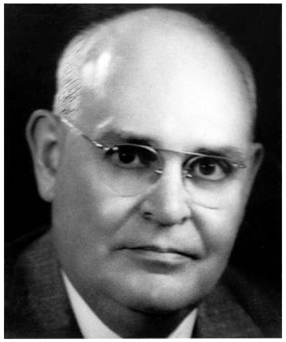
William A. McEllhiney Distinguished Lecturer Series Well Technology

Made possible by a grant from Franklin Electric Company to the National Ground Water Research and Educational Foundation

NGWREF McEllhiney Lecture Series



To foster professional excellence in water well technology, the National Ground Water Research and Educational Foundation has established the William A. McEllhiney Distinguished Lecture Series in Water Well Technology.

Initiated in 2000, the lecture series honors William A. McEllhiney, who was the founding president of the National Ground Water Association in 1948, and a ground water contractor and civil engineer from Brookfield, Illinois.

NGWREF McEllhiney Lecture Series

"McEllhiney and the other founders of the Association saw several primary functions for the new national group," explains Foundation Executive Director Kevin McCray, "including serving as a clearinghouse for information and its dissemination, serving as an intermediary in coordinating advances occurring in different parts of the country, and serving as a place to bring contractors together so that they might have a working knowledge of contracting from all parts of the nation. NGWREF's McEllhiney Lecture series promotes and perpetuates those original aims."

Franklin Electric

NGWREF McEllhiney Lecture Series

Annually, a panel of ground water contractors invites an outstanding ground water contracting professional to share his or her work with the industry. Individuals may nominate themselves or others they believe to be qualified to serve as the NGWA McEllhiney distinguished lecturer.

Franklin Electric

NGWREF McEllhiney Lecture Series

Effective May 2005, Franklin Electric Co., the world's largest manufacturer of submersible electric motors, has agreed to underwrite the next three years of this lecture series for presentations to organized groups of contractors and other qualified and interested parties. Meetings and conventions of state and regional associations are eligible. Foreign associations of ground water contractors, academic institutions teaching water well technology, gatherings of water well regulators, and other bodies with a direct and identifiable interest in water well design and construction are eligible as well.

2010 Lecturer

Mike Mehmert, B.S.

Director of Sales and Marketing-Well Products at Johnson Screens,
a Weatherford Company



You Drill a Hole – You Develop a Well



Why Well Development

Well Life Cycle

- Construct it.
- Use it. (Maintenance & Rehab)
- Abandon it.

Construction
- Design
- Installation
- Development
- Testing

Discussion Topics

- ❑What it is?
- ❑Why do we do it?
- ❑What impacts it?
- ❑How we do it?
- ❑When are we done?
- ❑What are the benefits?

What is development?

Intentional application of select mechanical techniques – often with chemistry - to remove drilling damage and restore or enhance near well hydraulic characteristics.

Why We Do It?

- #1 - Drilling changes things.
  - Disturbs natural conditions
  - Introduces fines & fluids.
  - Alters hydraulic conditions.

Why We Do It?

- #2 - Achieve original design expectations.
  - Sand control (formation, pack stabilization).
  - Enhance yield, maximize specific capacity.
  - Assure expected sample quality.
- #3 - Want to deliver a quality product.

  < efficient well >

Well Efficiency

$$E_w = \frac{drawdown_T}{drawdown_A}$$

Drilling Method

Type Screen

What effects well development?

Geology

expertise

contract

Drilling Fluids

Murphy's Law

Type Completion

Drilling Method

- ❑ Rotary
- ❑ Casing advance
- ❑ Cable Tool
- ❑ Auger

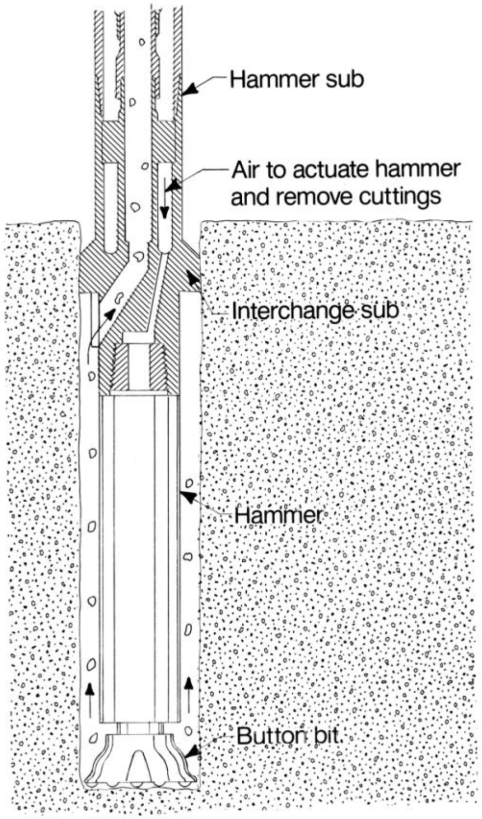
- ❑ *All methods, crush, rearrange, fill voids, alter and typically lower natural hydraulic conductivity*

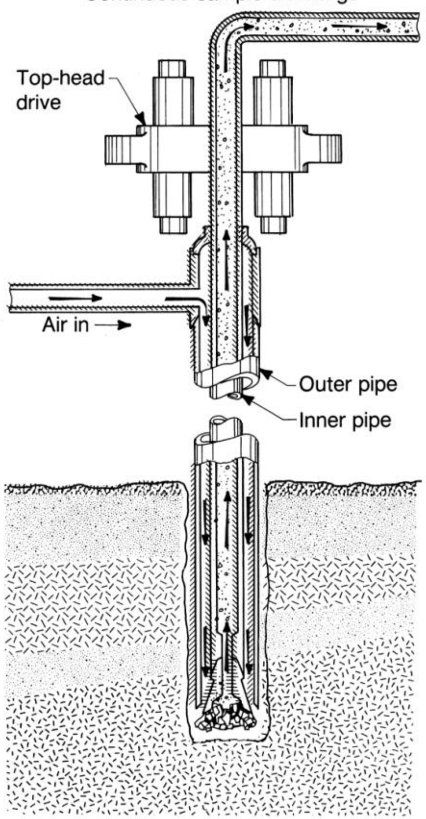
Rotary

Straight
Reverse

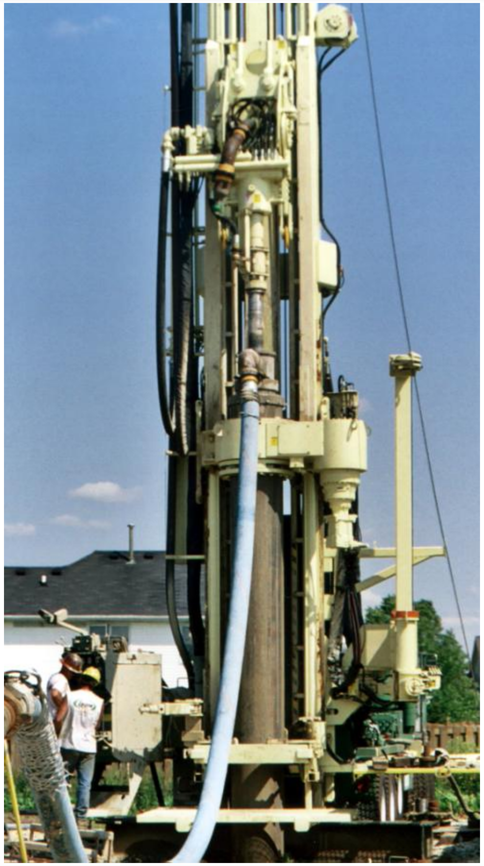
Air, Foam, Mud

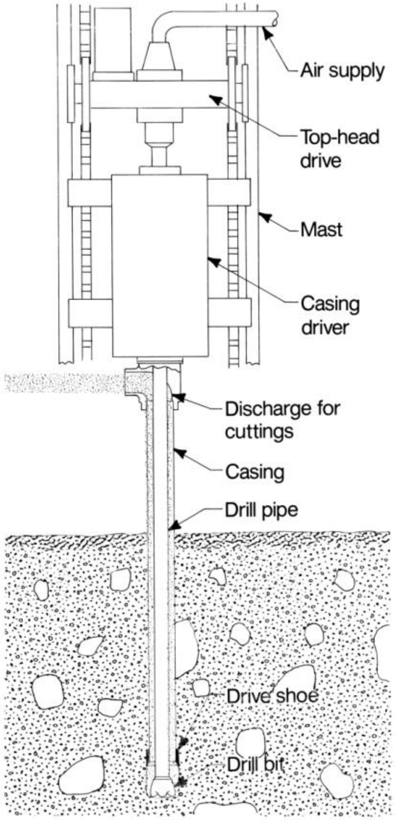
Specialized Rotary Methods





Specialized Rotary

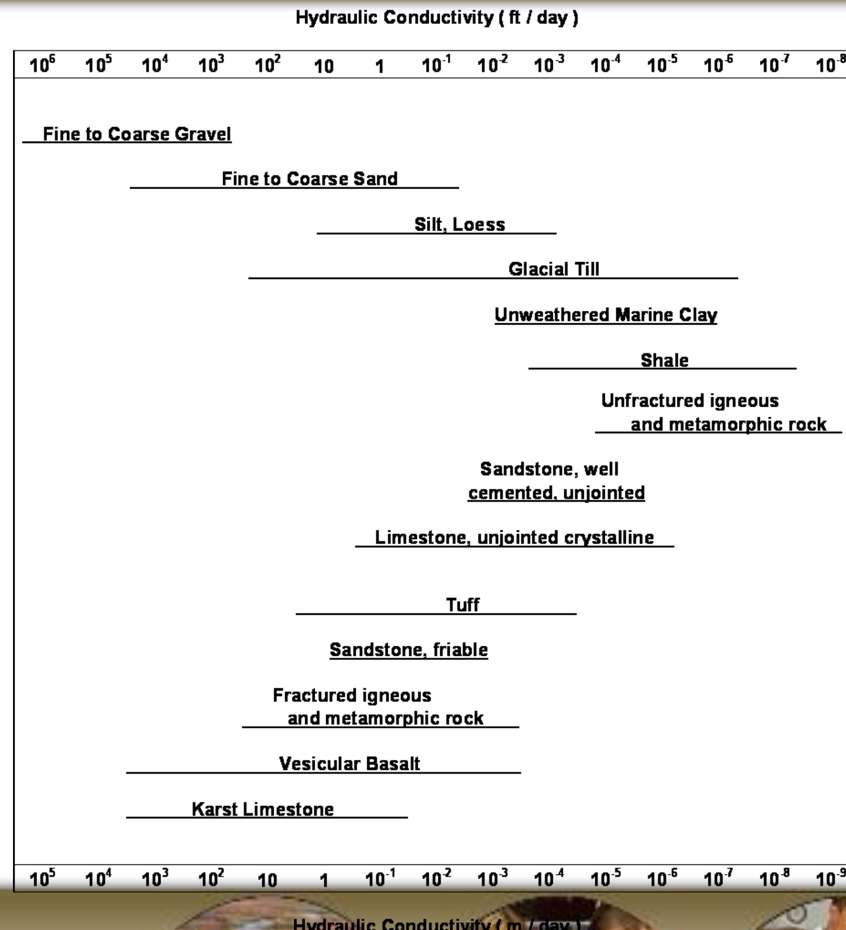




Auger

Aquifer Geology

- Determine Completion
  - Open hole
  - Natural develop
  - Artificial pack
- Method
- Time spent



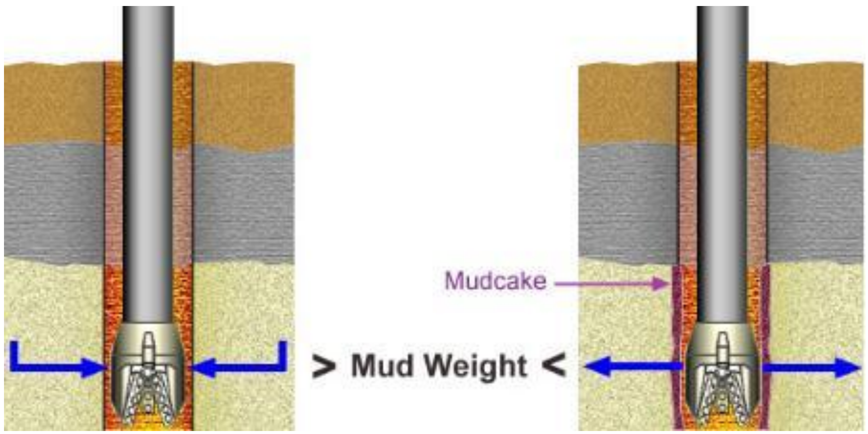
Drilling Fluids

- Type
  - Organic/Synthetic Polymers
  - Natural Clays, Bentonite
  - Air/foam

Fluids Management

skill

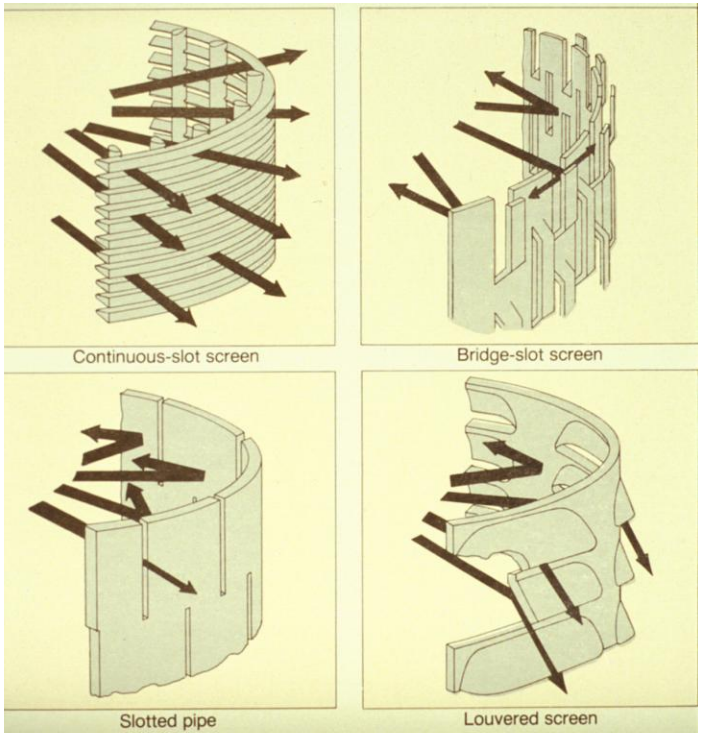
- ❑ Control Solids, Viscosity, Density
- ❑ Timely break-back
- ❑ Over balanced
  - ❑ Excess wellbore pressure
- ❑ Under balanced
  - ❑ Reduced wellbore pressure
  - ❑ Increased penetration & bitlife
  - ❑ Less formation damage
  - ❑ Less development time



Under-balanced Over-balanced

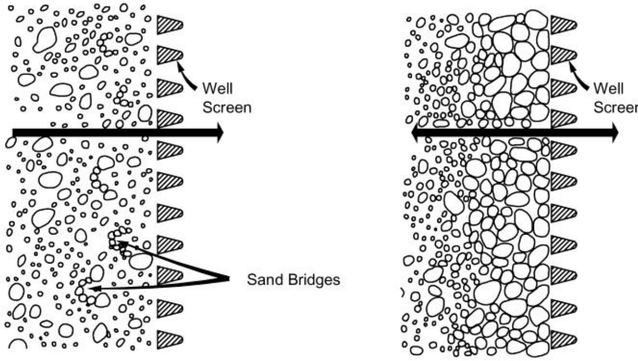
Screen Type

- ❑ Dictates slot geometry which affects energy transfer to and from the formation.
- ❑ Especially important as formation hydraulic conductivity decreases.
- ❑ Development method should compliment the screen design to maximize efficiency.



Screen Type
Open Area

- The higher the open area the less resistance to flow and the greater the access.
- Especially effective w/ jetting techniques.
- Improves success in low permeability situations
- Can save time.
- *A real plus years later for rehab!*



Type Completion

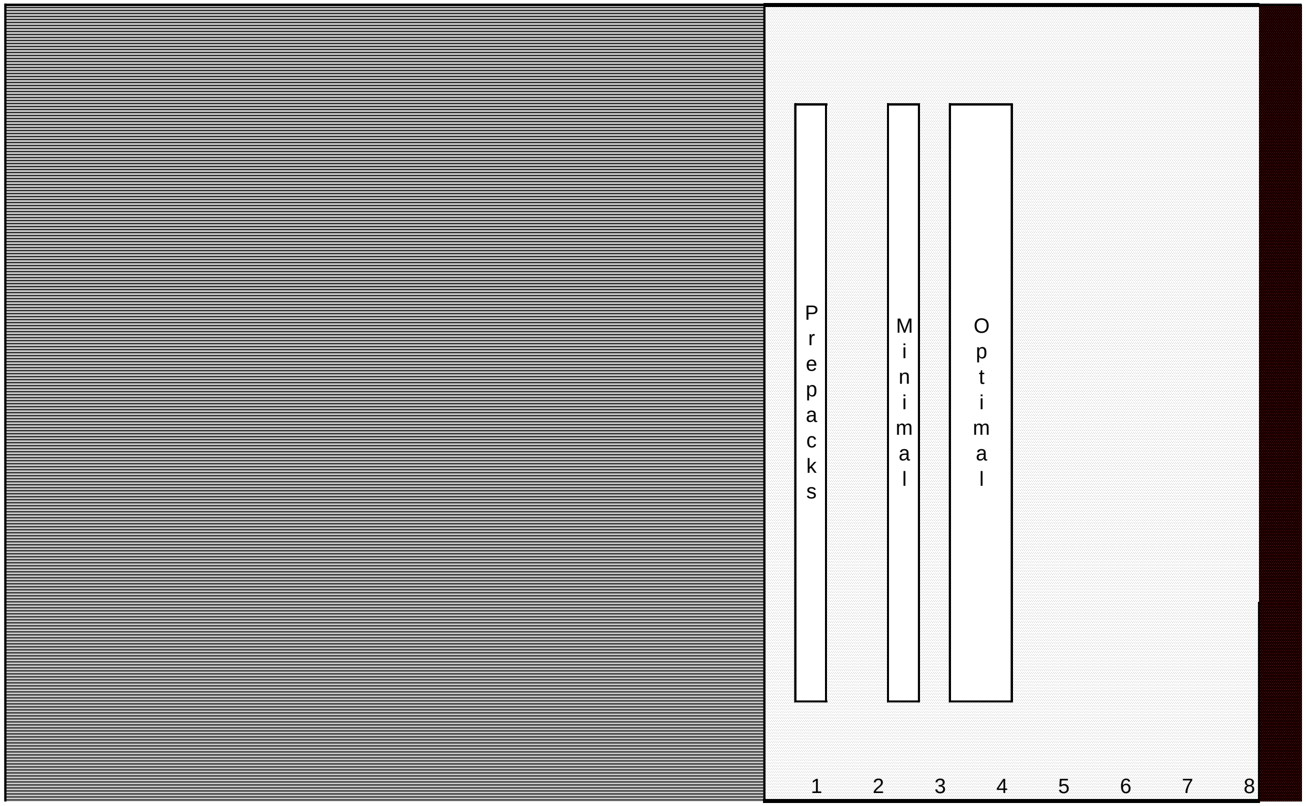
- ❑ Open hole
- ❑ Natural pack
- ❑ Artificial pack
- ❑ Pre-Pack

Artificial Pack

- Thickness
  - Approximately 3 – 4 inches is optimal
  - Thicker filter pack requires more development
  - Thin filter pack (< 1 inch) is conventionally difficult to place and fines can pass through
- Placement
  - Uniform
  - Segregation
  - Volume
- Pre-packs (typically ½ - 1 inch)
  - Ideal where the formation will readily collapse around the screen.



Pack Thickness

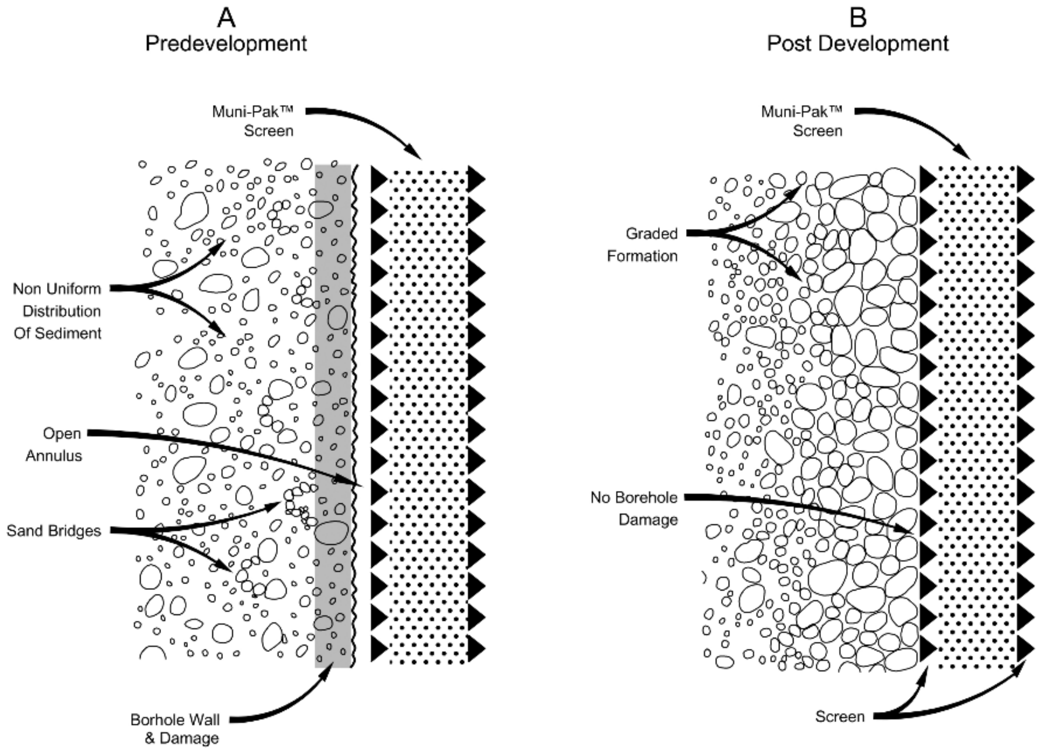


PrePack Screens

Properly sized filter pack.

Uniform placement assured.

Borehole collapse after development.

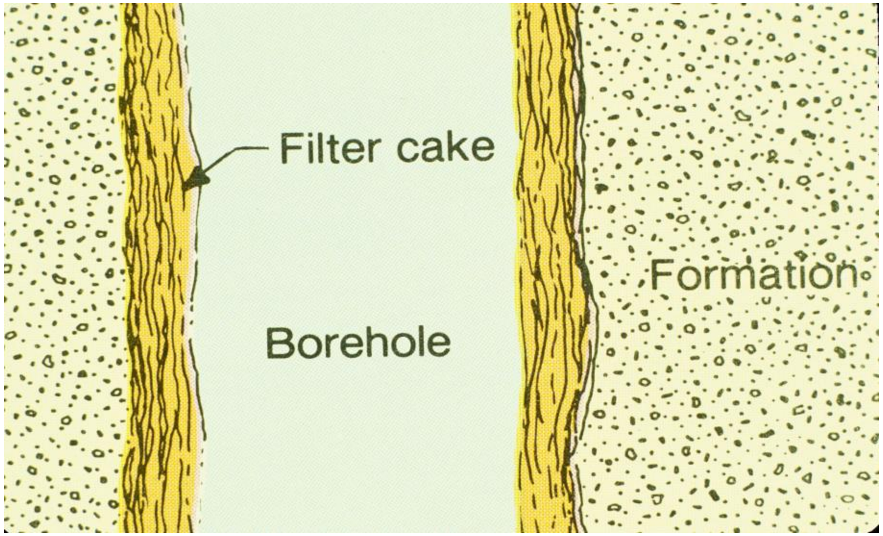


Murphy’s Law

Anything ever go wrong?

Common Scenario

- Conventional mud rotary
  - Filter cake
  - Invaded zone
  - Fill void spaces.
  - Decrease hydraulic conductivity.
- Breakdowns can increase the demands on development!



Contract

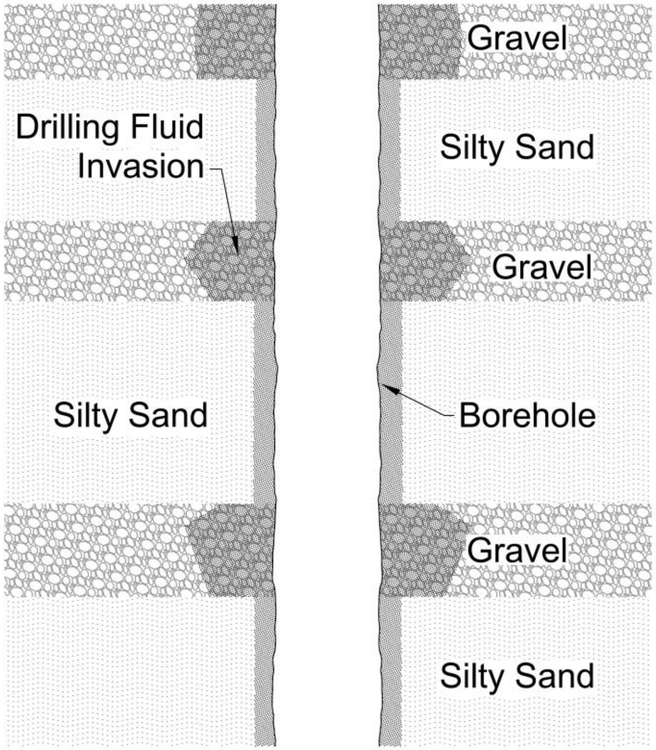
- Development Method
  - Method should match completion
  - Screen type
- Development Time
- Criteria for being done?
- Payment?

How Do We Do It?



Techniques to Agitate & Extract

- ❑ Development Techniques
  - ❑ Bailing
  - ❑ Pumping
  - ❑ Surging
  - ❑ Airlift
  - ❑ Jetting
- ❑ Chemical Additives





Bailing

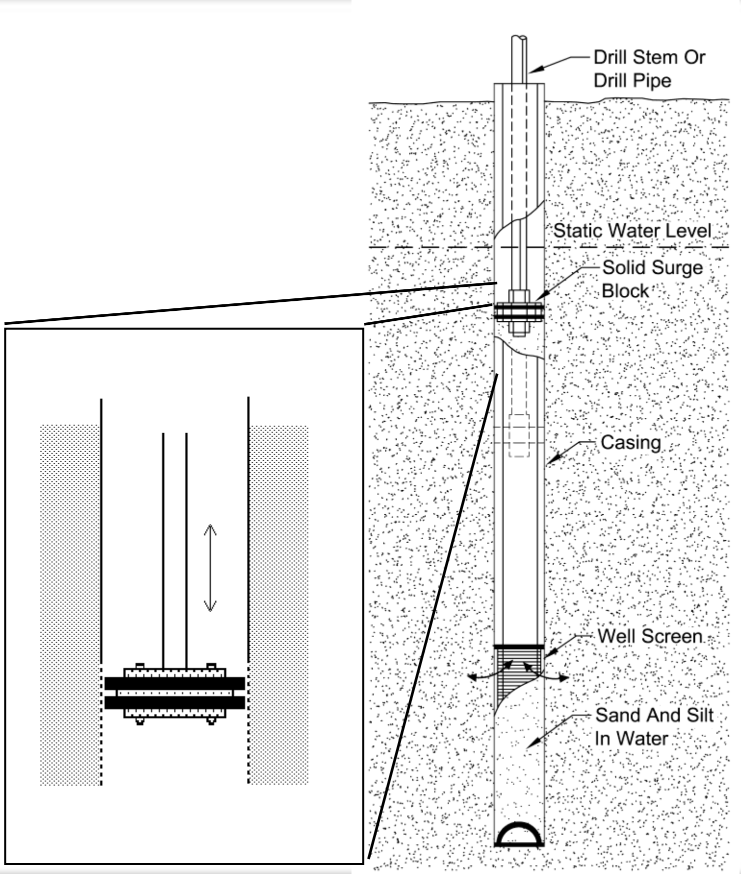
- Typically an initial step (especially in small diameter).
- Requires no additional power sources.
- Low yield well, gives indication of production (via recovery).
- Bailer size can aid surging action.

Pumping

- Most fundamental
- Typically at rates > design production.
- One-way flow unless backwash.
- Tends to develop most permeable zones.
- Temporary pump needed.
- Often a final step / pump test

Surging

- ❑ Forcing water in and out of formation
  - ❑ materials & tolerances important
- ❑ Force exerted depends on
  - ❑ length of stroke
  - ❑ velocity of tool
- ❑ Bailer works in SM Dia



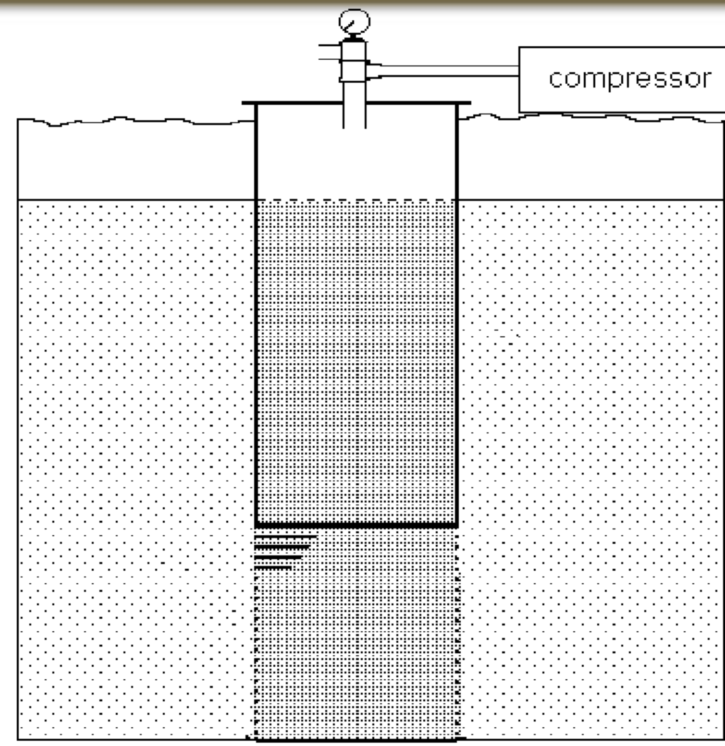
Mechanical Surging

- Higher risk of plugging in formations w/clay streaks.
- Swabbing may cause large differential pressures – use caution with PVC or slot < 0.010 inch

Pneumatic Surging

Step 1 - Setup.

Dosage includes entire static column + displacement dilution.



Chemicals are mixed thoroughly in static column.

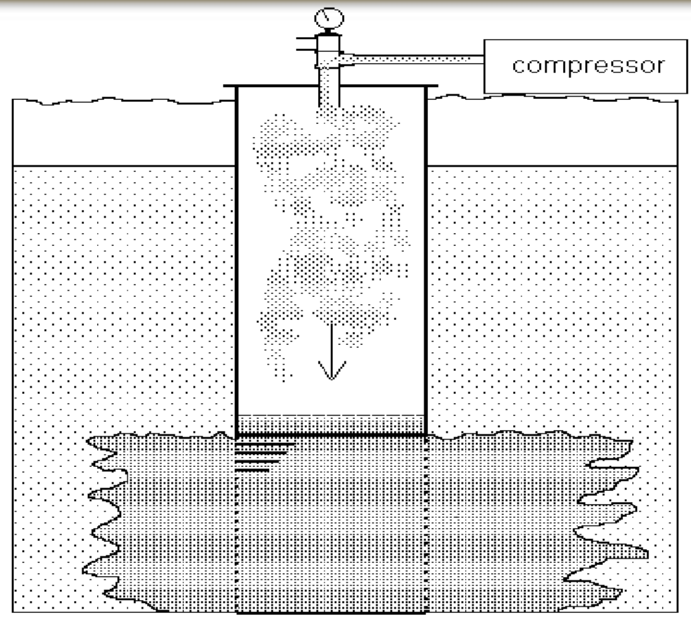
Air-tight seal is secured to well head.



Pneumatic Surging

Step 2 - Displacement

Depending on compressor size this can usually be done in 30 - 60 seconds.



Outlet valve is closed, well is charged with air to drive static level down to within 5 - 10 ft of the top of the screen.

Pressure necessary is found by:

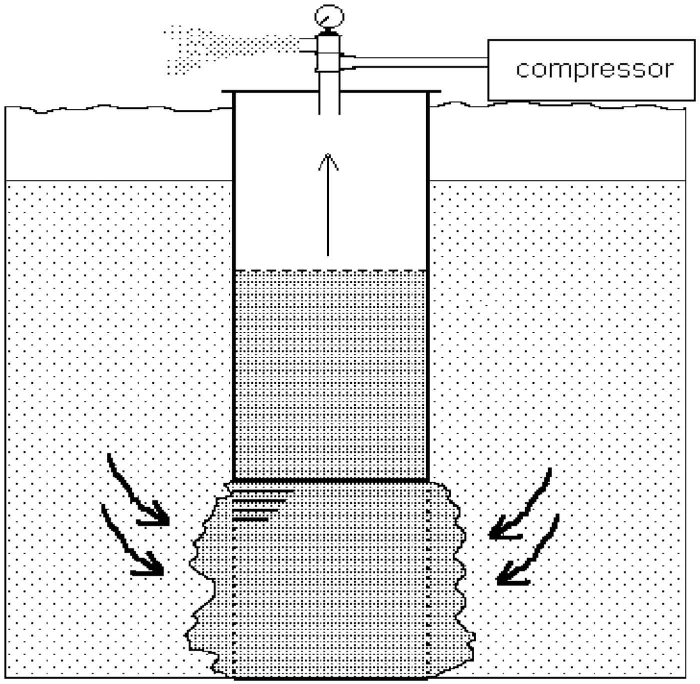
$$\text{PSI} = \frac{(\text{Depth to Top Screen - SWL})}{2.31}$$



Pneumatic Surging

Step 3 - Evacuation

Integrity of the wellhead seal is very important for obvious safety reasons.

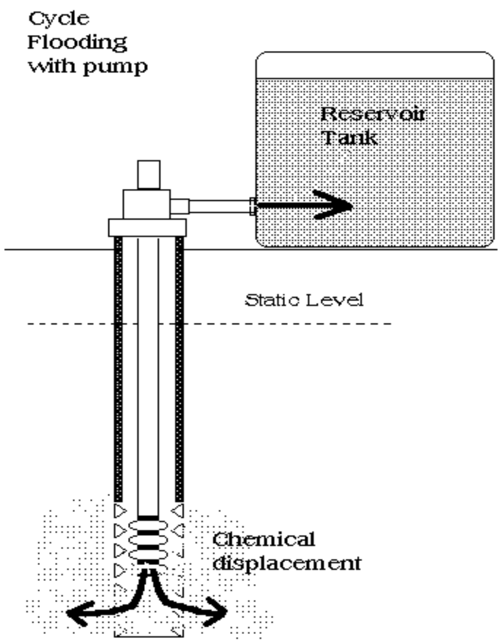


Release of pressure allows fluid to rush back into the well. Result is excellent agitation in the effected zone.

Cycles should be repeated frequently and pH checked periodically to determine level of activity.

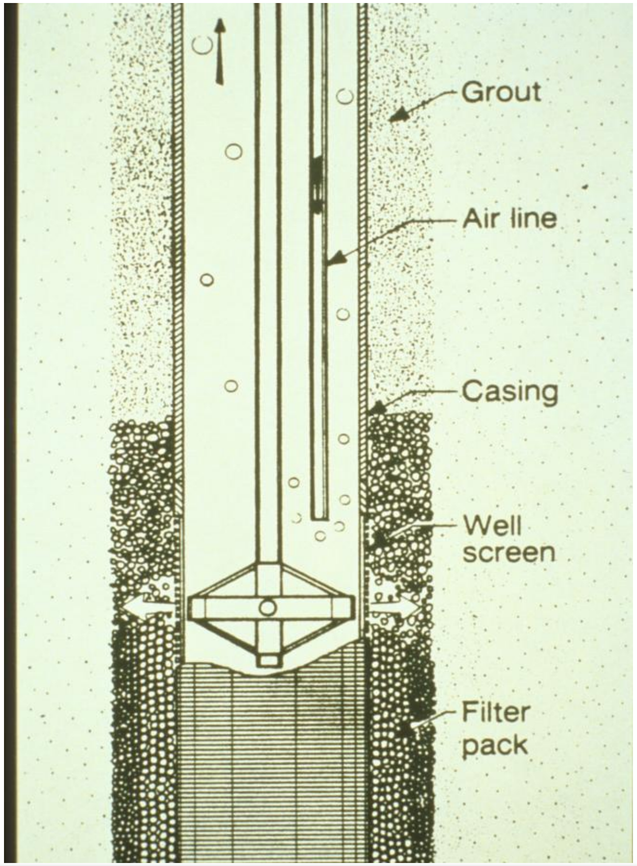
Pump-To-Tank Surging

- ❑ Manual or Automatic cycling
- ❑ Facilitates monitoring of chemical activity
- ❑ Chemicals added easily
- ❑ Fluid motion good for reactivity.
- ❑ Use of packers to isolate zones



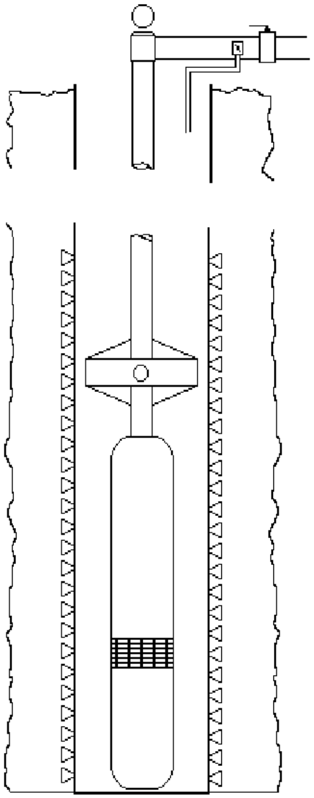
Conventional Jetting

- ❑ Effective in highly stratified aquifer
- ❑ Good for mud cake break up
- ❑ Can be done with air or water
- ❑ Most effective with simultaneous pumping.



Conventional Jetting Tool

- Minimum nozzle velocity of 100 fps, optimum 150 -300 fps.
- Jetting pressures of 100 to 300 psi.
- Easy to include chemicals
- Best application in wire-wrap screens



Higher Pressure Tools

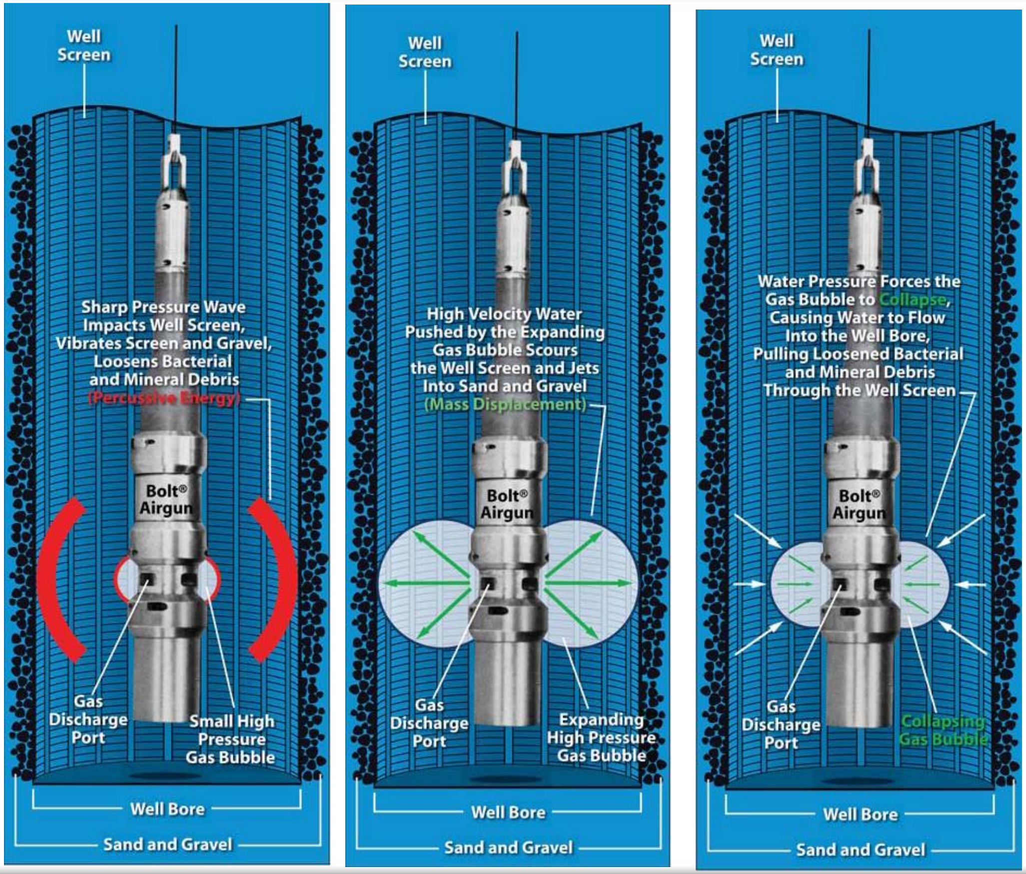
- Nozzles evenly spaced to hydraulically balance tool during operation.
- OD tool as close to ID of screen as possible (< 1 in away).
- Water should contain no sediment.
- Nozzles made of abrasion resistant material.

Courtesy Baski, Inc.

Impulse generator Hydropuls®

- Widely used in rehabilitation.
- Hydraulic “shock wave” by sudden expansion of highly compressed gas.
- Loosens fines, debris.
- Used in most completion materials (steel, pvc, fiberglass).

Impulse generator Airburst®





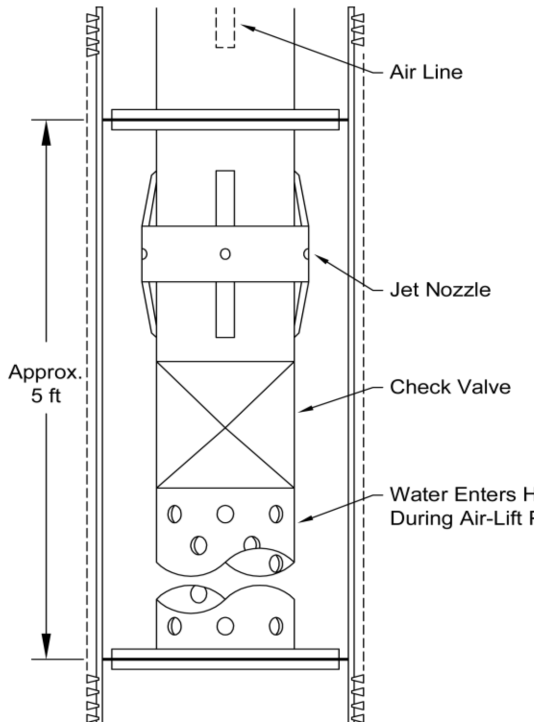
High Pressure Jetting MuniPak™

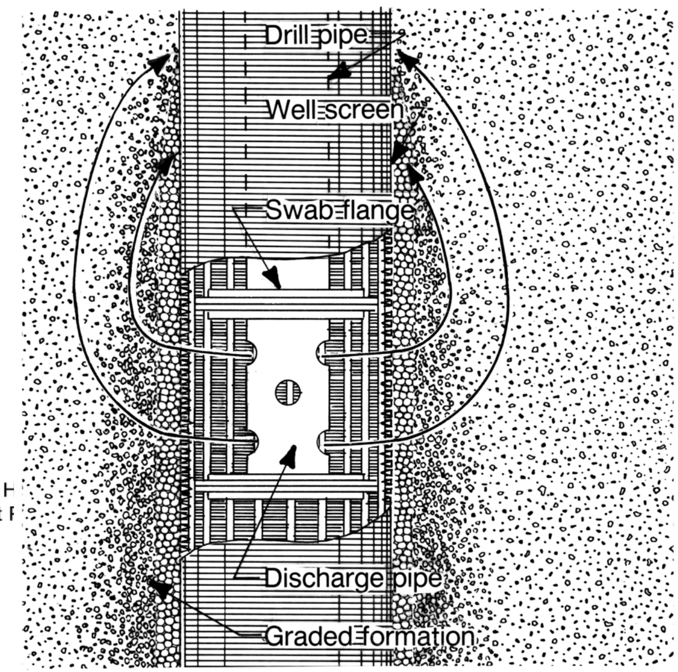
- ❑ Up to 10,000 psi.
- ❑ 1,000 ft/sec
- ❑ Effective in prepack
- ❑ Effective workover.
- ❑ Cautions:
  - ❑ Keep tool moving
  - ❑ No sediment circulating

AC Schultes 2006

Isolation Tools

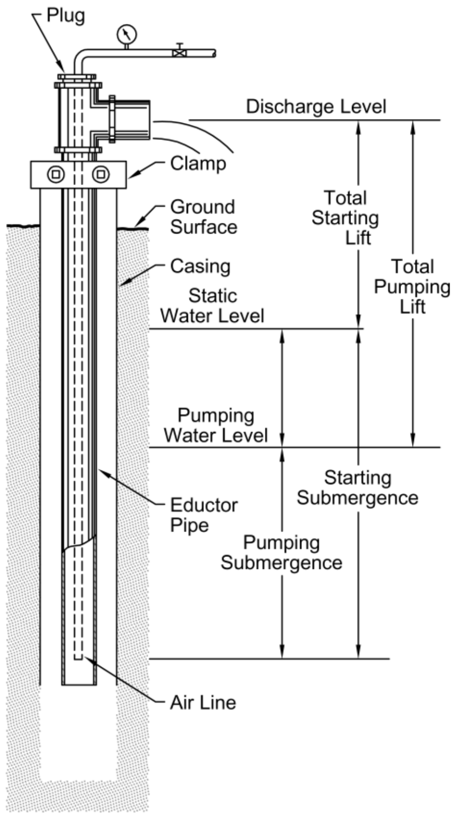
- ❑ Focus energy.
- ❑ Saves trip time.
- ❑ Combine techniques
- ❑ Chemical injection





Air Lift Development

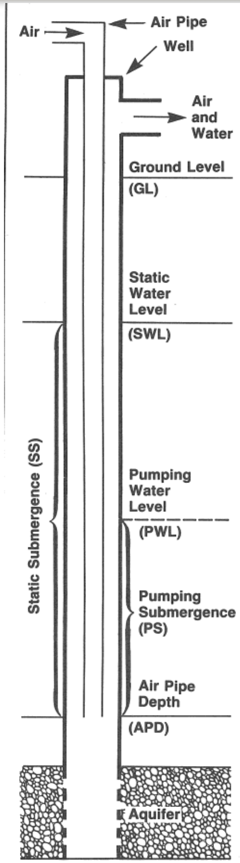
- Surging with an aerated column of water using an eductor pipe
- Sand removal requires velocities of over 1,000 ft/min
- Pumping rates are a function of submergence, air volume, annular space, pumping lift and aquifer characteristics.



Air Lift Pumping/Surging

- Develops most permeable zones.
- Better results when applied across the screen section.
- No pump required.
- Caution: can collapse casing/screen if premature.

Air Lift Pumping Chart



Approximate Air-Lift Pumping Capacities (gpm)

Borehole or Well	Air Pipe	Pumping Submergence %					Air Compressor Delivery
Pipe I.D. (inch)	Tube O.D. (inch)	10% (gpm)	20% (gpm)	40% (gpm)	60% (gpm)	80% (gpm)	(cfm)
3/8	1/8		0.08	0.3	0.5	0.7	7.4
1/2	3/16		0.17	0.6	1	1.4	12
3/4	1/4		0.4	1.4	2.4	3.4	20
1	3/8		1	3	5	7	31
1-1/2	1/2		3	8	13	18	77
Pipe I.D.	Pipe I.D.						
2	1/2	0.5	5	15	25	35	120
3	3/4	2.5	15	40	65	90	270
4	1	5	28	75	125	175	470
5	1-1/4	7.5	50	140	230	320	740
6	1-1/2	12	80	225	370	520	1100
8	2	25	150	450	720	1000	1900
10	2-1/2	50	300	800	1300	1800	3000
12	4	75	450	1200	1950	2700	4000
14	4	90	600	1700	2900	4000	5100
16	5	100	800	2400	3900	5500	6600

Air Compressor Requirements

- Pressure rating (psi) must be 20% greater than the Static Submergence
- Volume rating (cfm or cubic feet per minute) must equal or exceed values from above table for hydrology testing. If the water production surges, i.e. varies in gpm rate, then a GREATER cfm is needed. On the other hand, well development by air-lift pumping is enhanced by surging; therefore, a LOWER cfm is desired for part of the development period.
- Pumping Submergence % = $\frac{\text{APD} - \text{PWL}}{\text{APD}}$
- Static Submergence (psi) = APD − SWL
  NOTE: 1 foot of water = 0.433 psi

BASKI, INC

Development Chemicals

- Chlorine:
  - Breaks most synthetic polymers
  - Breaks the polyaccrylamides in most bentonites, improving removal.
- Surfactants / Wetting Agents
  - Improve penetration
- Phosphates should NOT be used as they promote biological growth.
- Almost always improve results and save time.

When is a Well Developed?

Components of Drawdown

$$S = Sl + Sn + Se + Sw$$

Where:

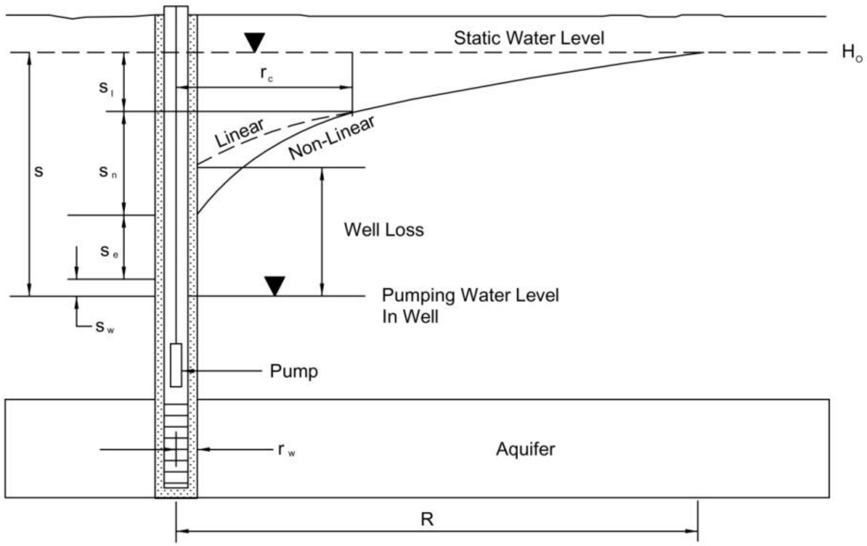
S = total drawdown

Sl = head loss due to viscous drag of water moving through the aquifer with low <u>laminar</u> velocity.

Sn = head loss due to <u>non-laminar</u> flow in the aquifer in the high-velocity region in the immediate vicinity of the well.

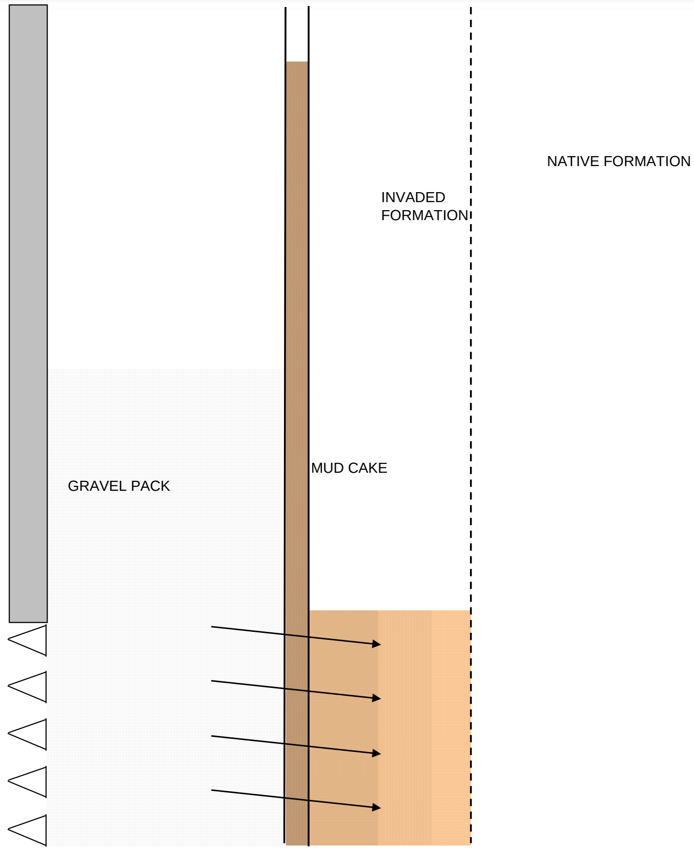
Se = head loss as the water <u>exits</u> the aquifer into the wellbore.

Sw = head loss as the water flows within the <u>wellbore</u> to the pump intake.

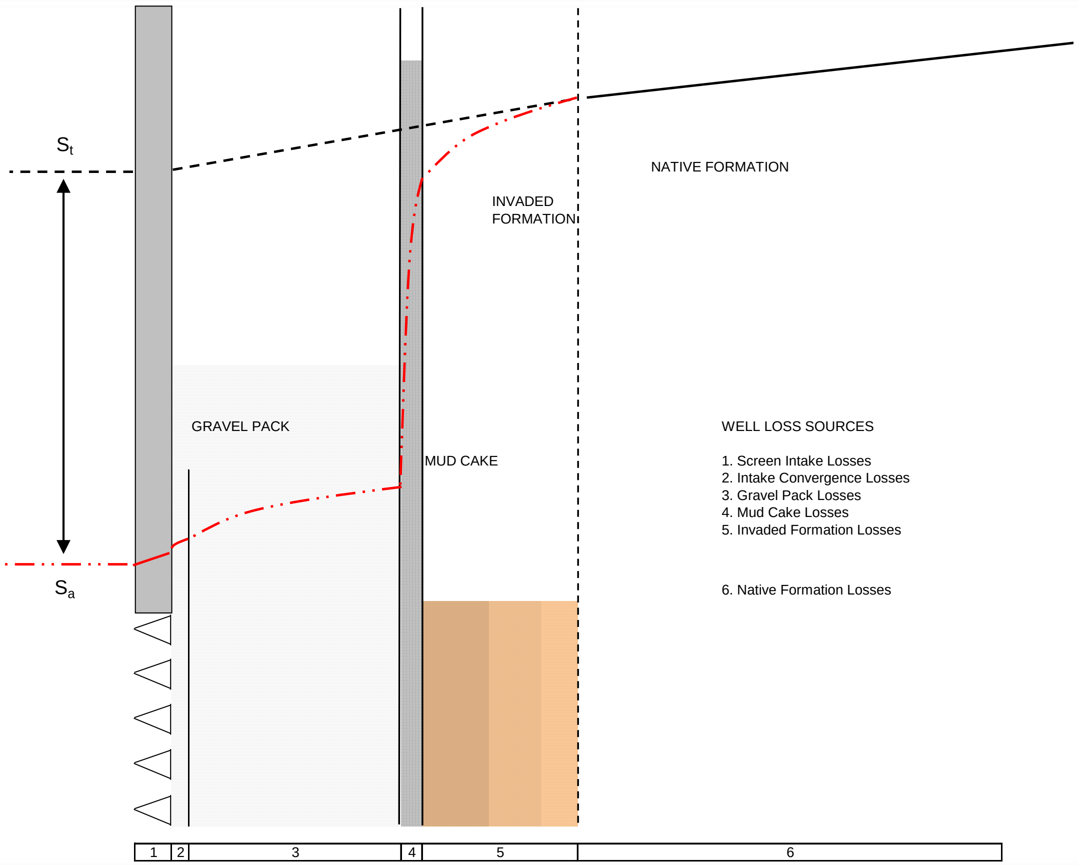


GWW-3rd Edition

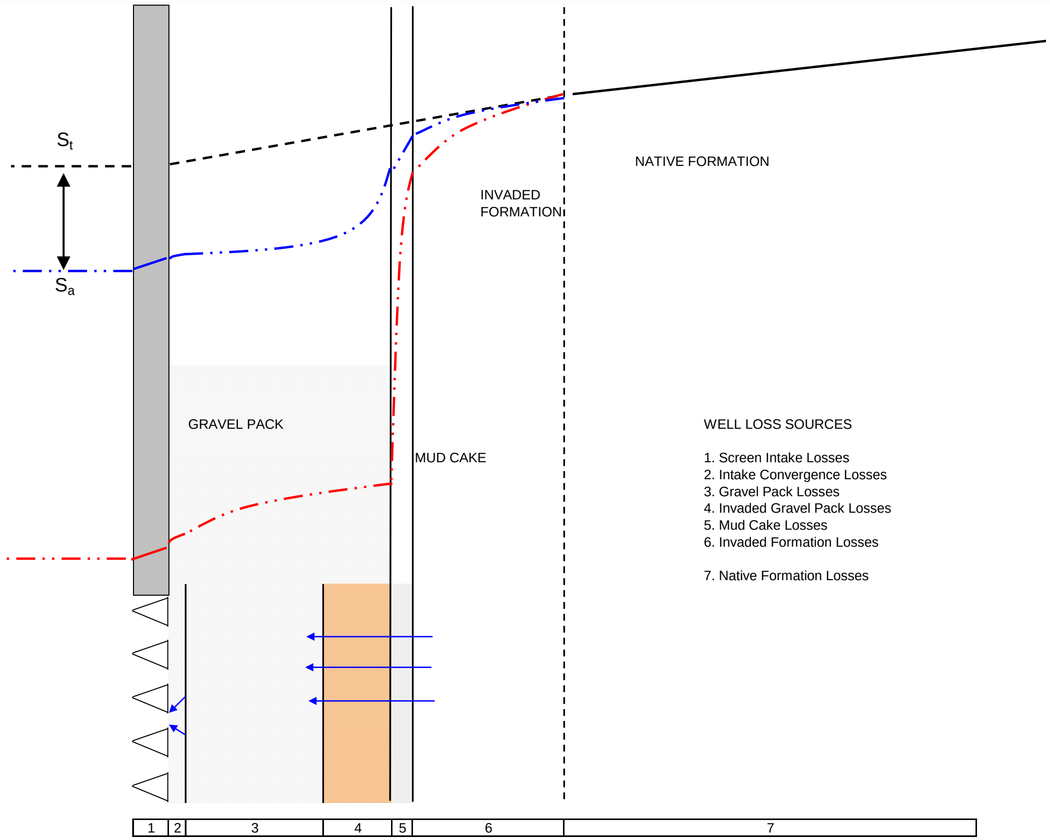
Before Development
Gravel Pack Well



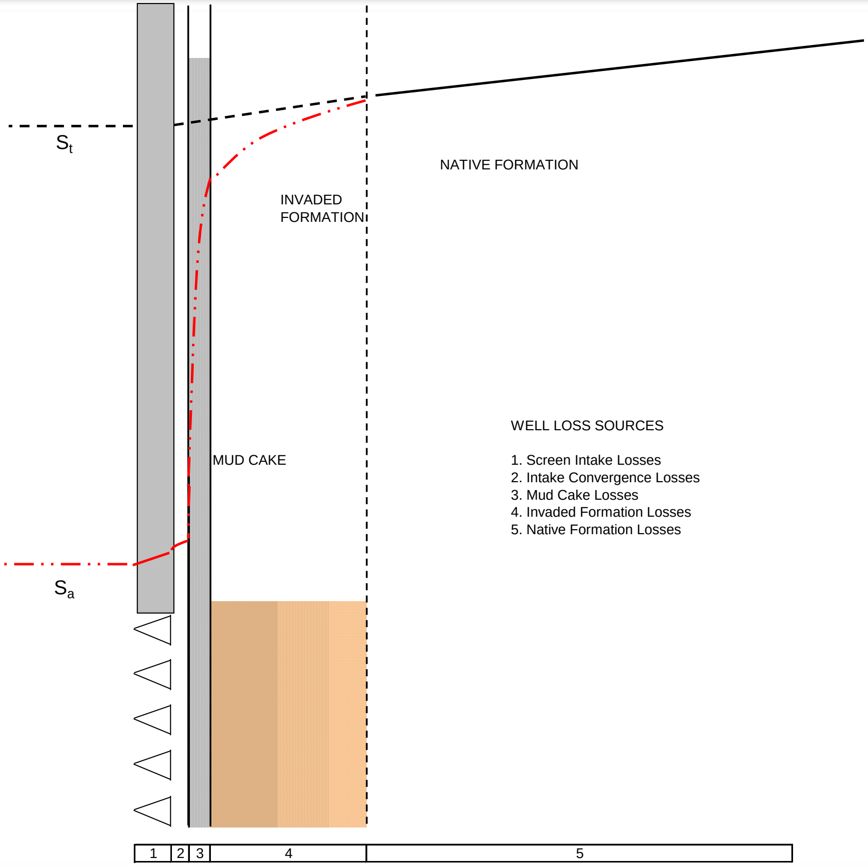
Well Losses
Gravel Pack



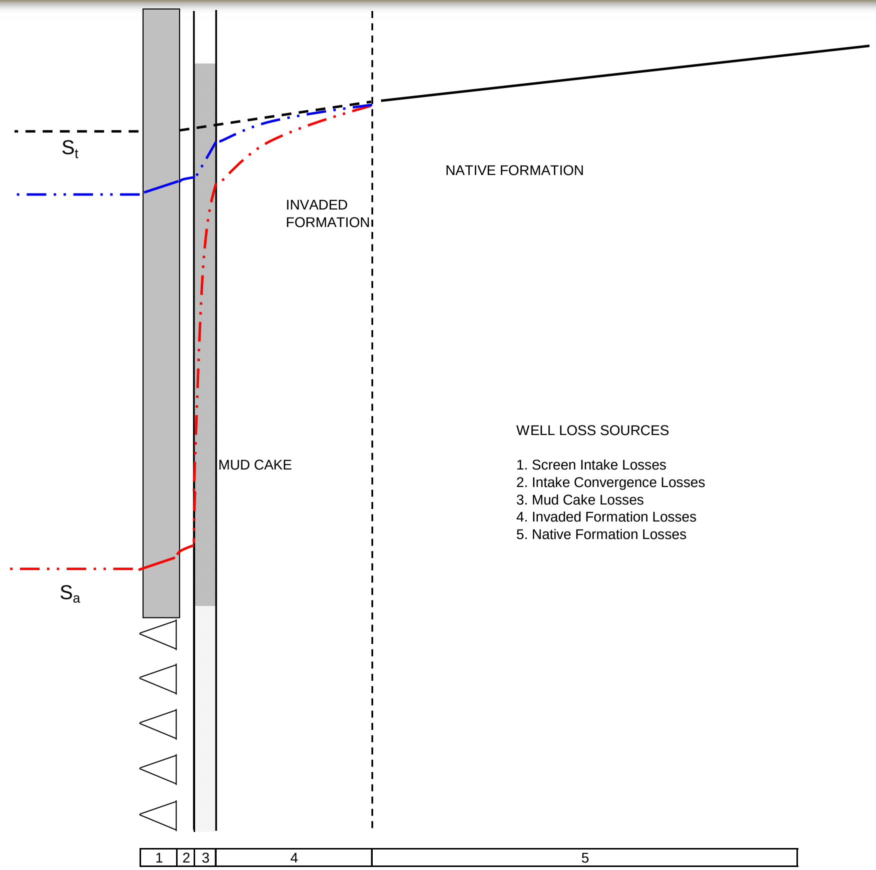
Development
Gravel Pack



Losses
Non-Gravel Pack



Development
Non-Gravel Pack



When is a well developed?

- When contract terms are fulfilled?
- When turbidity is absent after agitation?
- When the *specific capacity* stabilizes?
- When predetermined efficiency is achieved?
- When no further improvement can be obtained in *specific capacity* and *efficiency* at a particular yield?

Turbidity

10 ppm sand in 5-gal (19 liter) pail

Specific Capacity & Efficiency

$$\text{Sp Cap} = \text{yield} / \text{drawdown}$$

$$E = \frac{\text{theoretical drawdown}}{\text{actual drawdown}} \times 100$$

Drawdown Equations

$$s = \frac{264Q}{T}\log\frac{0.3Tt}{r^2S}$$ *Cooper & Jacob (1946)*

$$s = BQ + CQ^2$$ *Jacob (1947)*

$$s = BQ + CQ^n$$ *Rorabaugh (1953)*

$$s = BQ + B''Q^n + CQ^2$$ *Williams (1985)*



Well Efficiency
An evaluation of drawdown

$$E_w = \frac{S_t}{S_a}$$

$$E = \frac{(Q/s)_{actual}}{(Q/s)_{theoretical}} \times 100$$

$$E = \frac{BQ}{(BQ + B'Q + B''Q^n + CQ^2)} \times 100$$



Cost to Pump

$$KW = \frac{Q(s + SWL) \times (746)}{3960 \times E_o}$$

Drawdown

Real Results

Staples Minnesota

City San Antonio, TX

Shageluk, AK

Confluence Lake, Delta CO

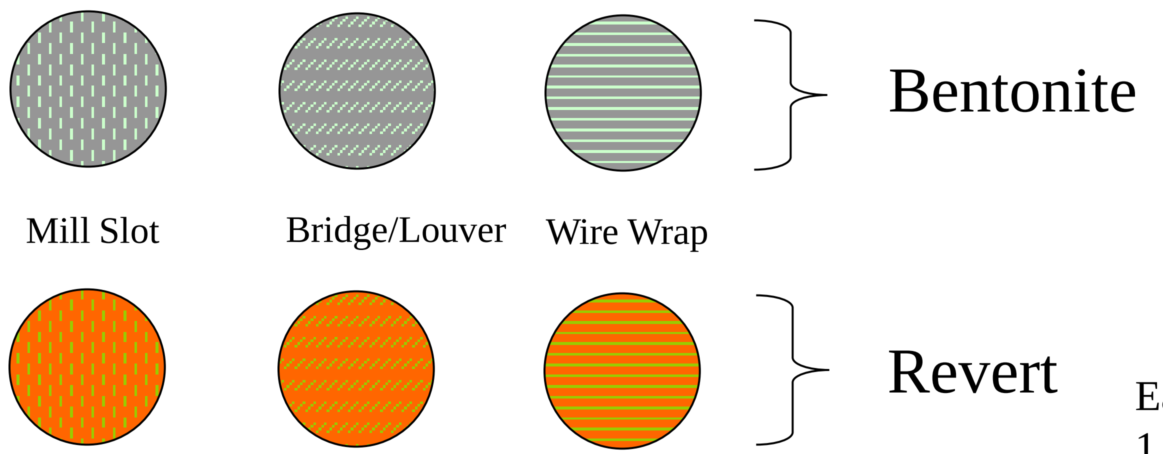
Staples Study

In early 1980's the Division of Energy Conservation of the US Department of Energy began a $1.5 million study to improve irrigation energy-efficiency.

Part of this study was a well-efficiency project at the Irrigation Research Center near Staples, Minnesota affiliated with the Extension Division of the Agricultural Engineering Department of the University of Minnesota.

Six wells were completed in close proximity, all drilled by rotary method in glacial alluvium. Three drilled with bentonite, three with Revert (biodegradable polymer). Two completed with mill-slot pipe, two with bridge louvers, two with continuous slot screens. All were developed and tested alike.

Overview of Staples Project

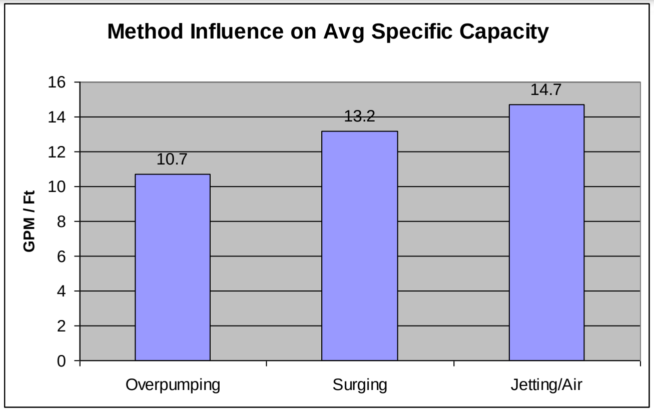


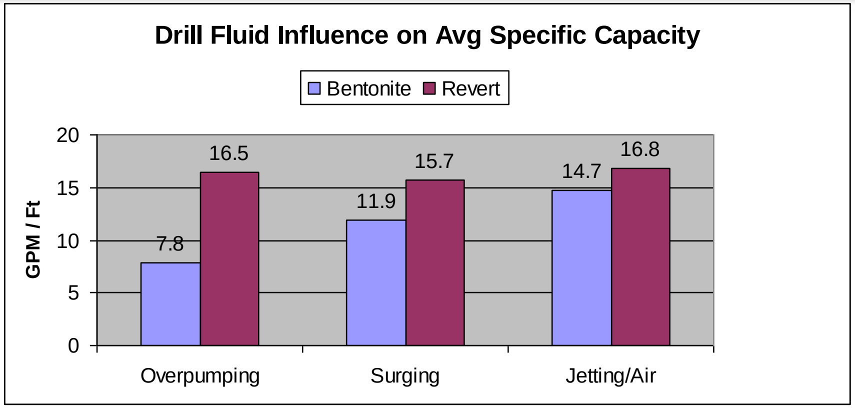
Each well developed by:
1. Over-pumping
2. Surging
3. Jetting w/Air Lift

Test Pumped after each step.

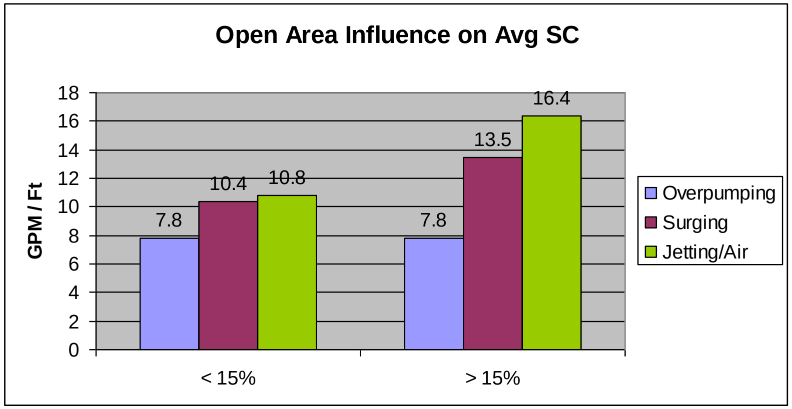


Staples Study - Findings





1. Aggressive mechanical agitation resulted in overall average S.C. increase of 23%.
2. Wells drilled with polymer drill fluid (Revert) yielded 24% higher S.C. on average.
3. Intakes with > 15% open area had average S.C.52% higher than those with < 15% OA.



San Antonio Wells

To meet the minimum well efficiency, construction records for three conventional gravel pack wells completed at the site indicated the average development time was approximately 1 hours per foot of screen.

MuniPak was considered and accepted for installation.

San Antonio Water Systems

Pumping Rate 1,400 gpm (~ 90 liters/sec)

- 16x18 inch MuniPak in 20-inch borehole (406mmx457mm / 508 mm BH)
- DD = 24.1 Ft (7.3 meters)
- SC = 58 GPM/Ft (12.1 l/s-m)

- 16-in rod base screen packed in 24 inch borehole (406mm / 610mm)
- DD = 30.5 Ft (9.3 meters)
- SC = 46 GPM/Ft (9.5 l/s-m)

San Antonio Conclusions

Borehole diameter was reduced 16% (from 24 to 20 inch)

Development time fell 37% (from 0.95 to 0.60 hr/ft-screen)

Drawdown decreased 21% (from 30.5 to 24.1 ft)

Specific Capacity increased 26% (from 46 to 58 gpm/ft)

Shageluk, AK

27 July 2009

MONITOR / SUPPLY WELL

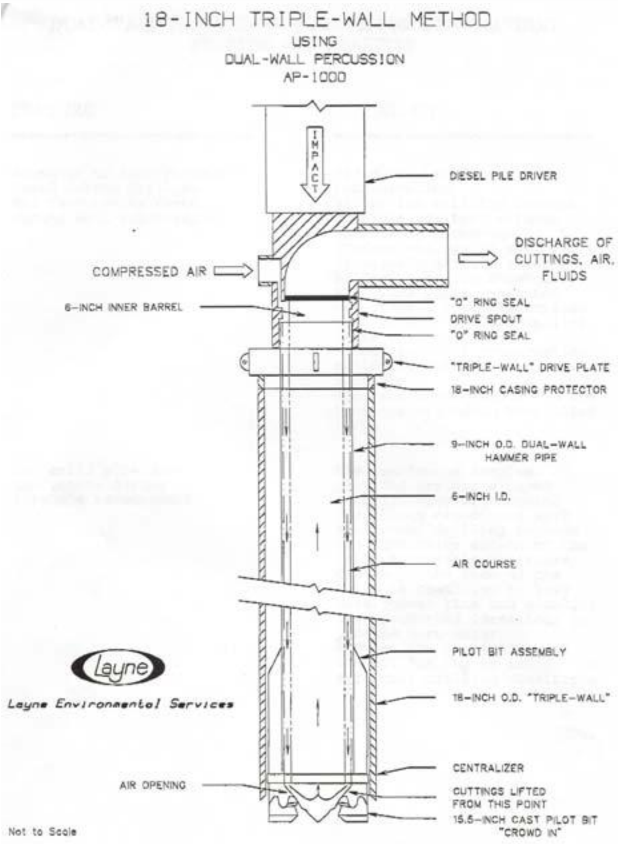
- Well Description:
  - TD = 110-ft (34 m), BH = 7-7/8” (200mm)
  - 8” (203mm) Pitless ~ 10-ft (3 m)
  - 6” (152mm) Sch40 PVC 10-93ft (28 m),
  - K-packer into pitless.
  - 6” (152mm) 20 slot (0.5mm) SS screen to 103ft (31 m)
- Geology: coarse sand&gravel w/clay
- Lost circulation

Shageluk, AK

- Drilling comments: stopped frequently to test; had to shove screen to final TD.
- Initial Development: bailer surged with *Aqua Clear*, pumped w/4" (102mm) submersible, < 1 GPM (0.06 l/s) flow
- Treatments: Displaced 1500+ ppm chlorine solution; soaked 12-24 hours (twice); surged w/modified bailer tool before evacuating each chlorine bath; effluent continued to yield turbidity.
- Improvement gauged by continuous yield of turbidity and faster recovery times.
- Final cycle pumping cleared the well; final yield was ~ 6 GPM (0.4 l/s) as originally anticipated.
- Total of 10 calendar days / achieved 6 fold increase.

Confluence Lake, Delta, CO

- 12” (305mm) Water source wells for fishery.
- Drilled dual wall percussion method; 18” (457mm) temp casing; 12” (305mm),125 slot (3.2mm) SS screen, 12” (305mm) LCS casing installed, ¼” x ½” (6.35mm x 12.7mm) gravel packed and 18” temp casing withdrawn.
- Geology: alluvial riverbed gravel, sand, silt and clay approximately 40-ft (12 m) thick.
- Theoretical Yield: estimates were 380 to 440 GPM (~ 25 liters/sec).



Confluence Lake

- Initial Development: airlifting 4-hours until discharge was free of sediment. Test pump installed and well surged 4 additional hours. (Poor production noted during this pumping.)
- Initial Step Test: (conducted at 50, 100, 150 GPM – 3, 6, 9 l/s) indicated poor initial yields at less than ½ anticipated.
- Formation Damage: Even though drill mud was not used, engineers concluded liquefaction of formation can occur adjacent to the casing due to formation vibration. The bottom-hole airlifted cuttings causes depressurization at the bottom of the borehole and (the liquefied) fine grained sediments moved toward the outer casing by moving from areas of higher pressure to lower pressure resulting in formation damage. This resulted in the need for further development.
- Secondary Development: Johnson's NW-220 Clay Dispersant was swabbed into the formation and surged for 6 hours and airlift pumped for 2 hours until the discharge was sediment free. (Clays & silts were removed that were not noted during initial development.
- Final Step Test: (conducted at 100, 200, 300 GPM – 6, 13, 19 l/s) yields that were originally anticipated.



Why is Development Important?

- Determines a successful (unsuccessful) completion
- Impacts Quality
  - Michigan study concluded wells properly developed had fewer problems with positive coliform tests. (Schnieders 2003).
- Has major impact on yield, S.C., efficiency.
- Financial impact / Operational cost
- Useful Well Life



Development is an investment in efficiency.

Don’t take short cuts!

It’s what makes the HOLE a WELL.

Thank you for your patience!



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