WELL DEVELOPMENT

This continuing education course is primarily written for an audience of groundwater professionals who live in a “water rich” state, Florida. Because Florida is blessed with one of the most productive aquifers in the U.S., the Floridan, the importance of “well development” can be underestimated.

The purpose of this CEU is to refresh the importance of “well development” as an integral part of the drilling process which can add significantly to the specific capacity of the finished well. In “water poor” areas of the U.S. well development takes on greater importance because any activity that can measurably increase a well’s specific capacity must be undertaken by all means possible. In these “water poor” areas the role of development in maximizing specific capacity is paramount, while in “water rich” areas the role of development in insuring “sand free” flows becomes the primary goal.

Drillers who have specialized their drilling in a specific formation area become expert at knowing the most effective and efficient (i.e. the best use of time and equipment) to develop the wells in their area. Some drillers have little experience with screen well development; other drillers have extensive experience in this area.

The material to follow is broad in scope in that it surveys well development practices used in the United States in certain formation areas. All the processes described have proven their worth in some formations with some well types.

THE BASIS OF ALL WELL DEVELOPMENT METHODS IS TO CARRY OUT ACTIVITIES THAT WILL MAKE IT EASIER FOR WATER TO REACH THE PUMP SUCTION
The graph above shows clearly the impact on specific capacity when overpumping was followed by surging, and then surging was followed by jetting. Specific capacity of the wells involved in this controlled test were improved 74% when a 3 step development approach was employed. The results shown above are for screen wells rotary drilled with bentonite fluid additives.

The general conclusion to be drawn is that well development is best done with a combination of methods approach, whichever methods are chosen.

Whatever the method used, the ultimate purpose of “developing the well” is the same. Well development is carried out to maximize well yield. All new wells should be developed before being put into production to achieve sand free flows and maximum yield.

There are two main objectives to be achieved through well development. To the extent that either or both objectives are achieved better well yield will be the result.

The first objective is to repair damage done to the formation immediately surrounding the borehole by the physical operation of drilling. It is in this area that cable tool drillers and rotary drillers often discuss the impact of their chosen method on the formation and ultimately on well yield.

Repairing the damage to the formation involves:

- Removing any “clay smear” or “mud cake” covering the aquifer surface.
- Flushing out of the borehole drilling fluids, which were introduced during the drilling process.
- Reverse any chemical or physical changes to the formation surrounding the borehole, which was brought on by the drilling activities and or drilling fluids.

The second objective of well development is to improve near-well permeability and stability. By improving the permeability and stability of the area immediately adjacent to production zones, water flow into the well is maximized.

Improving near-well permeability and stability involves:

- Removing the smallest size particles in the areas immediately surrounding the production zones. Whether a filter pack or open hole well is completed
the objective of improving near-well permeability and stability is the same. By removing sediment and fine particles from the near-well area, a high permeability zone is created. Thus, more water can be obtained from the well.

Often both objective one and objective two well development proceed at the same time.

Bentonite & Polymer Drilling Fluid additives

Some evidence exists that polymer drilling fluids create thinner wall cakes and break down naturally over time leaving no resistance to water flow in the near well area of the aquifer. Bentonite (clay) additives create thicker wall cakes, penetrate the aquifer and may lessen flow in the near well area unless thorough well development is done to insure the break down and removal of bentonite drilling fluid residues.

Bentonite additive

Polymer additive
Overview of rotary drilling fluid impact in the near well area of the aquifer:

Drilling damages aquifers

It is inevitable that some change in the permeability will occur. The impact may be slight or great, depending largely on the characteristics of the aquifer. Indeed the impact on the aquifer may even be beneficial, increasing permeability in the near well area. So too, the impact of drilling the well may be harmful in that loose grains in the near well area may be compacted decreasing permeability.

In “clayey” areas, the clays may be smeared over small aquifers reducing yield. The pictures above demonstrate the aquifer impact of drilling fluids introduced during the drilling process.

Drilling fluids have as one of their major purposes the stabilization of the borehole. However this purpose is achieved at the expense of the clogging of the aquifer. A balance must be struck between using drilling fluids to the degree necessary to permit the continued efficient making of hole and the need to quickly and efficiently remove these same drilling fluids from the water bearing formation once drilling is completed.

Planning for Well Development:

Before making any decision on well development methods or procedures, it is necessary to check on the exact situation that exists in the zone to be developed.
The overriding considerations are:

- The cost of the development techniques being considered and the relationship between these costs and the value of the well.
- The time available.
- The tools, equipment and materials available.
- The yield desired.
- The likelihood of achieving the desired yield.
- The risk of causing a decline in yield or loss of the well.

Important but secondary to the above considerations include:

- Drilling fluids used during the drilling process
- Type of drilling method employed
- The nature of the aquifer, its permeability and chemical composition.
- Well type i.e. rock well or screen well.

Development procedures are designed to create, in so far as possible, a non-turbulent flow into the well. As water from the aquifer flows toward the well, the flow lines crowd together as they approach the well. This crowding causes resistance. Any flow resistance decreases yield. It is to lessen flow resistance and improve permeability that we use well development techniques to remove any flow obstructions.

**Rock well Development**

Any discussion of well development for rock wells includes a wide range of formations.

In Karst formations drilling damage has less impact on formation yield than is the case in sandstone or granite-basalt aquifers where the yield occurs through fractures in the formation. In the sandstone or granite-basalt wells plugging is of significant concern as it may cause drastic reductions in yield.

Any material that clogs openings in rock aquifers must be removed by a development process. The full yield of the formation will only be realized if all fractures and crevices are able to provide water to the well. While pumping alone can sometimes pull out the remaining sediment, drillers have often found that
surging or other means of development is needed to obtain maximum yield from rock wells.

**Hard rock aquifers** (where the groundwater is held in joints, fractures, cracks, caverns or other types of permeability, free of any loose material). An open hole completion is best and cheapest. Grouted surface casing will be required to ensure that surface water does not enter the well.

One of the best combination methods for developing rock wells is water jetting and air lift pumping. Both these operations are described more fully below.
Screen Well Development

In screen well development, the processes are the same whether a natural pack or an artificial pack has been used in the construction of the well.

The picture below beautifully illustrates the end result of a properly developed natural packed screen well.

Notice how proper development of the screen well above has removed all the near well fines thereby increasing porosity and hydraulic conductivity (permeability) in the zone immediately surrounding the screen. Note too that the screen slot size has obviously been chosen with proper attention to the particle size to be retained after development. In other words the driller of this borehole sized his screen after examining his cuttings from this sand and gravel water bearing formation.

If an artificial pack had been placed around the screen, the goal would have been the same. The grain size of the artificial pack and the slot size of the screen are matched to provide an area of much higher permeability in the zone immediately outside of the screen. This high permeability zone reduces the head losses necessary to get the desired flow and reduces the chances of incrustation.
The artificial pack provides superior control over the movement of fine sand grains toward the well and permits a wider range of sand sizes to be screened. When surrounded by an artificial pack the screen may have a larger slot size and thus a larger open area. This larger open area allows for much more effective development.

2. By a carefully designed screen with the screen itself having openings suited to the aquifer grain size. The openings must be sufficient in number to provide an open area exceeding the permeability of the aquifer, even after part of the area of the opening is blocked by sand grains.
Pre-pack screens are available and can offer advantages in certain applications. Research has shown that pack thickness of one inch or less is just as effective as packs of much greater thickness. However, the thinner pack must have consistency throughout. For this reason industrial vibrators are used when filling pre-pack screens to ensure the consistence of the pre-pack. Also, artificial packing material is sometimes used rather than natural gravel packs. Ceramic beads have proven to offer less resistance to flow and incrustation because of their uniformity of size and shape.

Types of well development techniques:

- Chemical
- Washing and Backwashing
- Mechanical Surging
- Air Development
- Jetting

**Chemical**

Chemical agents are introduced into the development zone as solvents. Their action is intended to dissolve or loosen any clogging or blocking materials to make them easier to remove. The action of chemicals may also enlarge aquifer pores and improve permeability. Chemical based well development techniques can be gentle or violent in their action.

All chemical agents introduced into potable wells should be approved for such use by local authorities. Chemical methods are often used in conjunction with other well development techniques. This is particularly true when additional action is needed to break up mud cakes or flush out gelled muds. The chemical solution is allowed to stand in contact with the aquifer for the recommended soak period. After the soak period the solution is pumped or bailed from the hole. While well drilling fluids will break down naturally, the breakdown process may be enhanced by the use of chemical agents. Once degraded, the drilling fluids are much more easily pumped from the aquifer. Other chemicals may be used to break down clay smears and gelled bentonite. Chlorine breaks down polymers.

A tremie pipe can be used in conjunction with packing devices to isolate the areas of the borehole to be subjected to chemical treatment. Chemical treatment can be used to break down drilling fluids, clays and polymers. Acids are often used for improving the yield in limestone, dolomite and other calcium carbonate formations.
**Washing and Backwashing**

Drillers working in different regions have, through experience, come to rely on those well development techniques producing the best results in their areas. However, new techniques should always be considered and tried with the goal of obtaining the cleanest well with the best possible yield.

Overpumping is the simplest method of removing fine particles from formations. The theory is that if a sand free yield can be achieved by overpumping then a sand free flow will be the result when pumping at the normally expected lower rate. However, overpumping by itself is not considered the best well development approach. Overpumping is considered a limited approach to well development because water flows in a single direction only.

Backwashing reverses water flow and helps in the dilution, agitation and removal of sediment, fine particles and drilling fluids. Backwashing requires the introduction of water back into the well. If water taken from the well is to be reintroduced for backwashing, care must be taken to allow the settling out of particles from the removed water before reintroduction. Even so backwashing should not be the final step in the well development process; rather it may be an effective beginning or intermediate step. Washing and backwashing reverses the flow in the borehole during development. This reversal causes the collapsing of bridges in the particles of the near well area. This is desirable because collapsing these bridges further removes fines from the near well creating a cleaner flowing well.

**Mechanical Surging**

The forcing of water into or out of a well screen by use of a plunger type action is called surging. Surging tools can be used by both cable drillers and rotary drillers and can be used in combination with other development methods. Surging promotes a repeated change of direction in the flow of water in the well screen area. This repeated change of direction can produce good porosity in the near-well zone.

Mechanical surging is the first of two methods of well development that removes particles and clogging materials by the force of water impinging on them. A development method such as mechanical surging is a vigorous development method not suited to all aquifer types. However, mechanical surging has less potential for aquifer damage if a continuous flow of water into the well from the aquifer is maintained. Mechanical plungers may be fitted with one-way valves allowing them to lift water and fine sand out of the hole. Solid plungers do exist but have more potential to damage the aquifer. The results of mechanical surging should be measured by checking the well yield periodically, every hour after the process begins. Surge plunger should be a good fit in the casing. The plunger may be attached directly to the drill stem or operated by hand depending on well depth.
Figure 15.6. Typical surge block consisting of two leather or rubber discs sandwiched between three steel or wooden discs. The blocks are constructed so that the outside diameter of the rubber lips is equal to the inside diameter of the screen. The solid part of the block is 1 in (25.4 mm) smaller in diameter than the screen.
Mechanical surging does have potential to damage the aquifer and should be done with aquifer. The force exerted during mechanical surging depends on the length of the stroke and the vertical velocity of the surge block. Swabbing is another variation of surging. Swabbing does not depend on reversing flow into the well. Rather the swab is slowly lowered to the desired depth and then drawn upward. Swabbing creates a pressure differential below and above the swab during the upstroke. This differential creates a powerful action which draws fines from the near well area into the bore hole for removal.

**Air Development (air surging and pumping)**

Several techniques for the air development of wells exist. However, all inject air into the borehole such that aerated slugs of water are lifted irregularly out the top of the well casing. Air pressure may be cycled on and off to create a surging action desirable in well development. Sufficient air pressure will result in a continuous flow of aerated water out the top of the well, removing sediment and fine particles from the borehole.
For small wells, air may be injected down the drill stem into the formation. For larger diameter wells a separate airline and eductor pipe are inserted into the borehole. The size of the eductor pipe and airline depend on air pressures and volume available as well as the casing diameter. Numerous sources caution drillers that under some conditions the use of air development approach can create aquifer air locks, in such cases a development with water is a wiser choice. Even so air as a development is probably the most popular and widely used method of well development today.

The type of discharge produced from a well during air development depends on the air volume available, total lift, submergence, and annular area. In practice, two different flow conditions can be recognized when air is used when air is used for water well development although other flow regimes may exist at much lower or higher velocities in smaller diameter pipes. The picture above provides an illustration of how multiphase flow (water and air) occurs in the casing during air development. The percent submergence, total lift, and capacity of the compressor will control the relative proportion of air and water for a particular well.

A. Introduction of a small volume or air under high head causes little change in the water level in the well. In this case, the air pressure available is just sufficient to overcome the head exerted by the water column.

B. As air volume increases, the column becomes partly aerated. Displacement of the water by the air causes the water column to rise in the casing. Drawdown does not change because no pumping is occurring.

C. Further increases in air volume cause aerated slugs of water to be lifted irregularly out the top of the casing. Between surges, the water level in the casing falls to the near the static level.

D. If enough air is available, the aerated water will continually flow out the top of the well. With average submergence and total lift, the volume of air versus water is about 10 to 1. Higher air volumes may increase the pumping rate somewhat, but still higher rates may actually reduce the flow rate because flow into the well is impeded by the excessive air volume.
Well Jetting

Development by high velocity jetting may be done with either water or air. A jetting tool is attached to the lower end of the drill string and lowered to the bottom of the well screen. Rotation is controlled by the rotary rig. The jetting tool activated by either air or water forces high-pressure fluid out the nozzles of the tool very effectively, developing the formation. Because of the high pressures used damages to the well screens may result through improper use of jetting tools. However, jetting is seen as possibly the most highly effective development technique in terms of well yield after completion. The essential point to be made is that yield depends to a great extent on the development method used. Particles loosened by jetting tools may be later removed by pumping or bailing.
Aquifer Development Techniques

To this point, our discussion has been centered on development techniques in the near-well area. However, this discussion would not be complete without some mention of aquifer development as distinct from well development.

In regions where ground water comes from bedrock, when the volume of water is inadequate, aquifer development techniques may be effectively employed. Aquifer development or aquifer stimulation can increase well yield far beyond those discussed above.

In limestone or dolomite aquifers, acids can be beneficially used to open up the formation around the borehole. The acid dissolves calcium carbonate thereby increasing hydraulic conductivity.

Hydrofracturing

In Hydrofracturing, the production is isolated from the rest of the well using inflatable packers lowered in place and inflated. Once the production zone is isolated, high-pressure water is inserted in the isolated production zone at pressures up to 10,000 psi. These pressures are sufficient to fracture most formations causing small type breaks to open up and spread rapidly. Often these artificially created fractures will reseal unless artificially propped open. Often sand or plastic beads are forced into the newly created fractures as part of the hydrofracturing process. Hydrofracturing can be a useful technique in low yield formations for increasing yield and reliability of supply.
**Liquefied CO2 Injection**

A further method to open rock fractures and stimulate production is the injection of Carbon Dioxide CO2. One approach is to inject liquid CO2 into the producing formation, which has been isolated by inflatable packers. The introduction of the liquid CO2 freezes the surrounding water, opening nearby fractures. As the liquid CO2 becomes a gas, it expands into the formations, opening them further. This method is an improvement on an earlier method inserting dry ice into the production zone, which had been isolated.

This process too is found to work best when coupled with surging, air development or chemical rehabilitation as the final step to maximize development.
**Vibratory**

Uses of sonic technology have been transferred from drilling into well development techniques. One method is using high velocity shock waves for the removal of deposits around borehole walls and well screens. Once shock waves loosen, the hardened material, jets of fluid at high velocity are directed back and forth over the shock wave area. This dual approach of shock wave and jetting deep cleans productive aquifers.

**Explosives**

The goal of the use of explosives as an aquifer development technique involves targeting the blast force horizontally into the aquifer rather than letting the force dissipate vertically through the borehole. Great skill is needed to determine the size of the explosive charge, the placement of the explosive charge and the formations where this approach has good chances of success. Like hydrofracturing the goal of the use of explosive charges is to increase fractures in number and size, thereby increasing hydraulic conductivity.

Explosives in the form detonating cord and blast caps are used in well remediation. Although a much more controlled approach than described above, the detonating cord blasting caps approach creates high-energy gas upon detonation. The rapid movement of the high-energy gas breaks up encrustations in the near-well area. This method is most commonly used in rock wells.

**In Summary**

The results of development are seen in the improved hydraulic performance of the well. Whether the well will yield more water or it will yield the desired quantity with less drawdown. That is, the cost per volume of water will be less. Cheaper water is the real mark of improved well efficiency.

Lower pumping costs are associated with higher specific capacities, that is, with more water per unit of drawdown.

Correct well development including remediation and aquifer development can dramatically improve yield and eliminate sand pumping. The development step in new construction needs to be given the attention it deserves seeing as how it has a dramatic impact on the quality and production of the resulting well.

Well development is of critical importance, especially in areas of low and uncertain yields. After completion of any well development technique, the well must be pumped and cleaned until the water is clear and free from any residue of the development process. Complete records of all development and well completion must be maintained as part of permanent well or contractor records. These records such as, the specific capacity of the well after development and the standing water level in the well at the time of completion, allow operators to monitor changes in well performance over time.

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