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Michael E. Guilbert

Provost & Pritchard Engineering Group, Inc.

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Zone Testing for Water Quality Based Well Design

Michael E. Guilbert, PG; Provost & Pritchard Engineering Group, Inc.;

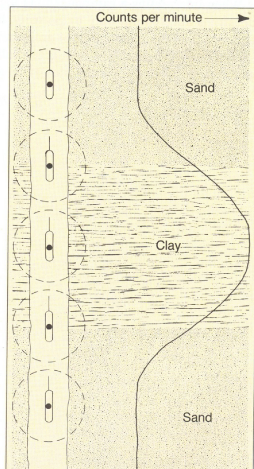
mguilbert@ppeng.com

559.449.2700

TESTING of water-producing zones, water quality based well design and careful installation can reduce the risk of a well producing water that exceeds drinking water standards in historically high-risk areas. Zone testing refers to the chemical analysis of groundwater in a small diameter test hole, prior to drilling large diameter boreholes and installing permanent casing. Using the methods outlined below, the water quality of the production well can essentially be chosen from the reported water quality of the zones tested.

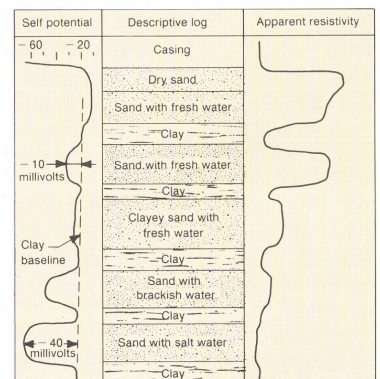
17-inch diameter test holes are drilled by the reverse rotary method². The reverse rotary method provides representative cuttings and a drilling-fluid filled borehole for geophysical logging. The cuttings are collected for geophysical log comparison and sieve analysis to design filter pack gradation. The total depth of the test hole should be deeper than existing low-quality water supply wells to assess alternative aquifers or at least 1000 feet. To avoid aquifers with elevated concentrations of arsenic and uranium in the San Joaquin Valley of California, well completion depths range from 800 to 1200 feet.

Immediately after reaching total depth, geophysical logging is conducted in the test hole to aid in the selection of water producing zones for testing. Geophysical logging includes the electrical suite (normal, short and long resistivity and spontaneous potential) and spectral gamma ray logs. Resistivity measures the electrical resistance of the subsurface formations; sand and gravel aquifers are resistive (low conductivity) and clay aquitards are non-resistive (high conductivity). Spontaneous potential measures the natural electrical measurement of the subsurface formations, delineating



saline or salt water aquifers from fresh. The diagram at right illustrates this. The spectral gamma ray log (example at left) measures natural gamma radiation sources (potassium, thorium and uranium) emitted from the subsurface formations and is key for uranium producing assessments. Clay strata usually contain more gamma emitting sources than sand and gravel. Note the increase in gamma counts per second from the clay strata. Lithologic logs alone are not sufficient to locate thin water producing zones or assess gamma-emitting zones; as such, geophysical surveys are always warranted for water quality based well designs.

²Reverse rotary drilling refers to the reverse circulation of the drilling fluid, as opposed to the normal or direct circulation direction of mud rotary. For a summary of drilling methods read *Groundwater & Wells*, H.G. Driscoll, 1986, Johnson Screens, St. Paul, MN.



Geophysical logs from *Groundwater and Wells*, 2nd Edition, F. G. Driscoll, 1986, Johnson Screens, St. Paul, MN

IN elevated-arsenic risk areas, chemical analysis of the clay strata bounding the target water producing zones is conducted, in addition to zone testing. Current research indicates the source of arsenic in the subsurface may be from leachable arsenic to the water producing zones from clay strata. A sidewall core-barrel gun depicted at right, is lowered into the test hole to clay strata depths separating target zones. The core gun contains 30 open-faced barrels (two inches in diameter and three inches long) that are ballistically charged. The barrels are shot horizontally into the sidewall and recovered by retrieving the core gun. The samples are analyzed for total and leachable arsenic; leachable arsenic concentrations are analyzed using a modified TCLP method replacing acetic acid with local groundwater. The zone test design (explained below) is based on the results of the electric log and chemical analysis of the clay.

Photograph depicting sidewall core-barrel gun ready for lowering in the open test hole. Each of the 30 barrels is ballistically charged to collect samples from clay strata bounding target water producing zones. The samples are analyzed for total and leachable arsenic by a modified TCLP method.



Photograph by C. Johnson.

For areas at risk to uranium produce elevated uranium a zone test design is based on the spectral gamma ray log. Zone testing is the placement of a sampling tool opposite the target water producing zones and installation of annular material used to isolate each zone in the test hole. The 10 to 20-foot long sampling tool is lowered into the test hole to the desired depth. Bentonite clay is installed across from the formation clay strata below the target zone. Around the perforated sampling tool and opposite the target zone, pea gravel is installed. A second bentonite clay seal is installed above the pea gravel. The construction of the zone effectively seals the zone sampling tool from the test hole, allowing groundwater from the targeted water-producing zone to be sampled for water quality parameters.

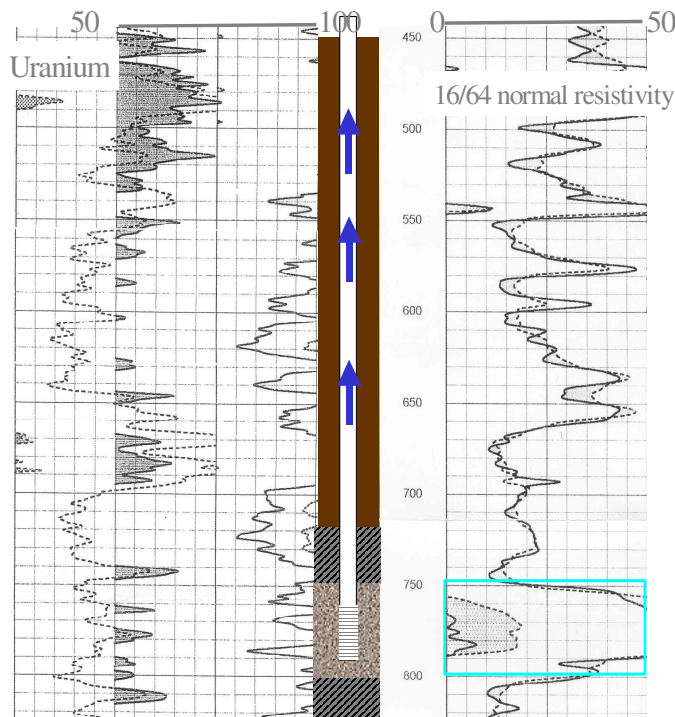
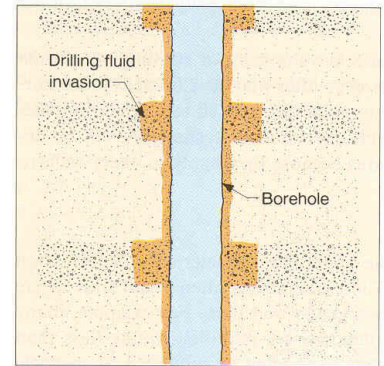


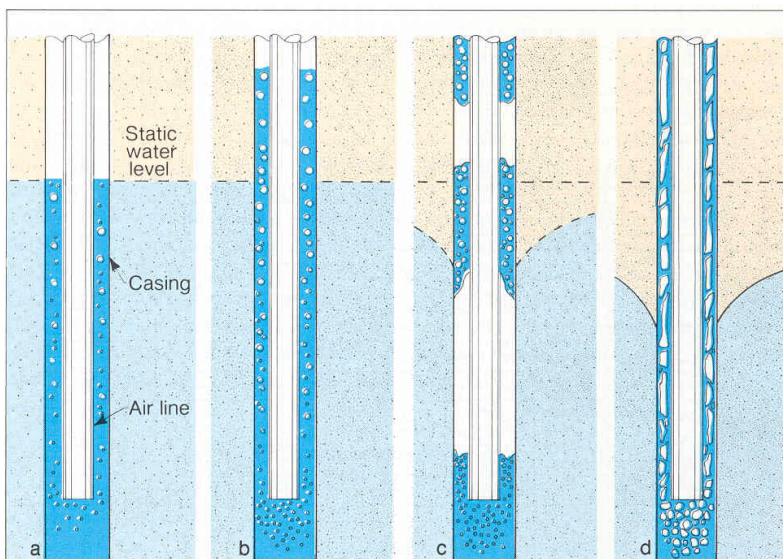
Diagram showing spectral gamma ray and resistivity logs bordering a fictional borehole. **Drilling fluid** floods the borehole, **pea gravel** encloses the zone test sampling tool placed opposite the **targeted aquifer**, with **bentonite seals** placed above and below the pea gravel. Groundwater from the water-producing zone is airlifted to the surface. Drawn by M. Guilbert.

BEFORE water samples can be collected from a zone, water must be purged in a sufficient volume to obtain representative groundwater. One of the benefits of a bentonite-based drilling fluid is the reduced damage or invasion of the drilling fluid (which contains fine-grained cuttings) into the water-producing zone. As the diagram at right illustrates, some volume of drilling fluid will always be lost to the zone even with good management and a concerted effort must be made to remove it, such that the water sample collected represents the water in the zone and not the drilling fluid.



From *Groundwater and Wells*, 2nd Edition, F. G. Driscoll, 1986, Johnson Screens, St. Paul, MN

Zone test purging is conducted by two methods: airlifting and pumping. Airlifting is conducted by installing an airline inside the drill pipe connected to the zone sampling tool to lift water up to the surface. Initial purged water is essentially drilling fluid, containing cuttings and debris that could damage a submersible pump. Several factors dictate the length of time required to purge water using this method. Discharge rates vary during airlifting, but rarely exceed a couple hundred gallons per minute; during drilling, hundreds of gallons of water can be lost to a single porous formation. But it's not just a matter of calculating the volume of drilling fluid required for removal and dividing by the discharge rate, because the drilling fluid becomes diluted in the water-producing zone. As such, the volume required to remove the drilling fluid may increase by 10 to 100 times. The purge water from the zone is monitored for physical parameters: electrical conductivity, total dissolved solids, pH, temperature and turbidity. Airlifting is considered sufficient when these parameters vary by less than 10 percent. Zone testing samples should not be collected during airlifting because of the volatilization and aeration of the sample that could affect the analysis. Instead, the airline



The diagram shows how pressurized air leaves the airline inside the casing; as the air rises it lifts water to the surface. Increasing volumes of air increases the rate at which water is airlifted. From *Groundwater and Wells*, 2nd Edition, F. G. Driscoll, 1986, Johnson Screens, St. Paul, MN

is removed and a submersible pump capable of pumping at least 100 gallons per minute is installed for final purging and collection of water samples. Monitoring of the physical parameters should continue, confirming that the purge water is representative of the water producing zone. Pumping is considered sufficient when these parameters vary by less than 10 percent.

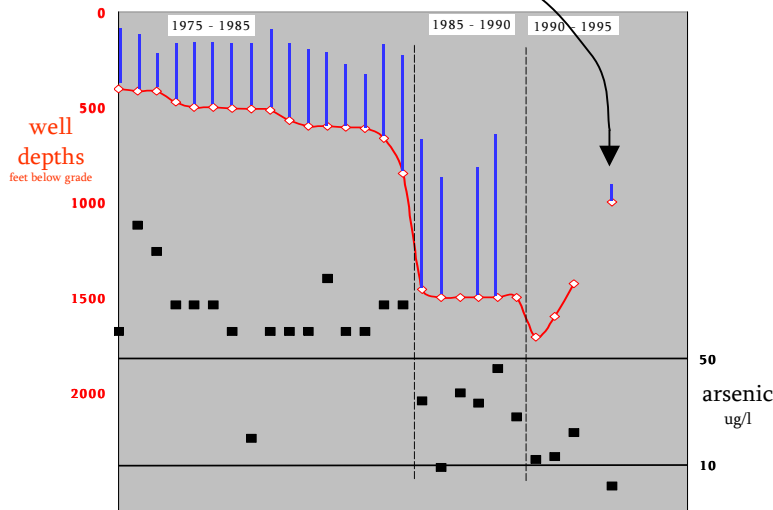
The zone test water samples are analyzed for general physical parameters and minerals, including selected metals. In addition, analysis of iron, manganese, arsenic and uranium should be analyzed as total and dissolved. Additional bulk samples should also be collected for re-analysis or other assessment, since access to the zones is temporary. The analyses are conducted on a quick turn around basis and tabulated, as shown here.

Analyte	Units	Zone 5	Zone 4	Zone 3	Zone 2	Zone 1	State of California Drinking Water Standard
		610 - 630	650 - 670	890 - 910	970 - 990	1065 - 1085	
Aluminum	mg/L	3.23	0.457	0.167	0.362	3.3	1.0*
Aluminum (Dissolved)	mg/L	ND	ND	ND	ND	ND	~
Arsenic (Total)	ug/L	ND	ND	2.4	2.3	4	10*
Arsenic (Dissolved)	ug/L	ND	ND	2.4	ND	ND	10*
Calcium	mg/L	6.76	1.61	1.44	1.42	6.73	~
Chloride	mg/L	9.4	12.1	91.5	85.4	93.1	250***
Color	Units	40	40	20	20	20	15**
Hardness (CaCO3)	mg/L	24.1	6.5	5.3	5.5	24	~
Iron	mg/L	5.59	0.876	0.374	0.46	5.65	0.3**
Magnesium	mg/L	1.76	0.6	0.418	0.481	1.74	~
Manganese	mg/L	0.155	0.0278	0.013	0.0148	0.153	0.05**
Odor	TON	3	6	ND	ND	ND	3**
Potassium	mg/L	1.1	0.527	0.539	ND	1.1	~
Sodium	mg/L	172	167	183	161	174	~
Specific Conductance	Umhos/cm	671	672	803	725	712	900***
Total Dissolved Solids	mg/L	482	427	488	409	398	500***
Total Uranium	ug/L	1.29	2.18	0.425	0.366	0.181	30*
Turbidity	NTU	112	14.8	5.0	6.3	3.5	5**

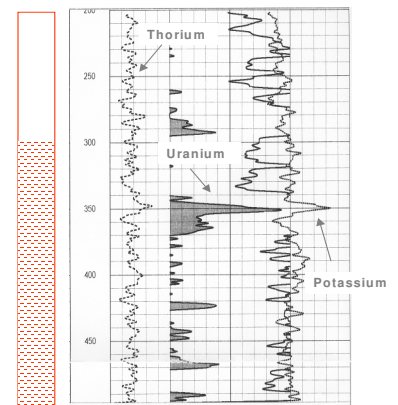
Client is presented with this table and becomes an active participant in the discussion of which zones and what water quality they would like. Well construction management is an integral step in the completion of a successful well and should be conducted by the qualified consultant.

THE diagram at right shows the results of a spectral gamma ray survey in an existing City of Kerman well which revealed elevated uranium activity at 350 feet below grade. This aquifer was avoided in replacement wells providing water with uranium concentrations below drinking water standards. Even though the wells were designed with shorter screen lengths than the destroyed wells, well yields and specific capacities increased.

The lower diagram shows the relationship between well depths (red line) and lowered arsenic concentrations (black squares) in the Lemoore-Hanford area. The most recent Lemoore well was completed in November 2004 and yields 1200 gpm, producing less than 3 ug/l of arsenic.



Although Zones 4 and 5 were reported to contain no detectable concentrations of arsenic, iron concentrations were reported well above secondary drinking water standards. Zones 2 and 3, highlighted in the table, were chosen for the well design. The production well produced arsenic concentrations of less than 3 ug/l and no other analytes tested exceeded drinking water standards.



City of Kerman Well No. 10 and associated spectral gamma ray log performed from inside completed well. Note elevated uranium signature at 350 feet, opposite perforated section of well.

Diagram at left depicting relationship between increasing well depth and lowered arsenic concentrations. Blue lines show actual screen lengths, suggesting that shorter and more discreet screen length design may reduce arsenic production below new MCL of 10 ug/l.

Diagrams by M. Guilbert, modified from C. Johnson.