for too long a period. If a decrease of 10 to 20 percent is observed in the well's specfic capacity, steps should be taken to evaluate the cause and correct the problem.

If the redevelop procedures described in this paper are adhered to and any problems that may occur are promptly recognized and corrected the well owner can greatly extend the production life of his well.

## References

Anonymous, 1974, Ground Water and Wells, Johnson, U.O.P. 3rd Edition 440 pp.

Schafer, D.C., 1974, "The Right Chemicals are Able to Restore or Increase Well Yield" January-February, Pgs. 1-3, 13, March-April, 4-6.

TABLE 1

Quantity of Hydroxyacetic Acid Required Per Foot of Screen Length or Open Borehole

| Diameter of well inches | Gallons of 70% Hydroxyacetic acid, per ft. of screen or borehole |
|---|---|
| 4 | 0.06 |
| 6 | .14 |
| 8 | .24 |
| 10 | .36 |
| 12 | .50 |
| 16 | 1.00 |
| 20 | 1.50 |
| 24 | 2.25 |

SOURCE: Schafer, 1974

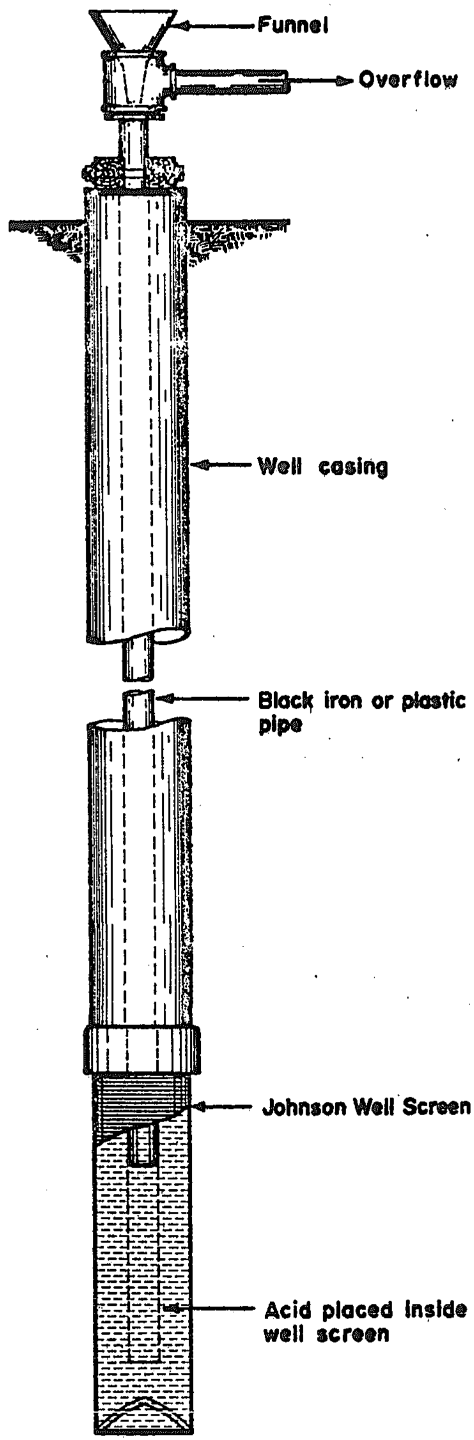


Figure 1. Typical arrangement for introducing acid inside well screen to avoid dilution of the chemical by water standing in the well.

SOURCE: Johnson Division, U O P Company, 1974.

# AN OVERVIEW OF THE FUTURE IN GROUND-WATER UTILIZATION

by Raphael G. Kazmann, P.E.*

In order to forecast the future, it is well to start with a summary of present conditions.

At this time the ground-water engineer and geologist can call on the drilling industry for water wells that produce water from depths of 3000 ft or more. Screen design principles are proven and reliable for, possibly, 95 percent of the applications. The exceptions usually have to do with water chemistry or dissolved gases.

The materials used in well construction range from the cements used in grouting the well casings to the subsurface environment, to PVC and stainless steel used in casings, not to mention epoxy-fibreglass and other unusual substances. Yet the corrosion of well casings still presents problems of maintenance to the engineer and well driller.

Pumps and motors are an integral part of the ground-water industry. Line shaft pumps are in common use, submersibles are less common but are becoming widespread as water levels decline. Pump column corrosion is a serious problem in Louisiana and the search for cures for this condition undoubtedly merits more time, money, and attention than it has received.

In short, the development of ground water, as far as the hardware is concerned, seems to be well established and well able to cope with current problems of technology. Of course, there are always incremental improvements to be made in technique, changes in materials of construction, utilization of new kinds of drilling fluid, maintenance procedures to counteract well deterioration and similar improvements in technology. What, then, is to be said about the future?

We can start with a question that is readily answerable by knowledgeable men in the field: "What is a well used for?" Answer: to provide potable water, to dispose of liquid wastes underground, to replenish a depleted water-

---

*Professor of Civil Engineering and Associate Director of the Louisiana Water Resources Research Institute, Baton Rouge.

bearing formation or to repressure it, to keep undesirable water away from a potable ground-water source, to dewater excavations, to dewater strip mines or underground mines--these are the uses that come to mind, excluding the petroleum and gas industry.

It would seem that the preceding summary has encompassed most past applications of wells and, presumably, the future applications as well. Such a conclusion would be premature, if nothing else.

If we step back and take a look at the upcoming problems we find two that are pre-eminent: the need for additional water storage as part of a system to supply surface water at all times; and a need to conserve energy--to operate more efficiently on the same quantity of fuel.

I believe that the ground-water industry has a major contribution to make in each of these areas. And if, indeed, such a contribution is made it will be the result of major improvements in technology as well as hydrogeologic concepts. The following discussion is based on research accomplished at Louisiana State University as well as a number of other places; by academic, governmental, and industrial investigators; by people engaged in laboratory and field testing as well as the design of mathematical models. In short the data base, small though it may seem, is, I believe, sufficient for a reasonable projection of future developments.

Let's look at the water storage problem first. Reservoir sites are becoming scarce, partly because the areas with the most favorable topography have been put to use, partly because the growth of the population has caused urban expansion into areas that might have been used to store water. Of course, in south Louisiana the flat topography and unstable organic soils equate reservoir construction with the construction of miles of ring levees within which water may be stored. Such reservoirs are subject to contamination and, during hurricanes, to overtopping and destruction. And unfortunately an "average" water production that meets the water demand is totally inadequate if a portion of the averaged water production is zero. People need a supply of water at all times.

It long since occurred to people to store water underground--usually in buried tanks. Another possibility that was tried as long ago as 1947 in Norfolk, Virginia, by D. J. Cederstrom, was to inject fresh water into an artesian aquifer that contained brackish water. The result was that the fresh water pushed the native water away from the well, did not mix significantly with it, and a large percentage of the injected fresh water was pumped out, uncontaminated by the native water.

A number of such qualitative experiments were made over the years (Moulder and Frazor, 1957; Harpaz and Bear, 1964; Brown and Silvey, 1973) and they demonstrated that the fresh water would miscibly displace (push aside) the native ground water and that most of the injected water would later be recovered.

With the establishment of the Louisiana Water Resources Research Institute in 1965, one of the first projects undertaken under its auspices was to start to investigate the parameters which affect the recovery efficiency of such water storage projects. Matters proved to be far more difficult to quantify than had originally been expected, but in October 1975 the Institute published Bulletin 10, "The Cyclic Storage of Fresh Water in Saline Aquifers," by Kimbler, Kazmann, and Whitehead. This publication contains details of field procedures and computational programs to enable an engineer to design a well field to store water in a saline aquifer and later pump it out at planned rates.

The results of the study should have widespread application in Louisiana: water is plentiful during a large part of each year and most of the state is underlain by water-bearing formations that contain saline water.

So one of the new applications of water well technology will be to utilize the underground space in porous materials for the storage of fresh water. A final, minor, point: What happens to the aquifer as a result of forcing all of this fresh water into it? Nothing much except a rise in the potentiometric head of the aquifer--water levels tend to rise. However, since the injected water is later removed, on a year-to-year basis there should be no permanent, damaging, change in aquifer pressures or water levels.

Another, different, potential application is the use of wells in conjunction with heat pumps. A heat pump operates in the summer by heating a fluid (in this instance, water) with the heat inside the house and disposing of the water, much in the way that a refrigerator heats air by removing heat from inside the volume to be refrigerated. In the winter the heat pump removes heat from the fluid (water) and puts it into the house and the spent, cooled water is discharged. A well that produces 5 gallons/min would furnish (or remove) 50,000 BTU/hr if the difference in temperature between the incoming and spent water is 20°F. This, from a heating standpoint, is the same as burning 50 cu ft of natural gas/hr.

This use of ground water is not new. However, as long as fuel was low in cost there was not much incentive to use the process. Moreover, in many areas the constantly dropping ground-water levels and campaigns against waste of water (and the water used with the heat pump was usually discharged to the sewer) created a climate of opinion opposed to the concept.

Matters are now different: the cost of energy is going up and, by using two wells and a single jet pump, we can use even saline aquifers as a source of water for the heat pump. The two wells are termed a "doublet": they would be separated by at least 100 ft and one would be completed at the top of the aquifer, the other at the base. The system would work like this: in the summer, for air conditioning, the deeper of the pair would supply water to the unit. The spent water would be returned, heated, to the shallower well. In the winter, for heating, the jet pump would operate on the shallow well, disposing of the spent water by injecting it in the deeper well. The following summer, of course, the deep well, now surrounded by water that was colder than the native water, would again be used for cooling.

The wells themselves, whether tapping a fresh water or saline water aquifer, would be made of four or six inch PVC casing with PVC or other suitable plastic screen, thus reducing corrosion problems. The drop pipes for the jet pump would be made of similarly corrosion proof material. The environmental impact of such a system would be negligible and, after a few years, it is possible that the 20°F temperature difference might, because of storing heat in the summer and using it in the winter, increase to 30°F or more with a consequent reduction in water demand. The speed at which such a ground-water technology will be introduced depends in part on energy price and in part on the ingenuity of the well-drilling profession in constructing low-cost, efficient, small diameter, small capacity wells.

A parallel development would be use of higher capacity wells for use as doublets for commercial and industrial heat pump applications. Naturally the spacing of the bigger units will be determined on the basis of aquifer characteristics whereas for the family-sized units the spacing could be selected from tables prepared for the purpose based on aquifer thickness and pumping capacity.

To sum up: In the next decade I would anticipate two new uses of wells to go forward in aquifers containing saline, or unusable, water: the cyclic storage of large quantities of fresh water in saline aquifers in conjunction with the operation of filtration plants for surface water, and the use of doublet wells, in conjunction with heat pumps, as an energy-efficient way to heat and air condition residences, offices, and other commercial establishments.

## REFERENCES


Brown, D. L., and Silvey, W. D., 1973, Underground Storage and Retrieval of Fresh Water from a Brackish-Water Aquifer, Preprints, Second International Symposium on Underground Waste Management and Artificial Recharge, Vol. I, New Orleans, Sept. 26-30, 1973, pp. 379-419.

Cederstrom, D. J., 1947, Geology and Ground Water Resources of the York-James Peninsula, Virginia, The Commonwealth, Dec. 1947, pp. 31, 71-73.

Harpaz, Y., and Bear, J., 1964, Investigation on Mixing of Waters in Underground Storage Operations, Int. Assn. Sci. Hydrol. Pub. 64, pp. 132-153.

Kimbler, O. K., Kazmann, R. G., and Whitehead, W. R., 1975, Cyclic Storage of Fresh Water in Saline Aquifers, Louisiana Water Resources Research Institute Bull. 10, Louisiana State University, Baton Rouge, October.

Moulder, E. A., and Frazor, D. R., 1957, Artificial-Recharge Experiments at McDonald Well Field, Amarillo, Texas, Texas Board of Water Engineers Bull. 5701, January.