WATER RESOURCES RESEARCH GRANT PROPOSAL

Title: A FIELD ASSESSMENT OF DIRECT-PUSH TECHNOLOGY FOR SITE CHARACTERIZATION INVESTIGATIONS

Project Category: Research/Educational/Extension

Kansas Water Resources Research Institute Funds Requested: $60,235

Kansas Geological Survey Funds Pledged: $150,733

Proposed Duration: July 1, 2000 - June 30, 2002

Keywords: Direct Push, Site Characterization, Hydraulic Tests, Water Sampling, Hydrostratigraphy

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Original Submission: November 1, 1999
Budget Revision: January 6, 2000

Abstract

Groundwater resources currently provide more than 85% of the water used in Kansas. A significant portion of the groundwater that is used for drinking water supplies comes from aquifers consisting of unconsolidated sediments lying in past or present river valleys. Effective management of these important groundwater resources depends on our ability to reliably assess the threat posed by potential sources of contamination (such as leakage from landfills and animal waste lagoons, intrusion of saline river water, etc.). This assessment, however, is only as good as the data on which it is based. Using conventional field methods, large amounts of time and money can be expended without necessarily improving our knowledge of conditions in the unconsolidated alluvial deposits that compose these aquifers. There is a critical need for efficient and scientifically sound methods that will provide the information necessary to reliably

evaluate the severity of contamination threats in a practically feasible manner. In this proposal, we outline a two-year plan of research directed at the development and evaluation of a set of practical site-characterization techniques designed to significantly reduce the uncertainty associated with hydrogeologic investigations. This set of techniques will be based on direct-push methods, an innovative alternative to conventional drilling approaches developed since the mid-1980s for obtaining soil-gas, water, and core samples at sites of groundwater contamination. The major focus of this research will be the development and evaluation of direct-push techniques for the detailed hydraulic, geochemical, and stratigraphic characterization of unconsolidated alluvial deposits. The information obtained from such a detailed characterization is essential for siting waste disposal and storage facilities, designing effective remediation schemes, evaluating the risk posed by existing contamination, and managing stream-aquifer interactions. The end product of this research will be a suite of techniques of demonstrated effectiveness for the hydraulic, geochemical, and stratigraphic characterization of unconsolidated alluvial aquifers. These techniques will form a low-cost, scientifically sound "tool set" that can be utilized by practicing water-resources professionals to address a wide variety of issues relevant to the protection and management of water resources in Kansas.

Technical Plan

Statement of the Problem and Research Need

Currently, groundwater resources provide more than 85% of the water used in Kansas. Many of the important aquifers for drinking water supplies consist of unconsolidated sediments lying in past or present river valleys. Protection of these resources is a matter of highest public concern. The quality of the water in alluvial aquifers can be threatened by contamination via a number of mechanisms, including point-source contamination from sites on the overlying flood plain (e.g., landfills, animal waste lagoons, hazardous waste storage areas, and accidental chemical releases) and intrusion of saline river water (e.g., Arkansas River). Effective management of these important groundwater resources depends on our ability to reliably assess the threat posed by existing and potential contamination. This assessment, however, is only as good as the data on which it is based. Using conventional field methods, large amounts of time and money can be expended without necessarily improving our knowledge of conditions in the subsurface. There is a critical need for efficient and scientifically sound field methods that will enable us to acquire the information necessary to reliably evaluate the severity of contamination threats in a practically feasible manner. The development of such a "tool set" for regulators and practicing water-resources professionals in Kansas is the primary objective of this proposal.

Nature, Scope, and Objectives of Proposed Work

Alluvial deposits are not homogeneous in character. Instead, these deposits are a complex intermingling of lenses of gravel- through clay-sized material. This natural variability (heterogeneity) can seriously confound efforts to predict groundwater flow and contaminant transport. Although a great deal of time and money may be spent using conventional field methods to account for this heterogeneity, the uncertainty regarding how groundwater and its dissolved constituents move at a site can still be very large. In this proposal, we outline a two-year plan of research directed at the development and evaluation of a set of practical site-characterization techniques designed to significantly reduce the uncertainty associated with hydrogeologic investigations. This set of techniques will be based on direct-push methods, an innovative alternative to conventional drilling approaches that has been developed since the mid-1980s for obtaining soil-gas, water, and core samples at sites of groundwater contamination. The major focus of this research will be the development and evaluation of direct-push techniques for the detailed hydraulic, geochemical, and stratigraphic characterization of unconsolidated alluvial deposits. The information that can be obtained from such a detailed characterization is essential for siting waste storage and disposal facilities, designing effective remediation schemes, and evaluating the risks to human health and the environment posed by existing contamination. Although direct-push technology is currently limited to environmental site investigations, it has the potential for much broader application. As a secondary objective of this project, we will attempt to extend the use of direct-push technology to include characterization of stream-aquifer interactions, a key component of the hydrologic budget of many aquifers in Kansas. In the first eighteen months of the project, the primary emphasis will be on methodology development. Work will be concentrated on two existing KGS field areas where a considerable amount of information has been gathered through previous research. The primary emphasis of the final six months will be on demonstration of the methodology at two sites of contrasting hydrogeologic characteristics. The end product of this work will be a “tool set” of direct-push-based, site-characterization techniques that can be used to address a wide range of issues relating to the effective management of groundwater resources in Kansas.

The planned program of research addresses at least two of the Objectives of the State Water Plan. The research most directly addresses Objective 3.1.12, as the technology developed in this work will improve data collection methods that support and help guide water resources management programs in Kansas. The information obtained with these methods will, for example, enable more accurate assessments of the threats posed by groundwater contamination and the possible water-quality impacts of large-scale pumping activities, considerations that are an essential component of any groundwater management program. This research also addresses Objective 3.1.8a, as this technology will lead to better predictions of contaminant movement in alluvial aquifers. Improved predictions will result in, among other things, more effective aquifer remediation strategies and more appropriate placement of waste storage and disposal facilities, both critical issues for efforts to significantly reduce the percentage of contaminated monitoring wells in Kansas.

Related research

In the last decade, direct-push technology has become a widely used alternative to conventional drilling-based approaches for environmental site investigations. The use of this technology has accelerated in recent years because: 1) it provides a faster, cheaper, and more versatile means of subsurface characterization than do traditional drilling-based methods, and 2) regulatory agencies have begun to place an increasing emphasis on more rapid, interactive characterization approaches, such as the expedited site characterization methodology (Benson et al., 1998), for which direct-push methods are well suited. Direct-push methods for groundwater applications developed from the cone penetrometer (CPT) technology employed in geotechnical investigations (e.g., Farrar, 1996). Although conventional CPT equipment has been used in groundwater investigations (e.g., Smolley and Kappmeyer, 1991; Zemo et al., 1994), depth and access limitations, and cost have severely restricted its use (e.g., Tillman and Leonard, 1993). In order to circumvent these restrictions, a hybrid direct-push technology was developed specifically for groundwater investigations. This hybrid technology couples the direct-push capabilities of the CPT with a high-frequency percussion hammer (e.g., Geoprobe Systems, Inc., 1998). This coupling, which is implemented in vehicles that are much lighter and more mobile than traditional CPT truck units, enables the rapid installation of temporary boreholes to depths as great as 100 feet in unconsolidated alluvium without generating drill cuttings and with minimal site disturbance. Until now, use of direct-push methods for groundwater applications has primarily been limited to collection of soil-gas, water, and core samples in support of environmental investigations. This technology, however, has the potential to provide much more. Exploiting the unprecedented access to the subsurface provided by direct-push methods to obtain detailed information about the hydraulic, geochemical, and lithologic characteristics of unconsolidated alluvium for a variety of hydrogeologic applications will be the major focus of this proposal.

Hydraulic conductivity (K) is the parameter that determines how readily groundwater will move through a particular material in the subsurface. Geotechnical engineers have developed a number of empirical relationships for prediction of K from the results of CPT surveys (e.g., Farrar, 1996). Although the information can be obtained quite rapidly, the resulting K estimates should only be considered order of magnitude (at best) estimates of formation K. Recently, a variety of efforts have been made to reduce the uncertainty associated with K estimates obtained from direct-push investigations. These include the performance of constant-drawdown pumping tests (Hurt, 1998; Wilson et al., 1997) and slug tests (Scaturo and Widdowson, 1997) in direct-push equipment, and drive-time injection monitoring (Pithkin, 1998). None of these approaches, however, have met with much success because of equipment limitations and use of inappropriate procedures for the collection and analysis of test data. Although the results are preliminary, some very recent work (Butler et al., 1999b) has shown that performance of hydraulic tests in direct-push equipment can provide K estimates that are in agreement with those obtained from tests in conventional monitoring wells. A major goal of the proposed research is to fully assess the potential of hydraulic tests in direct-push equipment and define a set of practical field guidelines.

For over a decade, direct-push equipment has been used for the collection of groundwater samples (e.g., Tillman and Leonard, 1993). Although routine direct-push sampling protocols have been established, there is still a need to evaluate the capability of these methods for the accurate description of steep vertical gradients in various geochemical parameters (e.g., Farrar, 1996; Puls and Paul, 1997; Pithkin et al., 1999). Additional unanswered questions about the use of this methodology for groundwater sampling include, for example, the relation of the volume of the aquifer sampled with direct-push installations to the volume sampled with a conventional monitoring well, and the degree of cross-contamination created during the installation process. One of the goals of this proposal will be to fully address these questions and assess the applicability of direct-push methods for detailed geochemical characterization.

Logs of the electrical conductivity (or its inverse, resistivity) of a formation have been used for decades in a wide variety of geosciences applications (lithologic delineation, soil salinity surveys, etc). Except for studies within a few feet of the land surface, these logs have been obtained using various sensing tools in conventional wells. Recently, electrical conductivity (EC) sensors have been incorporated into CPT and direct-push equipment (e.g., Christy et al., 1994). The resulting product can provide valuable information about site hydrostratigraphy without the need for an existing well (Butler et al., 1999a). This information can be obtained very rapidly (45 minutes to reach 70 ft (Butler et al., 1999a)) prior to any drilling, and can actually be used to guide subsequent drilling activities (e.g., Benson et al., 1998). Initial work by Butler et al. (1999a) has found that direct-push-based EC sensors are especially useful for locating thin clay layers. These features, which can be difficult to locate using conventional approaches, often play an important role in controlling groundwater flow in alluvial aquifers. One of the goals of the proposed research will be to fully assess the utility of this technology for characterizing the hydrostratigraphy of unconsolidated alluvium.

In summary, although direct-push methods have primarily been used for collection of soil-gas, water, and core samples in support of investigations of groundwater contamination, they have the potential to be used for a wide variety of site-characterization activities relevant to the protection and management of groundwater resources in Kansas. The exploration of that potential, with a particular emphasis on the detailed hydraulic, geochemical, and stratigraphic characterization of unconsolidated alluvium, is the primary focus of this proposal.

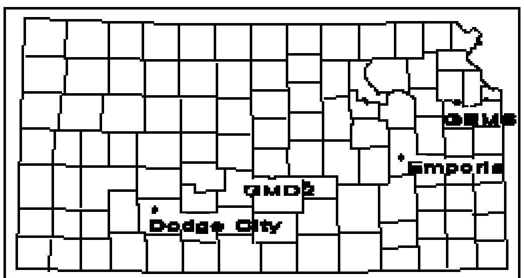


Figure 1. Sites of Proposed Research

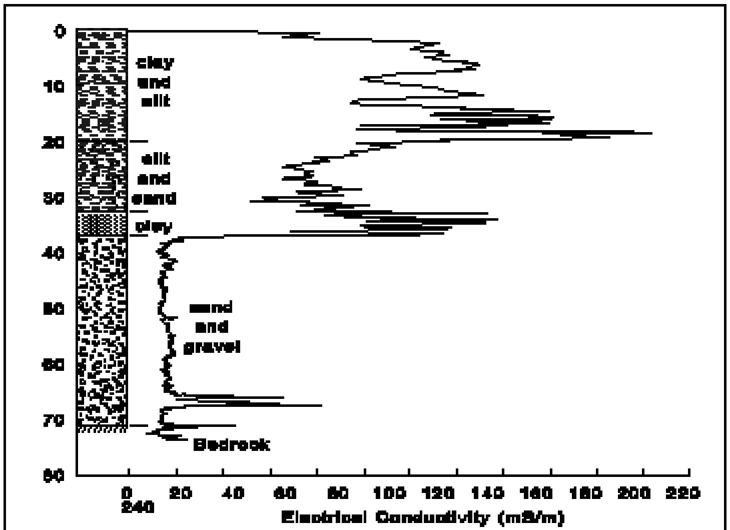


Figure 2. Cross Section of Unconsolidated Sequence at GEMS

Depth from land surface (ft)

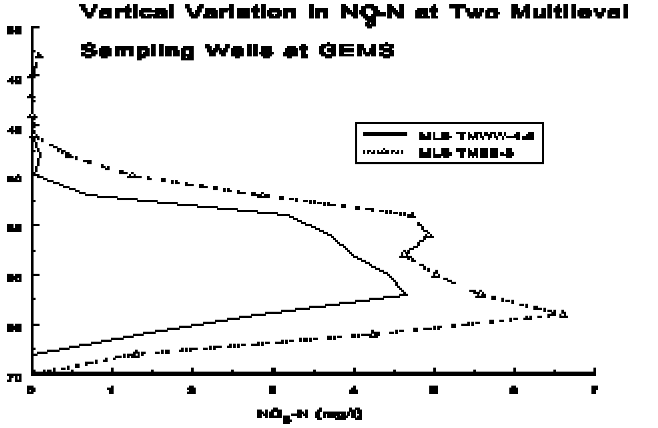
Methods, procedures, and facilities

The proposed plan of research is two years in duration and involves work at four sites in Kansas (Figure 1). In the first eighteen months, the primary focus will be on methodology development at two existing Kansas Geological Survey (KGS) field areas where a considerable amount of previous work has been done. Initial development efforts will mainly be concentrated at the Geohydrologic Experimental and Monitoring Site (GEMS), a KGS research site located just north of Lawrence. Established in the late 1980s, GEMS overlies approximately 70 feet of Kansas River alluvium. These unconsolidated Holocene sediments overlie and are adjacent to materials of Pennsylvanian and Pleistocene age. Figure 2 displays a cross-sectional view of the shallow subsurface at GEMS with electrical conductivity logging data obtained using a direct-push unit, and a geologic interpretation from core and logging data. As shown in Figure 2, the heterogeneous alluvial facies assemblage at GEMS essentially consists of 35 feet of clay and silt overlying 35 feet of sand and gravel. GEMS has been the site of extensive research on flow and transport (e.g., McElwee et al., 1991; Butler et al., 1996, 1998a,b, 1999a,b,c; Bohling, 1998), and spatial/temporal geochemical variability (Macpherson and Schulmeister, 1994; Schulmeister, 1996; Hall, 1998) in heterogeneous formations. This previous work will enable the methodology development to be performed in a relatively controlled field setting.

A major goal of the work at GEMS will be the development of a set of practical guidelines for performing hydraulic tests in direct-push equipment. In the summer of 1999, a series of multilevel slug tests were performed at two wells (4N and 4S - approx. 32 ft apart) screened across the sand and gravel interval. The K estimates obtained from these tests (Figure 3) were in agreement with estimates obtained at the same wells two years earlier with a dipole flow probe (Butler et al., 1998a). A series of slug tests will be performed near these wells using two types of direct-push tools: 1) an exposed screen groundwater profiling tool (variable screen length of up to 10 in) designed for applications where multiple hydraulic tests/water samples are to be performed/collected as the tool is driven to successively deeper parts of the aquifer; and 2) a protected (or shrouded) screen groundwater sampling tool (screen length up to 40 in) designed to be driven to a single depth at which a hydraulic test is performed or a groundwater sample collected. Installation and slug-test protocols will be developed to assess the conditions under which K estimates from slug tests in direct-push tools are in agreement with those from the neighboring wells. In addition to the testing in the sand and gravel interval, slug tests will be performed in the silt-sand interval of Figure 2. In this case, particular attention will be placed on the definition of well-development guidelines to ensure that low-K well skins are not severely impacting slug test estimates.

An extensive network of multilevel sampling wells (MLSs) was installed in the sand and gravel interval at GEMS in the spring of 1994. These MLSs consist of bundles of small-diameter (<5 mm ID) polyethylene tubing, with each tube of the bundle terminating at a different depth (vertical spacing is 1.0 or 2.0 ft). The open-ended tubes sample discrete, narrow horizons within the sand and gravel interval, and have been used to identify vertical profiles of NO_3 (Figure 4) and SO_4 at GEMS (Hall, 1998). Recent data (Schulmeister, unpublished data) demonstrate that dissolved oxygen, Eh, and pH also vary with depth in this same interval. These well-constrained chemical profiles provide a baseline against which direct-push chemical profiling methods can be tested. At least three geochemical profiles will be obtained using the direct-push profiling tool described earlier. These profiles will be compared to those constructed from adjacent MLSs in order to evaluate the capability of direct-push methods to resolve vertical chemical gradients. The shrouded-screen tool described earlier will be used to take a series of groundwater samples in an interval in which an adjacent MLS indicates significant vertical changes in geochemistry. The tool will be set at a given depth and a series of samples will be collected as the shroud is pushed back in a series of steps, gradually increasing the length of the exposed screen. Comparison of samples obtained from MLSs, direct-push profiling, and fixed depth sampling with multiple screen lengths will enable us to evaluate the sampling volume and likelihood of cross-contamination for direct-push sampling methods.

Figure 4
Vertical Variation in NO_3-N at Two Multilevel Sampling Wells at GEMS



Results of direct-push electrical conductivity (EC) logging recently done at GEMS (Figure 2) indicate that this approach has great potential for rapid delineation of site hydrostratigraphy (Butler et al. 1999a). The specific conductance of the water at GEMS does not vary significantly in the alluvial sequence, so the EC log is assumed to primarily record conductivity changes produced by lithology differences. In order to assess the viability of that assumption at GEMS and the scale of stratigraphic features that can be observed with the EC log, a series of core samples will be taken to the base of the clay unit using direct-push equipment. The lithologic descriptions of these samples will be compared to a nearby EC log. A profile of the specific conductance of pore fluid in the saturated portions of this interval will also be collected, so that conductivity changes produced by variations in water chemistry can be considered. This work should allow the resolution, accuracy, and advantages/limitations of direct-push EC logging to be evaluated.

The development work at GEMS should result in a set of preliminary guidelines for hydraulic, geochemical, and lithologic characterization using direct-push methods. Beginning late in the first year of the project, these guidelines will be refined for systems with a significant component of stream-aquifer interactions at a second KGS field site near Dodge City. The Dodge City site was established by the KGS in 1998 as part of a Kansas Water Office study of the upper Arkansas River (Whittemore et al., 1999). The site, which is 1/4 mile south of the Arkansas River just west of Dodge City, consists of four wells screened over different vertical intervals in the alluvial and underlying High Plains aquifers. Figure 5 displays the vertical contrast in specific conductance and total dissolved solids observed at the site as a result of the movement of saline river water into the alluvial aquifer. Although a thin clay layer is assumed to be responsible for the dramatic vertical contrast, this layer is not observable using conventional borehole geophysics probes. Given the high conductance water and the assumed clay layer, this site will be an excellent location to evaluate the potential of direct-push EC logging for lithologic description, especially the identification of thin clay layers, in the presence of high conductance water. Prior to the work at Dodge City, a series of controlled experiments will be performed using 55-gallon drums packed with sand and/or clay, and sequentially filled with waters of increasing specific conductance. EC logs will be run in a drum packed with sand only and one packed with two sand layers separated by a clay layer. These experiments will enable us to better understand the nature of EC responses in alluvial sequences with high conductance waters. We will use the results of these experiments and the work of Mack (1993) to devise a protocol for differentiating the EC response to high-conductance water from that due to the presence of a clay layer. This protocol will involve combining information from the EC logging with that from a small-diameter natural gamma probe run inside the direct-push equipment and with groundwater specific conductance data obtained from geochemical profiling performed concurrently with the EC logging. The protocol will be tested in a series of direct-push surveys at the Dodge City site conducted at several locations along a traverse oriented perpendicular to the Arkansas River. The traverse will extend from immediately adjacent to the river to over 1/2 mile away. Direct-push hydraulic tests will be used to supplement the stratigraphic information obtained from the EC logging. The results of this traverse will be used to demonstrate how direct-push EC logging and hydraulic tests can provide a very rapid means of defining the nature of stream-aquifer interactions when there is a large contrast in specific conductance between the water of the river and that of the aquifer. Four additional wells will be drilled between the present site and the Arkansas River, and water levels and stream-stage fluctuations will be monitored. A recently developed analytical solution (Butler and Tsou, in prep.) will be used to predict how water levels in the alluvium should respond to stream-stage fluctuations based on the information from the direct-push survey. The comparison between the predicted and measured responses will be used to assess the validity of the predictions based on the direct-push methods.

The primary focus of the final six months will be on methodology demonstration at two new sites in interconnected stream-aquifer systems. These sites were chosen so that the "tool set" developed at GEMS and Dodge City can be tested in contrasting hydrogeologic settings. One site will be located along the Arkansas River in Ground Water Management District #2 (GMD2) on alluvial deposits composed of coarse sand and gravel separated by less-frequent intervals of clay and silt. This site will be established in cooperation with Mike Dealey, the manager of GMD2, and will be in close proximity to existing well nests. A second site will be established in the Neosho River valley near Emporia on land owned and managed by Emporia State University. In contrast to the GMD2 site, the site at Emporia primarily consists of clay and silt with less frequent intervals of sand and gravel. At both sites, intensive direct-push surveys will be performed to characterize the hydraulic, geochemical, and lithologic characteristics of the alluvial sediments. The application of the "tool set" to these contrasting settings should enable us to better understand the strengths and weaknesses of the proposed methodology.

We have assembled a team of researchers well suited to perform all phases of the proposed work. The core team of researchers consists of the two PIs (Butler and Zheng), a half-time post-doctorate researcher (Schulmeister), and a field hydrogeologist (Healey). All four have considerable experience with direct-push equipment as a result of previous research cooperation with a manufacturer of direct-push equipment (Butler et al., 1999a, b) and Schulmeister's half-time position at the Kansas Department of Health and Environment (KDHE). Butler has a great deal of experience in both the theoretical and practical aspects of hydraulic testing (e.g., Butler, 1997; Butler and Healey, 1998). Zheng, a recent Ph.D. from the University of Notre Dame, is very experienced in geostatistics and the performance of controlled laboratory experiments in constructed aquifers. Schulmeister's doctoral research has focussed on the evaluation of spatial and temporal variations in groundwater chemistry at GEMS. Healey, the KGS field hydrogeologist and a licensed well driller, has a great deal of practical experience in all phases of the proposed research. Although this group of researchers is highly qualified to work on methodology development at GEMS, they have less experience with the hydrogeologic settings at the Dodge City site and the two demonstration areas. Thus, additional cooperators will assist at these sites. Don Whittemore will assist in the interpretation of information from the Dodge City and GMD2 sites. Whittemore has worked along the Arkansas River between Wichita and the Colorado border for many years and has extensive experience at both sites. The doctoral dissertation of our Emporia State cooperator, Richard Sleezer, has focussed on the soils and near-surface hydrogeology of a portion of GMD2, so he and Margaret Townsend, a KGS water chemist with extensive experience in central Kansas, will assist Whittemore in the interpretation of information from the GMD2 site. Sleezer and Townsend will also assist in the interpretation of information from the Emporia site.

The KGS owns a trac-mounted direct-push unit (Geoprobe Systems, Inc. – Model 66DT) with an electrical conductivity logging system. Given our past experience with this equipment, we anticipate no problems in reaching the depths required for this study at all sites. The KGS has all the equipment needed for the proposed work (e.g., dataloggers, laptop computers, peristaltic pumps, etc.). All chemical analyses for this project will be done either in the field or at the analytical laboratories of the KGS.

Information transfer plan

The results of this work will be disseminated using three mechanisms: 1) short courses for regulators and practicing professionals; 2) presentations at local, regional, and national scientific meetings; and 3) articles in the peer-reviewed literature. In early May of 1999, Butler and Healey presented a one-day course on slug-test technology to personnel of the Remedial Section of KDHE. This course, which had field, lecture, and data analysis sections, was favorably received by attending personnel. We propose a similar one-day course to disseminate the results of the current project to KDHE and, if sufficient interest, Division of Water Resources personnel. A similar mechanism could be use to disseminate the results to practicing professionals (e.g., Butler and Healey, 1999). The results will be presented at scientific meetings ranging from the American Institute of Hydrology meeting in Topeka to the Water in the Future of Kansas meeting in Manhattan to national meetings of the relevant scientific organizations. The results will also be presented in the scientific journals most frequently read by practicing hydrogeologists (e.g., *Ground Water* and *Ground Water Monitoring and Remediation*).

In addition to the educational components of the above activities, a summer student will be trained as part of this project. The student will be a participant in the Applied Geohydrology Summer Research Assistantship program of the KGS. This program is not limited to students at the University of Kansas (KU), students from any university may participate. Sleezer is a full-time faculty member at Emporia State University (ESU) and will incorporate the research results into his classes. The other members of the team will be available for guest lectures at KU, ESU and the other Regents institutions.

Statement of Anticipated Results and Benefits

The end product of this research will be a suite of techniques of demonstrated effectiveness for the hydraulic, geochemical, and stratigraphic characterization of unconsolidated alluvium. These techniques will form a low-cost, scientifically sound "tool set" that can be utilized by practicing water-resources professionals to address a wide variety of issues relevant to the protection and management of water resources in Kansas. Specifically, there are four expected results of this work: 1) the definition of practical field guidelines for the performance of hydraulic tests in direct-push equipment;

2) the refinement of existing field guidelines for geochemical sampling in direct-push equipment; 3) the definition of a practical field protocol for lithologic delineation using direct-push EC logging in the presence of high-conductance water; and 4) the development of practical direct-push-based strategies for the characterization of stream-aquifer interactions.

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