DRILLING AND WELL CONSTRUCTION

Many ground-water studies, particularly those intended to determine, in detail, the distribution of contaminants or hydraulic properties of aquifers, require the installation of monitoring wells to supplement existing wells. Existing wells may be poorly constructed; not have available lithologic data (geologic units encountered) and construction information (well depth, length/type of open interval); may be used for water supply (which can affect the quality of samples collected); and (or) require special permission (or not permitted) for use).

Most wells installed for ground-water studies are two-inch diameter wells, which have the benefit of allowing the use of existing small diameter sampling pumps, limiting purge time and volume, and reducing installation costs. Larger-diameter wells (4- to 6-inch diameter) also may be installed, generally as pumping wells for multiple-well aquifer tests and contaminant extraction systems (Lapham and others, 1977).

A properly constructed well is intended to provide water and pressure data from the aquifer of interest only will not contribute erroneous water-quality results because of leaching and adsorption by the well casing, screen, or backfilling materials, or from liquids or other additives used during drilling. (BEWARE THE “ENEMIES”)

USEFUL REFERENCES:

Lapham, W. W., Wilde, F.D., and Koterba, M.T., 1997, Guidelines and standard Procedures for studies of ground-water quality: selection and installation of wells, and supporting documentation: U.S. Geological Survey Water-Resources Investigations Report 96-4233, 110 p.

U.S. EPA, 1991, Handbook of suggested practices for the design and installation of ground-water monitoring wells: EPA/600/4-89/034

Shuter, E. and Teasdale, W.E., 1989, Application of drilling, coring, and sampling techniques to test holes and wells: U.S. Geological Survey Techniques of Water-Resources Investigations of the United States Geological Survey, Book 2, Chapter F1, 97 p.

The process of well installation requires:

- Establishing installation criteria
    - to ensure wells installed for intended purpose and will yield data that accurately represents the hydrogeologic system and its water quality
    - each aspect of well installation will comply with appropriate regulations, utilities; will be identified, safety issues considered

- Designing wells – compatibility with data objectives
    - Whenever possible design well to meet needs of future studies
    - Considerations
        - nature of subsurface materials (unconsolidated?, fractured?)

    - relation between subsurface material/screen selection
    - casing and screen material
        - typically PVC or stainless steel, may be PTFE (NSF approved)
            - leaching-sorption advantages/disadvantages
            - avoid PVC solvents/cement
            - flush threaded with o-rings
        - aperture has sufficient open area
    - screen length and type (affect water quality, hydraulic measurements)
        - typically continuous wire-wound or machine slotted
        - open area (aperture) sufficient to allow sample be withdrawn without entrainment of sediment; based on size of sediment (often 10-slot or 0.01 ft aperture)
    - diameter casing/screen/ or open hole
    - depth to water
    - depth to top of aquifer
    - depth to monitoring interval (tensile strength important with depth)
        - Schedule 80 PVC generally recommended for wells > 100 ft
    - operational issues (budget, site accessibility; equipment access)
  - well may be open hole w/ surface casing; open hole with packers; screen well and casing with filter pack, annular seal

- Decontaminating the equipment; selecting the appropriate drilling, construction, completion, and development methods.

DRILLING FOR INSTALLING WELLS FOR WATER-QUALITY SAMPLING AND HYDRAULIC TESTING

Select method that minimizes contamination of subsurface materials and pore water by foreign drilling fluids and minimizes cross contamination vertically between subsurface materials during drilling.

AUGER DRILLING

• Hollow-stem, continuous-flight augering	2
• Solid-stem, continuous flight augering	2
• Bucket augering	1
• Hand augering	1
•	

ROTARY DRILLING

• Direct rotary with mud and air	3
• Direct rotary with advance casing	1
• Reverse circulation	3
• Dual wall reverse circulation	1

PERCUSSION DRILLING

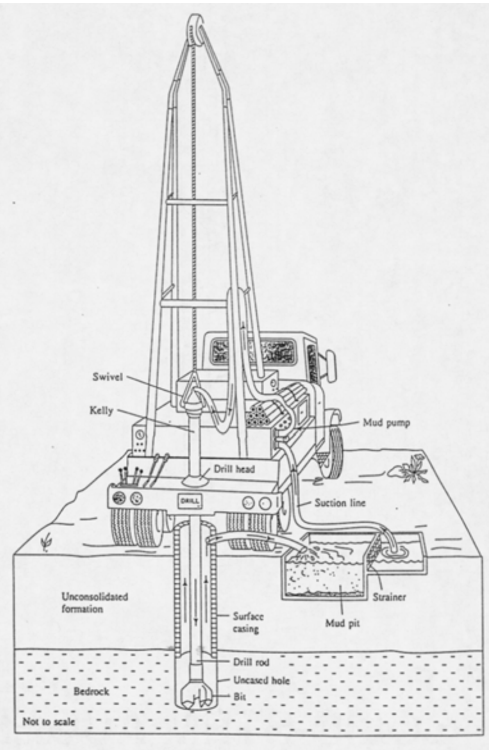
• Air hammer	1
• Cable tool	1

- Jet wash 3
- Jet percussion 3
- Hand driving 1

1. Most preferred because avoids use of drilling fluids, and drill casing advanced during drilling
2. Avoid use of drilling fluids, but drill rod not advanced during drilling.
3. Least preferred because uses drilling fluids, and drill casing not Advanced during drilling.

Consider these issues when selecting drilling method:

- Introduction of air into aquifer (avoid air rotary?)
- Introduction of oil (from air) into aquifer (avoid air rotary?)
- Cross contamination between aquifers (use advanced-casing method?)
- Introduction of drilling fluids (bentonite mud) into aquifer (avoid mud rotary?)
- Cost and Speed



.--Typical rotary water-well drilling rig and circulation of drilling fluid in mud-rotary drilling. (Fetter, 1993)

Figure – Rotary drill rig

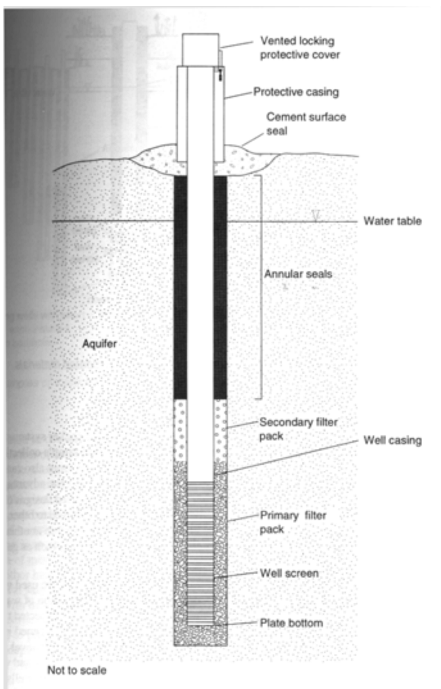
Table 1: Advantages and Disadvantages of Auger, Rotary, and Cable Tool Drillin

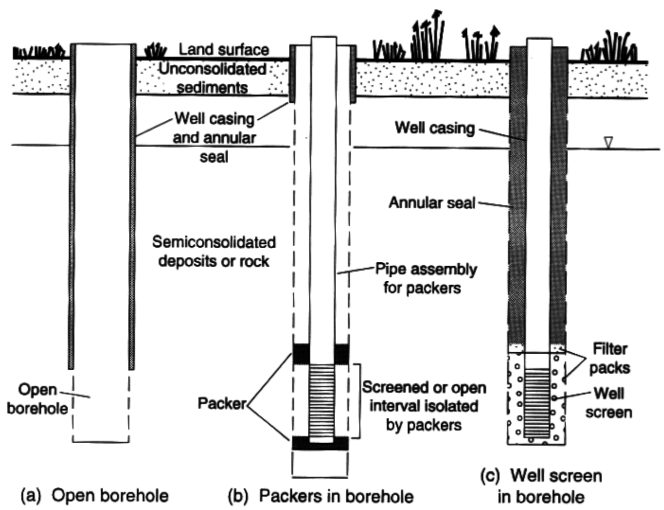
Type	Advantages	Disadvantages
Auger	Minimal damage to aquifer No drilling fluids required Auger flights act as temporary casing stabilizing hole for well construction (if hollow stem) Good technique for unconsolidated deposits Continuous core can be collected	Cannot be used in consolidated deposits Generally limited to wells less than 150 feet in depth, depending on soil/regolith thickness May have to abandon holes if boulders are encountered
Rotary	Quick and efficient method Excellent for large and small diameter holes No depth limitations Can be used in consolidated and unconsolidated deposits Continuous core can be collected	Requires drilling fluids, which alter water quality Results in a mud cake on the borehole wall, requiring additional well development, and potentially causing changes in water quality Loss of circulation can develop in fractured and high-permeability material May have to abandon holes if boulders in unconsolidated deposits are encountered

Table—Comparison of auger and rotary drilling methods.

Rotary drilling will produce a skin of fine-grain materials (mud cake) on the borehole wall. The cake will consist of rock flour produced during drilling and drilling fluids (generally bentonite mud). The drilling fluid can penetrate into the formation. The drilling fluids and fine-grained materials in the “screened” interval must be removed upon completion of well installation.

WELL CONSTRUCTION





Figures – Examples of various well constructions

WELL COMPLETION

- Well completion consists of filling and sealing the annular space between the well casing and borehole wall to ensure that:
  - The hydraulic head measured in the well is that of the “screened” interval
  - Only the interval “screened” contributes water to the well
  - There is no vertical conduit along the annulus for flow of water and contaminants

WELL SCREEN SLOT-SIZE SELECTION

- On basis of grain-size distribution
    - Effective size = 90 % retained (D10)
    - Uniformity coefficient = ration of 40% retained (D60) to effective size
- Justify natural filter packs if:
    - D10>0.01 inch
    - D60/D10 >3.0
- Most designers install standard 10-slot screen; may lead to problems with well development and performance

ARTIFICIAL FILTER PACK REQUIREMENTS

- use if fine-grained materials present; with long screens in highly stratified, non-uniform sediments; in bedrock with fractures
- 20-slot or less screen opening is required to retain 50% of material
- select filter-pack size/screen-opening size at same time
    - too large a filter pack/slot size, fines are lost to well
- too small, filter pack lost to aquifer, unstable filter pack uniform pack = better filtering, better placement

Table 13.12. Desirable Filter Pack Characteristics and Derived Advantages

Characteristic	Advantage
Clean	Little loss of material during development Less development time
Well-rounded grains	Higher hydraulic conductivity and porosity Reduced drawdown Higher yield More effective development
90 to 95% quartz grains	No loss of volume caused by dissolution of minerals
Uniformity coefficient of 2.5 or less	Less separation during installation Lower head loss through filter pack

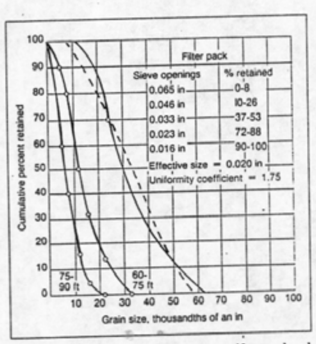


Figure 13.10 Grain-size curves for aquifer sand and corresponding curve for properly selected filter pack material.

Table and figure. – Selection criteria for proper filter pack and screen size

Polytetrafluoroethylene (PTFE) [1,2]

- Virgin PTFE readily sorbs some organic solutes (Parker and Ranney, 1994).
- Ideal material in corrosive environments where inorganic compounds are of interest.
- Useful where pure product (organic compound) or high concentrations of PVC solvents exist.
- Potential structural problems because of its low tensile and compressive strengths, low wear resistance, and the extreme flexibility of the casing string as compared to other engineering plastics (Driscoll, 1986, table 21.6; Dablow and others, 1988; Aller and others, 1989, table 25).
- Potential problems with obtaining a seal between the casing and the annular sealant because of PTFEs low coefficient of friction and antistick properties as compared to other plastics (Aller and others, 1989, p. 151).
- Maximum string length of 2-in. (~5-cm) diameter schedule PTFE casing should not exceed about 375 ft (~115 m) (Nielsen and Schalla, 1991, p. 262).
- Expensive.

Polyvinylchloride (PVC)[1,2]

- Leaching of compounds of tin or antimony, which are contained in original heat stabilizers during polymer formulation, could occur after long exposure.
- When used in conjunction with glued joints, leaching of volatile organic compounds from PVC primer and glues, such as THF (tetrahydrofuran), MEK (methylethylketone), MIBK (methylisobutylketone) and cyclohexanone could leach into ground water. Therefore, threaded joints below the water table, sealed with o-rings or Teflon tape, are preferred.
- Cannot be used where pure product or high concentrations of a PVC solvent exist.
- Maximum string length of 2-in. (~5-cm) diameter threaded PVC casing should not exceed 2,000 ft (~610 m) (Nielsen and Schalla, 1991, p. 250).
- PVC can warp and melt if neat cement (cement and water) is used as an annular or surface seal because of heat of hydration (Johnson and others, 1980; Driscoll, 1986, p. 324).
- PVC can volatilize CFCs into the atmosphere within the unsaturated zone, which can be a potential problem for studies of gas and moisture transport through the unsaturated zone.
- Easy to cut, assemble, and place in the borehole.
- Inexpensive.

Stainless steel (SS)[1]

- Generally has high corrosion resistance, which differs with type.
- Corrosion can occur under acidic and oxidizing conditions.
- Corrosion products are mostly iron compounds, with some trace elements.
- Primarily two common types:
  (1) SS 304: Iron alloyed with the following elements (percentages): chromium (18-20 percent), nickel (8-11 percent), manganese (2 percent), silicon (0.75 percent), carbon (0.08 percent), phosphorus (0.04 percent), sulfur (0.03 percent).
  (2) SS 316: Iron alloyed with the following elements (percentages): chromium (16-18 percent), nickel (11-14 percent), manganese (2 percent), molybdenum (2-3 percent), silicon (0.75 percent), carbon (0.08 percent), phosphorus (0.04 percent), sulfur (0.03 percent).
- Corrosion resistance is good for SS 304 under aerobic conditions. SS 316 has improved corrosion resistance over SS 304 under reducing conditions (Parker, 1992).
- Expensive.

Table – Some general characteristics of materials used for well casings and screens (Lapham and others, 1997)

GENERAL CHARACTERISTICS OF MATERIALS FOR WELL COMPLETION

- Primary filter pack
    - An envelope of sediment backfilled around the screen
    - Grain size should be similar to the prevailing grain size of the screened unit
    - Consists of well sorted quartz sand or gravel
    - Should not contain carbonate material
    - Should not contain organic material (wood fragments)
    - Best placed by a tremie pipe, backfilling slowly from the bottom to 1-5 ft above top of the screen
- Secondary filter pack
    - Purpose is to prevent the overlying grout from infiltrating and clogging the primary filter pack
    - Length of about 1 ft
    - Alternative is a primary filter pack that extends a minimum of 5 ft above the top of the screen
    - Plugs consisting of a packing shoe or a cement basket shoe not be substituted because of possible effects on water quality
    - Grain size of the secondary filter pack should be intermediate between the grain sizes of the primary filter pack and grout
    - Consists of well-sorted quartz sand
    - Should not contain carbonate material
    - Best placed with a tremie pipe

- Grout
    - Purpose is to seal annulus above secondary filter pack
    - Ideal grout is chemically inert, permanent, stable, and resists chemical and physical deterioration
    - Commonly used grouts are bentonite, cement,mixtures of bentonite and cement
    - In general, high solids bentonite is recommended material
    - Bentonite-cement mixture limits affect cement shrinkage
    - Use Portland Type I cement – no additives
    - Best placed with a tremie pipe

- Surface seal
    - A cement platform providing a seal at land surface that:
        - Prevents surface runoff down the well annulus
        - Holds the protective casing in place
    - Installed to a depth from land surface to prevent frost heaving (in general about 3 ft)
    - Bentonite not recommended because of likely desiccation
    - Protective casing: steel casing with vented (weep hole), locking cover

WELL DEVELOPMENT

Well development is a process of removing the fine grained material from the part of the filter pack around the well screen (Ideal filter pack90% retained by screen/10% will pass through the screen. Usually less retained) by pumping, surging, bailing, or otherwise removing many well-volumes of water from the well. This is necessary so that when the well is sampled, an absolute minimum of silt and slay will be present in the sample and the hydraulic characteristics of the filter pack do not limit accurate assessment of the hydraulic properties of the aquifer. The removal of the water needs to be at a rate sufficient to create velocities that will remove the fine particles. Generally, the well is pumped at a conservative rate so as not to create a severe gradient which could disturb the placement of the filter pack. If rotary drilling was used to construct the hole and drilling mud was used, well development can require days or weeks. This is usually not the case for shallow monitoring wells constructed in unconsolidated sediments or bedrock wells drilled by percussion or water rotary. The pumping or bailing associated with monitoring well development usually only continues until a minimum of turbidity is present.

Bedrock boreholes consisting of an open hole in the bedrock and a surface casing cemented into upper part of the bedrock unit and grouted where it penetrates the overlying unconsolidated deposits must be developed before the borehole can be sampled, used for hydraulic tests, or packer tested. Goals of development for these holes are similar to those for monitoring wells; pumping rates may greatly exceed those used for monitoring wells

- Objectives
    - To remove fine-grained sediments and drilling fluids introduced into formations during drilling
    - To provide water free of suspended solids to reduce pump wear
    - To provide water free of suspended solids for sampling (fines may affect water-quality results, particularly trace metals)
    - Eliminate bridging in filter pack
    - Removes water introduced during drilling

- Goals
    - Typically a minimum of 10 well volumes
    - Typically a goal of 5 nephalometric turbidity units (NTU's)
    - Typically a rate of 2.5 – 10 gallons per minute; may approach 30 gal/min for bedrock boreholes

- Well Development Methods (often used in combination)
    - Backwashing
        - Water injected out into subsurface materials
    - Surging (surge block)
        - Water injected out into subsurface materials then drawn back into well
    - Pumping or Overpumping

- Well Development Methods (often used in combination)--continued

        - Water withdrawn from well
    - Bailing
        - Water drawn back into the well
    - Jetting with water or air
        - Water, air, or both injected out into subsurface materials, then removed from the well

Well Development Methods in order of preference for water-quality sampling

- *Best method includes surge in both directions combined with pumping*
- Bailing
- Mechanical surging
- Pumping or Overpumping and Backwashing
- Indirect Eduction Jetting
- Backwashing
- Jetting or Surging with Water or Air
- *Avoid methods that*:
    - introduce water into the aquifer
    - introduce air into the aquifer (Fe bacterial/biologic activity)
    - pushes fines into sandpack

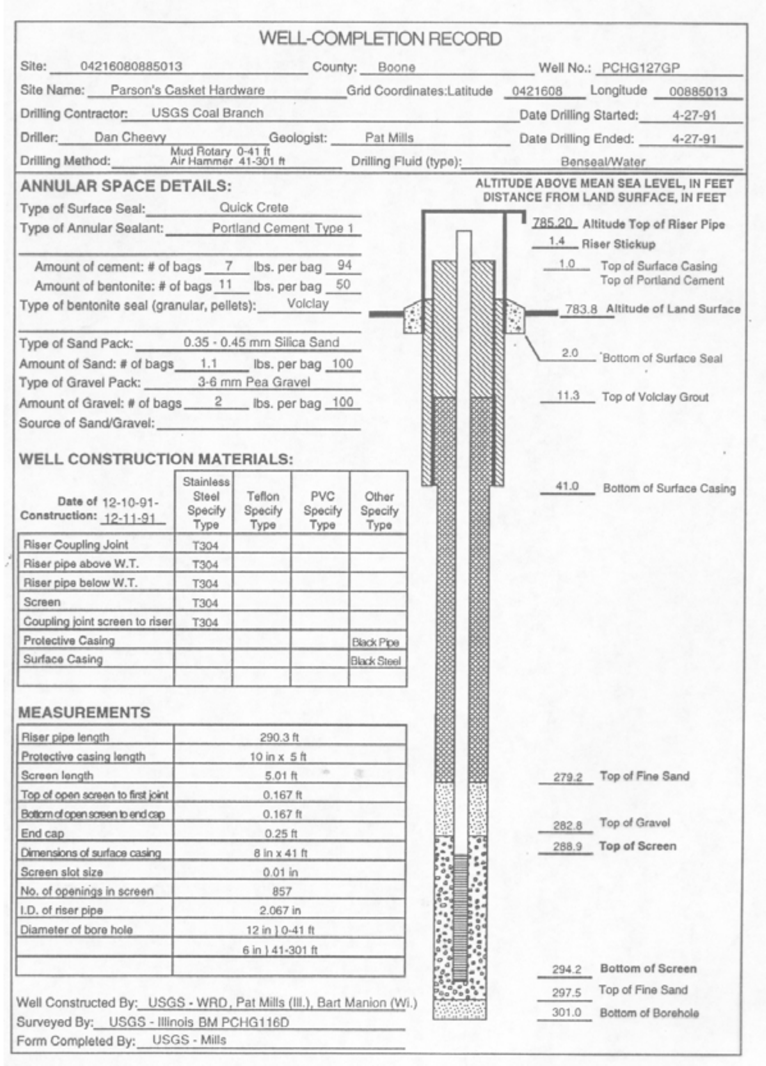
DRILLING SAFETY

Reference: Drilling Safety Guide, International Drilling Federation

Drilling can be very dangerous. Heavy equipment is used that can injure back feet, hands, etc. Additionally, drilling in the immediate vicinity of electrical lines or underground utilities one risks, electrical shock, explosions, vaporous releases and other responses that could result in death.

- Safety guidelines

    - To avoid electrical shock and arcing from power lines, maintain a minimum distance of 100 ft between the drill rig and the lines. Lesser distances must be reviewed with local utilities (see OSHS Reg. 29 CFR 1910.180)
    - Call underground utility locator (JULIE in Illinois) before drilling or excavating. Check to be sure all utilities are covered by JULIE – UI utilities not covered
    - Never operate the drill alone. Have a safety plan in place with local hospital identified



WELL-COMPLETION RECORD

Site: 04216080885013 County: Boone Well No.: PCHG127GP

Site Name: Parson's Casket Hardware Grid Coordinates:Latitude 0421608 Longitude 00885013

Drilling Contractor: USGS Coal Branch Date Drilling Started: 4-27-91

Driller: Dan Cheevy Geologist: Pat Mills Date Drilling Ended: 4-27-91

Drilling Method: Mud Rotary 0-41 ft Air Hammer 41-301 ft Drilling Fluid (type): Benseal/Water

ANNULAR SPACE DETAILS:

Type of Surface Seal: Quick Crete

Type of Annular Sealant: Portland Cement Type 1

Amount of cement: # of bags 7 lbs. per bag 94

Amount of bentonite: # of bags 11 lbs. per bag 50

Type of bentonite seal (granular, pellets): Volclay

Type of Sand Pack: 0.35 - 0.45 mm Silica Sand

Amount of Sand: # of bags 1.1 lbs. per bag 100

Type of Gravel Pack: 3-6 mm Pea Gravel

Amount of Gravel: # of bags 2 lbs. per bag 100

Source of Sand/Gravel:

WELL CONSTRUCTION MATERIALS:

Date of Construction: 12-10-91- 12-11-91	Stainless Steel Specify Type	Teflon Specify Type	PVC Specify Type	Other Specify Type
Riser Coupling Joint	T304			
Riser pipe above W.T.	T304			
Riser pipe below W.T.	T304			
Screen	T304			
Coupling joint screen to riser	T304			
Protective Casing				Black Pipe
Surface Casing				Black Steel

MEASUREMENTS

Riser pipe length	290.3 ft
Protective casing length	10 in x 5 ft
Screen length	5.01 ft
Top of open screen to first joint	0.167 ft
Bottom of open screen to end cap	0.167 ft
End cap	0.25 ft
Dimensions of surface casing	8 in x 41 ft
Screen slot size	0.01 in
No. of openings in screen	857
I.D. of riser pipe	2.067 in
Diameter of bore hole	12 in) 0-41 ft
	6 in) 41-301 ft

Well Constructed By: USGS - WRD, Pat Mills (Ill.), Bart Manion (Wi.)

Surveyed By: USGS - Illinois BM PCHG116D

Form Completed By: USGS - Mills

ALTITUDE ABOVE MEAN SEA LEVEL, IN FEET
DISTANCE FROM LAND SURFACE, IN FEET

785.20 Altitude Top of Riser Pipe
1.4 Riser Stickup
1.0 Top of Surface Casing Top of Portland Cement
783.8 Altitude of Land Surface
2.0 Bottom of Surface Seal
11.3 Top of Volclay Grout
41.0 Bottom of Surface Casing
279.2 Top of Fine Sand
282.8 Top of Gravel
288.9 Top of Screen
294.2 Bottom of Screen
297.5 Top of Fine Sand
301.0 Bottom of Borehole

Figure – Example well construction record.

DOCUMENTATION

Well-drillings logs include:

- Borehole drilling methods and materials
- Well construction method and materials
- Well location (and datum if available) and ownership