CASE STUDIES AT SEVERAL ENVIRONMENTAL SITES USING A MULTI-PARAMETER BOREHOLE WATER QUALITY INVESTIGATION TOOL

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Abstract

Water quality studies conducted by the U. S. Environmental Protection Agency have been underway for the past several years using a relatively new and commercially available borehole investigation tool. The tool's design was specifically tailored to operate in monitoring and water wells for the purpose of rapidly assessing various water quality issues. Multiple sensors are applied simultaneously within the tool's housing which include pressure (depth), temperature, dissolved oxygen, fluid conductivity, redox and chloride. Additionally, one optional sensor can be selected. The choices include ammonia, nitrate, pH, sulfides, copper and iodine. The tool can operate in wells as small as two inches in diameter and its sensors have rapid response times allowing it to be trolled down a well at speeds of 15-20 feet per minute, while collecting and viewing data in real-time. All sensors are capable of withstanding pressures of at least five thousand feet of hydraulic head or six thousand six hundred ninety one feet without a pH sensor. Applications for the tool include detection of water quality anomalous zones and re-occurring periodic borehole fluid monitoring. Data can be applied to more accurately isolate anomalous zones within the borehole for conventional laboratory sampling routines.

Introduction

In-situ water quality measurements have been collected for more than 35 years in the environmental field using multi-parameter surface water probes, and over a longer period of time using traditional borehole logging instruments, although borehole instruments have very limited options for obtaining water quality measurements. Within the last few years a new borehole water quality probe was introduced as a joint endeavor between an established marine instrumentation manufacturer and a recognized borehole geophysical instrumentation company. This newly formed alliance modified an existing deep marine water quality probe to be compatible with traditional commercial borehole logging systems for operation in borehole wells as small as two inches in diameter.

The idea of integrating a versatile water quality probe to existing commercial logging systems is a unique design combination since it has the advantage of brining a full spectrum of borehole geophysical tools to the well site simultaneously. Such a combination allows data to be collected at a well site for in-situ geologic, hydrologic, and now a larger universe of water quality/chemical parameters. Since the tool integrates with an existing borehole logging system, there is no need for separate wirelines, consoles or data loggers to operate the system. For those remote areas that are difficult to access with commercial logging vehicles, recent advances in borehole logging systems have essentially condensed the basic capabilities of a logging truck down to the size of a backpack. These portable units can be easily purchased or rented, shipped and operated with this new tool.

Tool Description

The tool is twenty six inches in length with a diameter of 1.7” and can easily fit into two inch diameter environmental monitoring wells. Configuration of the sensors for this paper can be seen in Figure 1.

Figure 1: Sensor configuration for this study

Sensors for the tool can be configured using several selectable and interchangeable options. The tool configuration used for this paper consisted of a reference sensor, temperature, pressure (depth), fluid conductivity, dissolved oxygen, chloride, redox, with an ammonia and nitrate sensor being easily interchangeable in the field. Sensor options not evaluated by this paper include pH, sulfides, copper and iodine. Other sensor options may become available in the future. Sensor options, other than nitrate and ammonia, can be interchanged by the manufacturer, dealer or a qualified electrical technician having appropriate tools for sensor removal and replacement. There are nine options for pressure sensors ranging from 10 dbar to 6000 dbar but keep in mind that the tool’s depth limitation is established by the sensor having the least depth limitation. For extreme depth investigations a special version of the tool is available with all individual sensors having a depth limitation to 7000 dbar or 23,418 feet. A combination of five to eight selectable sensors would be housed within a titanium tool housing having a diameter of 50 millimeters.

This system is unique in several ways. Operating limits of the tool can withstand depths to at least 5,018 feet of head. All manufacturer available Ion Selective Electrodes (ISE) sensors including ammonia, nitrate and chloride allow operation to depths of 200 bar or 6,691 feet of head.

Another significant operating specification exists for sensor acquisition rates. Data are recorded at a rate of 25 milliseconds with sensor response times of 50 milliseconds for all except oxygen, pH, redox which are 3 seconds.

Applications

The tool's design is meant for in-situ fluid profiling or short term static analysis applications in boreholes to assess water quality issues. It is not designed to operate at the wellhead as a flow through cell. It can be operated within cased holes (plastic or metal) or open holes. Its use in cased holes it may be more effective operating within the screened portion of cased wells, unless it is used for specifically for detecting breaches in casing above screened intervals.

The integrated data collection system has superb vertical resolution due to high sensor and data acquisition rates which is comparable to, and complements, traditional borehole geophysical data. Tool applications include, initial screening of borehole fluids, rapid borehole fluid assessments, pinpointing borehole fluid anomalous zones, data providing guidance for further actions/sampling, periodic or re-occurring monitoring for long term well evaluations, evaluating water chemistry during pumping stresses and deducing inflow/outflow zones.

The tool can be applied in sea or fresh water environments by initiating an internal software sequence which the operator selects and switches to the appropriate conductivity range before immersion into the borehole fluid.

Perpetration of the borehole fluid prior to logging is dependent on the project mission and operator discretion. The tool can be operated in stagnant or equilibrated fluid conditions, during or after pumping or purging conditions. Caution should be used when operating the tool when pumping within the borehole as to avoid entanglement of the wireline with other lines in the well.

Logging is typically done moving downhole at speeds between 15-20 feet per minute or less. Slower speeds produce more accurate readings and reduce disturbance of borehole fluids.

Calibration and Maintenance

Temperature and conductivity sensors are factory calibrated and do not generally require field calibration. Pressure, pH and dissolved oxygen sensors may require infrequent calibration by the operator which can be initiated using internal software. However, calibrations of ammonia, chloride and nitrate, or other optional Ion Selective Electrode (ISE) sensors, require at least two calibration standards, preferably more, per parameter to accurately quantify sensor data. A built-in linear algorithm is provided within the operating software that can be either turned "on" or "off" to apply calibration corrections to raw data.

As with most water quality tools, significant maintenance is necessary to keep the tool in good working order. When not in use, special sensor caps and solutions are required to keep pH and reference sensors moist. In addition, certain ISE sensors require individual fluid caps be filled with appropriate electrolyte solutions. Membranes of ISE sensors must be periodically replaced and those on the oxygen sensor must also be fitted to match the desired data acquisition rates. For example, there are 3 options for oxygen sensor membranes; one for very fast profiling another for average profiling and finally one for static data acquisition. Each option is related to the time needed to sample the surrounding fluid. The timing requirements for data acquisition between all three membranes range from 0.9 seconds to 15 seconds. Oxygen membrane options can easily be changed by the operator, but those on the remaining ISE sensors are replaced by purchasing a new fluid reservoir cap since they have built-in membranes.

Other maintenance routines include connecting the tool to the data acquisition system for a few hours at monthly intervals to recharge the oxygen polarization capacitor. Ensure that the internal flow cell of the conductivity sensor is clean. Redox sensor and temperature sensors may require a very light sanding to remove fouling.

Case Study Example 1

The first case study is located in northern Illinois where several volatile organic compounds were found in ground water. Wells in the study area typically had a diameter of four inches to allow temporary pumps to be lowered into the wells. Ground water was approximately 78 feet from the ground surface with wells terminating at depths of about 135 feet. Overburden in the area ranges from 9 to 52 feet and was cased using a steel riser, the remainder of the hole was not cased. The hole was logged with the water quality tool on several separate occasions: 1) when the well was undisturbed for several days; 2) and again when a pump was drawing water from the top of the water table. During this later process the pump was set at about 85 feet and drawing at a rate of 2 gallons per minute.

Figure 2 presents the water quality data taken from the well when it was stagnant. Note the change in all parameters, excluding pressure, seen at about 90 feet and again at approximately 115 feet where conductivity changes again, but minimal effect to chloride and nitrate values. Figure 3 is the same well logged while it was being pumped at 2 gallons per minute. Changes in water chemistry are significant as seen at the 91 to 93 foot levels as fluid is drawn through the borehole from the aquifer. Additional logs are presented in Figure 4 to better understand geologic conditions. The driller of this well reported a two inch thick oxidized clay layer at 93.4 feet between two dolomite layers.

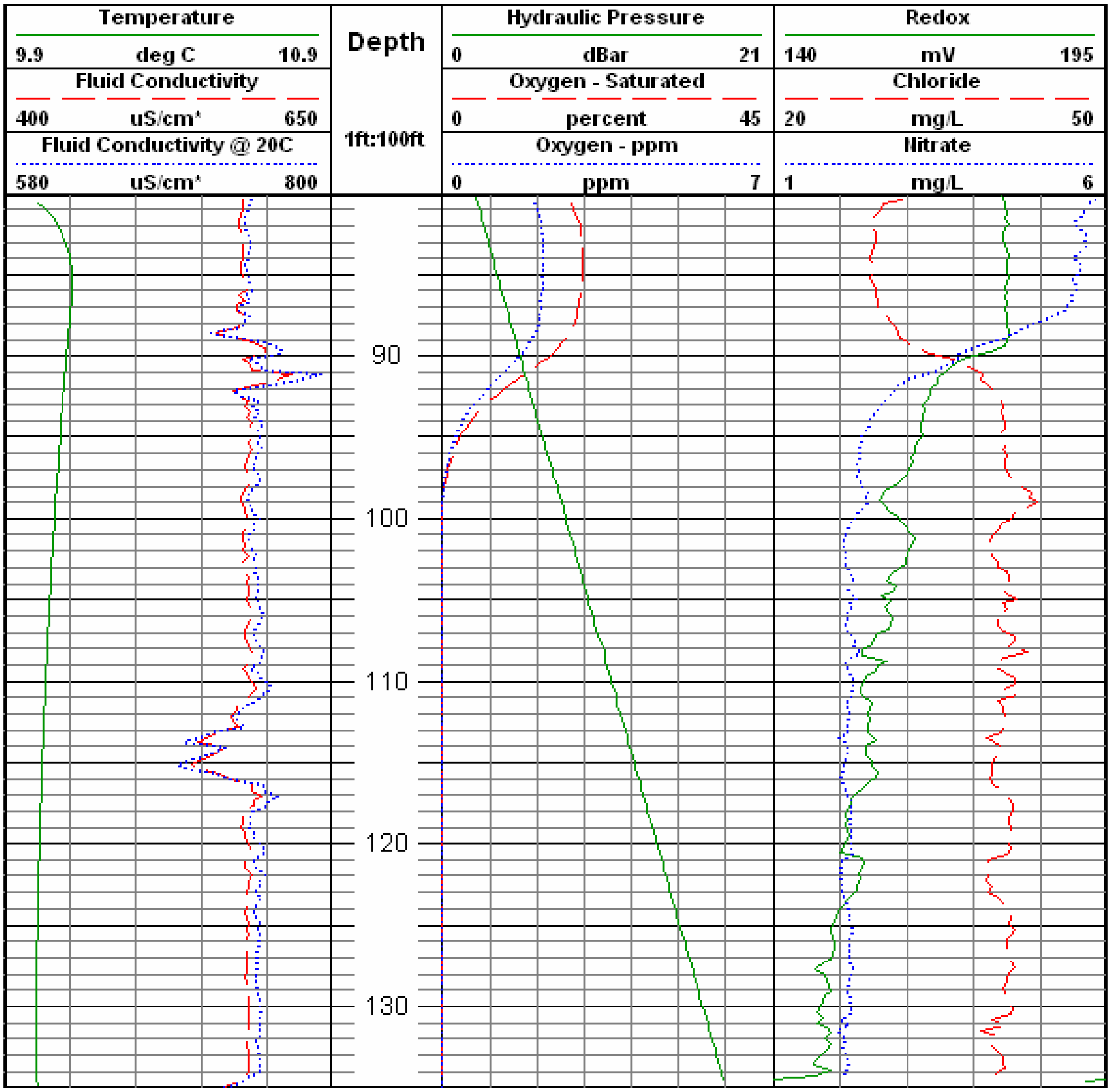

Figure 2: Case study 1 showing initial log acquisition without purging the wellbore.

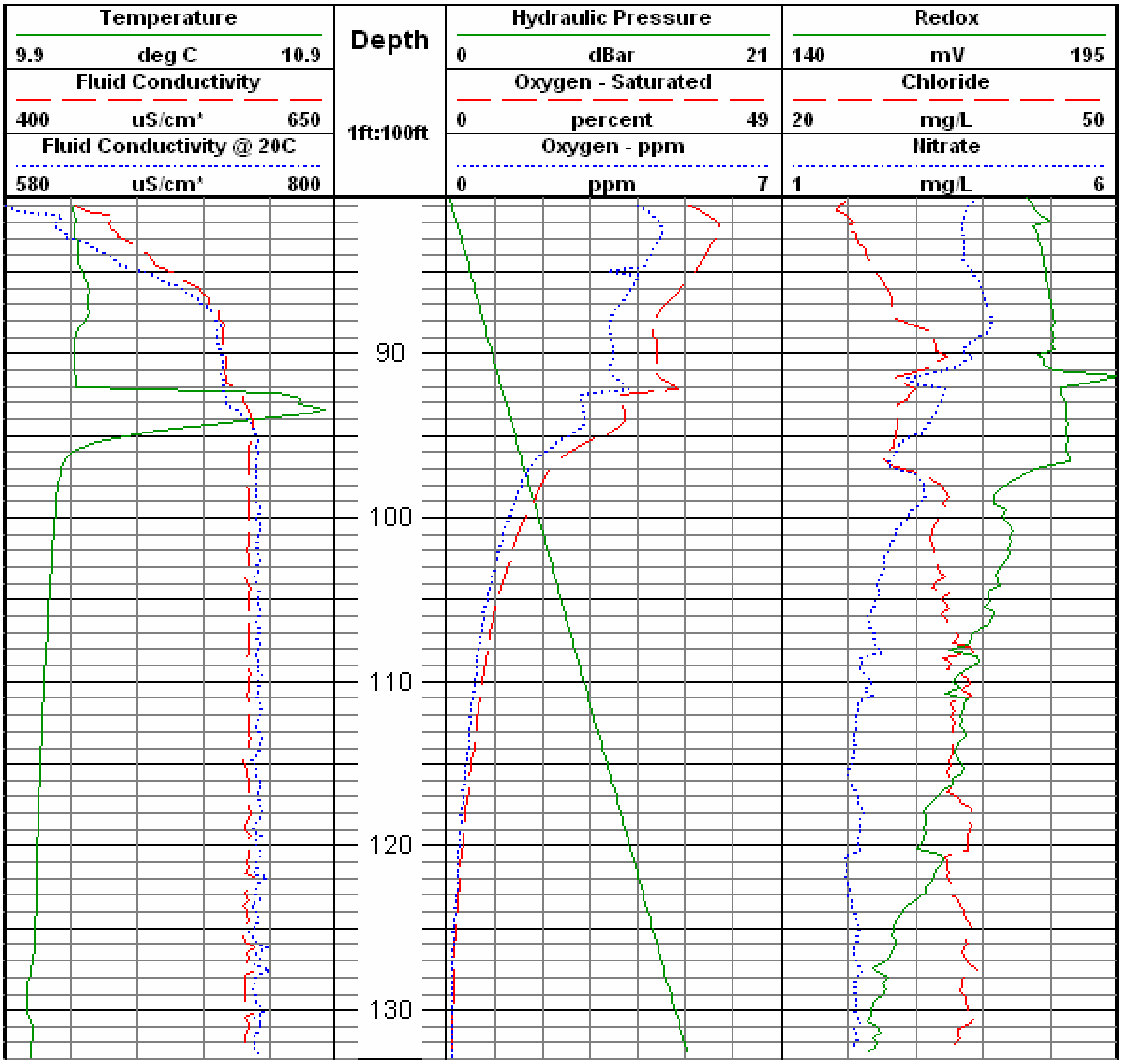

Figure 3: Case study 1 well logged while being pumped at 2 gpm at 85 feet.

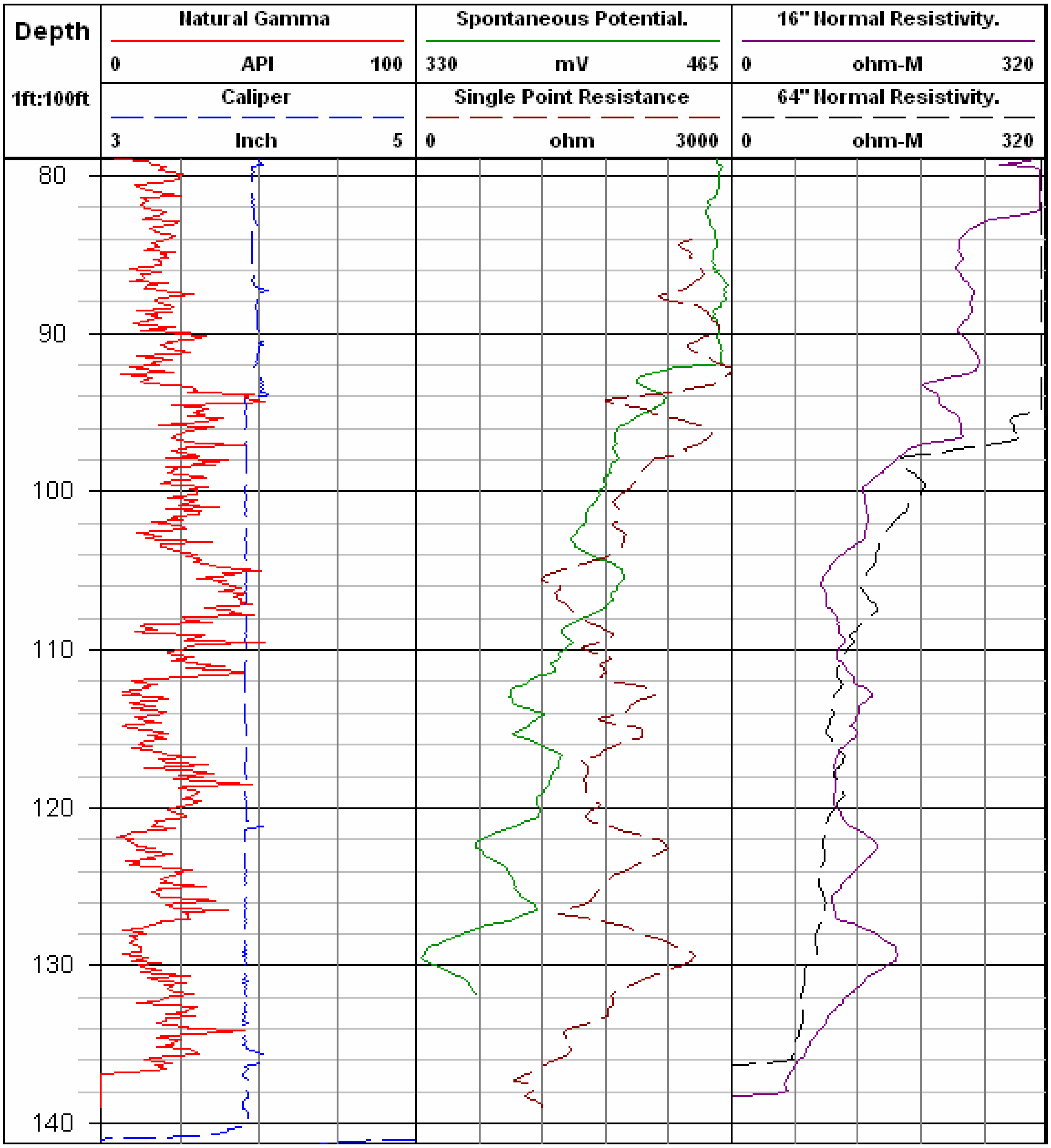

Figure 4: Case study 1 well natural gamma and caliper logs.

Case Study Example 2

Another case study, also located in northern Illinois, involves a well adjacent to an industrial park known to have ground water contamination from various industrial solvents. The well has a diameter of five inches and is cased to 103.5 feet, just below the overburden, and the remainder of the hole is open. In addition to the water quality tool being deployed, an EM flowmeter was later lowered into the well which obtained flow rates at a few specific elevations after the water quality tool was removed. A multi-parameter geologic logging tool was used in addition to the flowmeter and water quality tool to obtain stratigraphic data. Figures 5 and 6 present the data for this case study.

The water quality tool data shows significant changes quite frequently throughout the well. The most significant changes can be seen at depths from 121 feet to 125 feet. Unfortunately, no flowmeter data were collected above this depth (e.g. 121-125) to establish if there is an outflow of fluids near this point. Other significant changes in water temperature are noted at 148 feet, 163 feet and after 172 feet until the end of the hole. Sharp data fluctuations of chloride, redox and ammonia at depths, 163, 171, 181 and 186 are interpreted as being valid supported by temperature and flowmeter data. It is quite possible that these fluctuations may be an indication of where contaminants are intersecting the well.

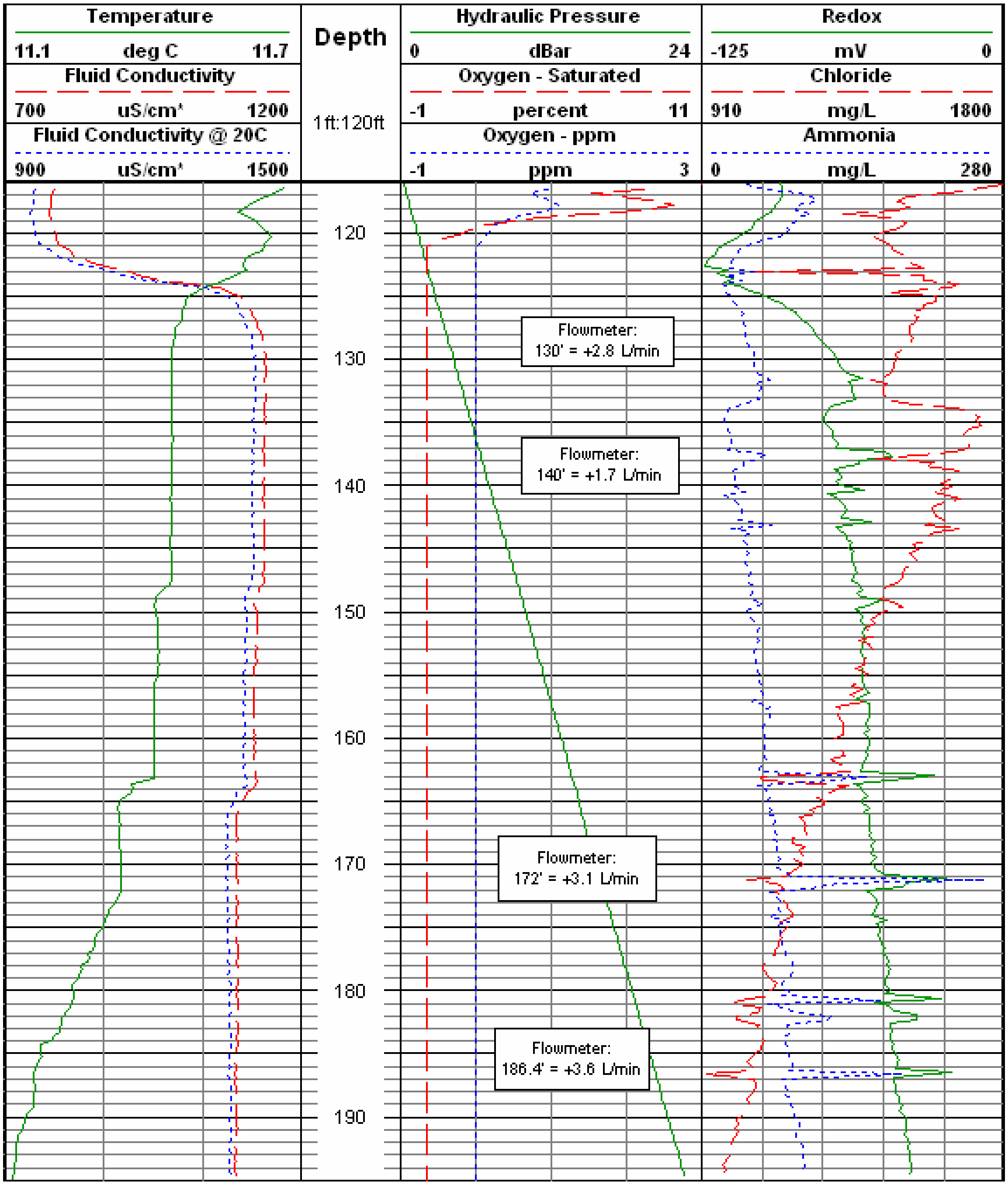

Figure 5: Case study 2 fluid log near industrial park.

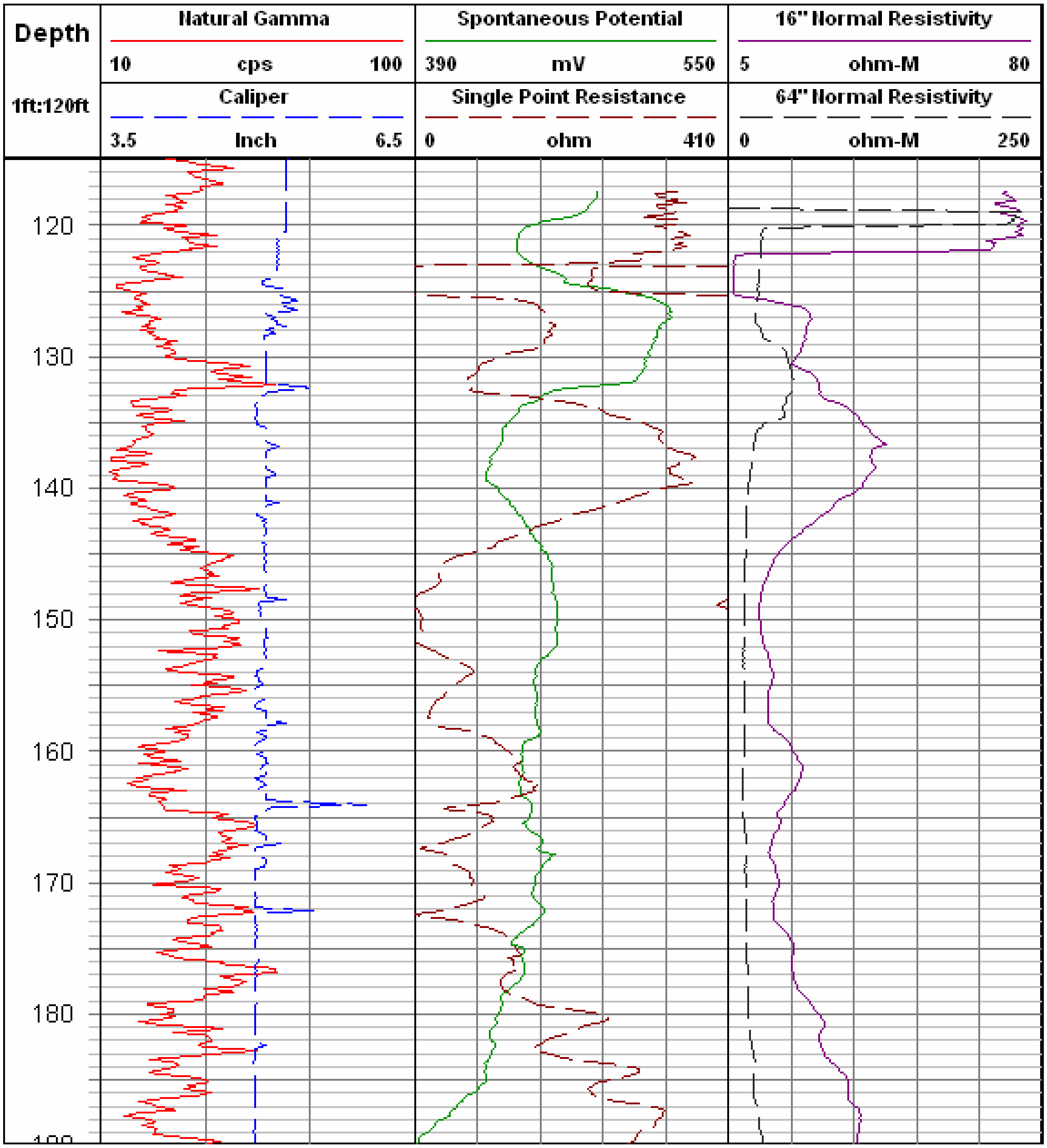

Figure 6: Case study 2 geologic log near industrial park.

Conclusion

A multi-parameter water quality tool capable of withstanding significant head pressures while incorporating fast data response sensors can be a beneficial addition to a logging suite. It may provide in-situ indications of where fluid changes occur in a well, allowing for further sampling or investigation. As with most if not all borehole geophysical tools, no one tool can provide the solution to a complicated environmental water well problem. It often requires gathering a relevant combination of parameters to help a scientist solve a problem. This tool is just another device to aid in evaluating borehole fluids for environmental issues.

Acknowledgments

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Disclaimer

The U.S. Environmental Protection Agency does not endorse or disapprove of the use of this tool. The purpose of the paper is solely to present several data files obtained using the Idronaut 303 tool. Individuals must evaluate the benefits and limitations of this tool with regard to their own applications.