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Nebraska Grout Task Force In-Situ Study of Grout Material 2001 - 2006 and 2007 Dye Tests

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NEBRASKA GROUT TASK FORCE

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by

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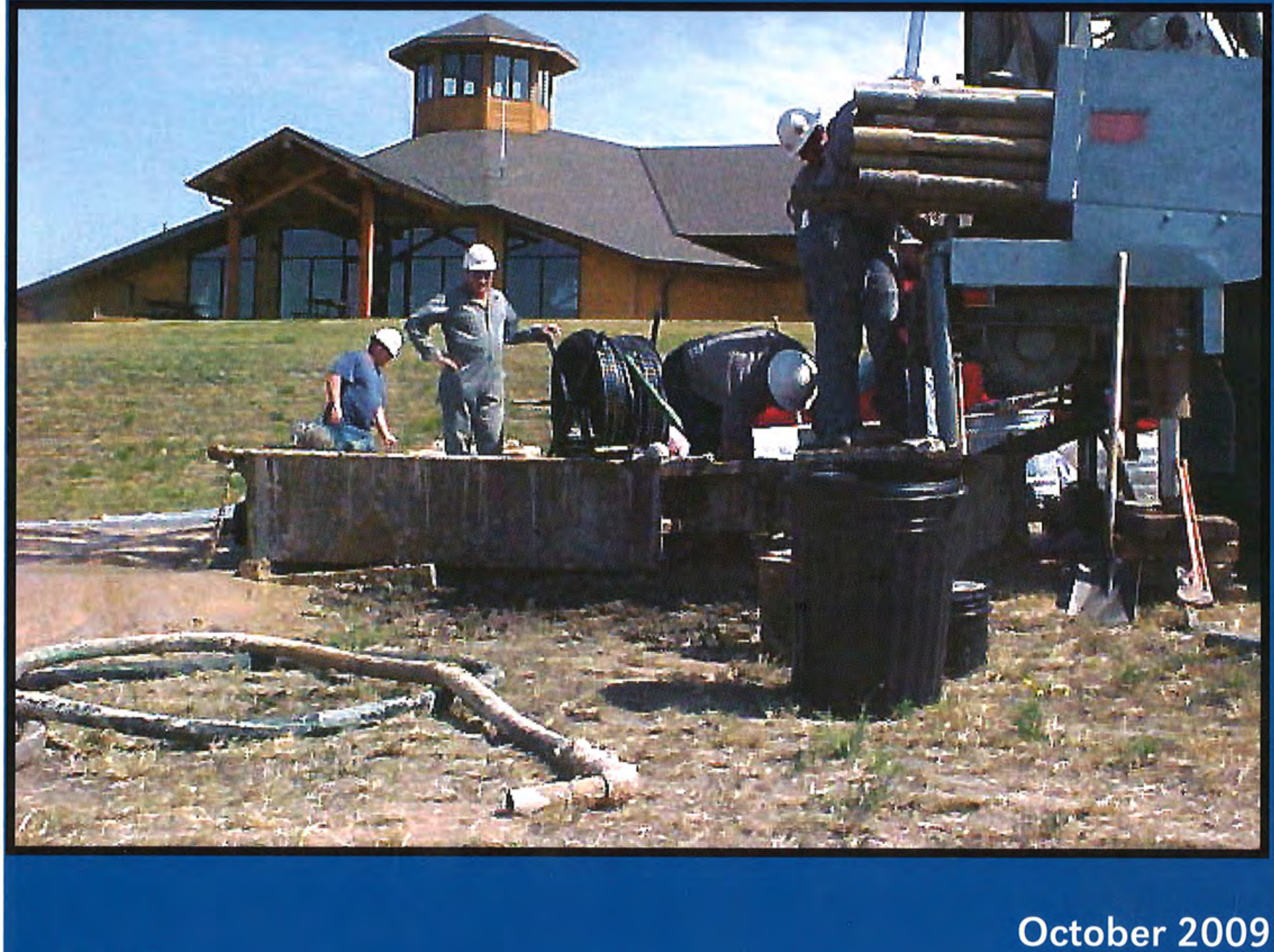

October 2009

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Conservation and Survey Division, School of Natural Resources
Institute of Agriculture and Natural Resources
University of Nebraska–Lincoln

NEBRASKA GROUT TASK FORCE

In-Situ Study of Grout Materials 2001-2006
and
2007 Dye Tests

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The Conservation and Survey Division of the University of Nebraska–Lincoln is the agency designated by statute to investigate and interpret the geologically related natural resources of the state, to make available to the public the results of these investigations, and to assist in the development and conservation of these resources. It consists of program areas in geology, water, soils, and remote sensing-geographic information systems.

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Front cover: Installing geothermal heat loops and clear access casing in grout observation installations at Lake McConaughy. Clear access casing is visible above the drill rods to the right of the driller. The driller's helper is feeding the black loop pipe into the borehole as it is being unrolled from the reel.

Back cover: Geothermal heat loop installation at Lake McConaughy. Black tubes on left are loop pipes. Hose on right is a tremie pipe used to place grout. Pipe with white cap is clear access casing.

R.F. Diffendal, Jr., Editor
Dee Ebbeka, Cartography and Design

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ABSTRACT

Grouts are intended to provide an annular seal that prohibits movement of surface contaminants through this space over extended periods of time. The Nebraska Grout Task Force (NGTF) conducted an in-situ study of the stability of grout materials in northeast, central, and southwest Nebraska after investigators observed cracks and voids in the grout column of a well constructed with clear PVC casing. The Technical Team made these observations using a down-hole video camera 16 months after the well was constructed. Between 2002 and 2004, the team installed 63 grout observation wells using clear polyvinyl chloride (PVC) casing. Grout materials included bentonite slurry, bentonite chip, geothermal bentonite slurry, and cement-based grouts. The team performed down-hole video camera surveys several times on each well over a two-year period culminating with dye tests in each well.

The two-year study of bentonite slurry grouts, completed in 2005, confirmed that sediment particle size and moisture content have the largest impact on the stability of these grouts. Dye test results from the NGTF expanded study indicated that hydrogeologic conditions in southwest Nebraska had the worst impact on these grouts. This site is in the semi-arid climatic zone where the unsaturated zone sediments are dominated by silt-sized particles. Conditions at the central site had the least impact on bentonite slurry grout. The sediments there are mainly sand-sized particles and the area is in the subhumid zone.

The Technical Team used the percentage of the unsaturated zone penetrated by dye to rate the performance of each grout, with the lowest percentage indicating the best performance. The results indicate that sand-cement and bentonite chip grouts performed the best with 24% and 27%, respectively. Results for the other cement-based grouts were between 37% and 48%. The bentonite slurry with more than 20 percent solids and the geothermal grout with sand results were 65% and 67%. The bentonite slurry with 20 percent solids results indicated that 75% of the unsaturated zone was penetrated. These data suggest that bentonite slurry with less than 20 percent solids and geothermal grout without sand performed the worst with 86% and 87%, respectively.

1.0 INTRODUCTION

1.1 Background

In October of 1999, representatives from the Nebraska Well Drillers Association, Nebraska Department of Health and Human Services, University of Nebraska-Lincoln Conservation and Survey Division, Baroid Industrial Drilling Products, and Design Water Technologies constructed a water well with transparent casing and screen to use in an educational program. The goal of the program was to provide state and local agency personnel with a working knowledge of well design, construction, and development. The transparent casing and screen were clear enough to allow a down-hole camera to provide a view of the placement of sand filter pack and bentonite sealing materials. The down-hole videos recorded during the two-day course indicated that the materials reacted as predicted.

Technicians performed a down-hole camera survey on the well 16 months after the initial installation. The data collected showed that the grout column contained cracks and voids that could potentially allow for surface contaminants to move through the grout and into the groundwater. The alterations in the grout had previously not been noted and warranted further study to determine if alteration was occurring in other well installations. In June 2001, the Nebraska Grout Task Force (NGTF), which included representatives from the Nebraska Department of Health and Human Services (NDHHS) the Nebraska Well Drillers Association (NWDA), the Conservation and Survey Division of the University of Nebraska–Lincoln (CSD), the Nebraska Department of Environmental Quality (NDEQ), and from grout industry suppliers Baroid, Cetco, and Wyo-Ben, Inc., was formed to consider administrative, fiscal, and technical issues related to investigating these alterations further.

The NGTF originally developed this project to study in-situ bentonite grouts over a two-year period to assess state regulations related to minimum percent solids requirements and to observe the nature and possible alteration of grout material under varying geologic and hydrologic conditions. Wells were constructed with bentonite slurry grouts containing less than 20, equal to 20, and greater than 20 percent solids and observations and assessments were then made.

1.2 Project Expansion

In 2003, after the Technical Team performed a part of the site monitoring, it became evident to the members that the bentonite slurry grouts did not perform as expected in the unsaturated zone. Therefore, the NGTF decided to expand the project. First, the task force decided to test all grouts approved by the State of Nebraska, which increased the number of grout observation well installations to a total of 63. The results of this expanded study are presented in this circular. Secondly, the NGTF decided to support a study to provide detailed analyses of the physical and chemical properties of the unsaturated zone and to compare these analyses to the nature of the bentonite slurry grout observed in the 90-day down-hole camera surveys. The results of this study were reported in August 2005 as a University of Nebraska master of science thesis by Will F. Myers entitled "Water Well Annular Seal Conditions and Stratigraphic Characteristics of the Unsaturated Zone: Case Studies from Nebraska".

In 2007, the Technical Team performed follow-up dye tests on all grout observation installations. These tests were designed to compare results to the original dye tests and to obtain a 24-hour inspection of all grouts that were included in the study. The results of these comparisons are also included in this circular.

2.0 PROJECT DESIGN AND FIELD PROCEDURES

2.1 Study Site Selections

The NGTF selected three locations across Nebraska for in-situ testing of grout materials to target variable climatic conditions and geologic sequences in which to analyze grout materials in environments that are common in Nebraska (Fig. 1; Pilger, Grand Island, and Trenton). In order to minimize project costs, the NGTF established a maximum observation well depth. Each site had to be capable of producing domestic quantities of water, 2 to 10 gallons per minute, from a maximum depth of 100 feet. The NGTF later expanded the number of study sites to five (Fig. 1; Maskenthine and Lake McConaughy) due to the expansion of the project to include functioning geothermal heat loop installations.

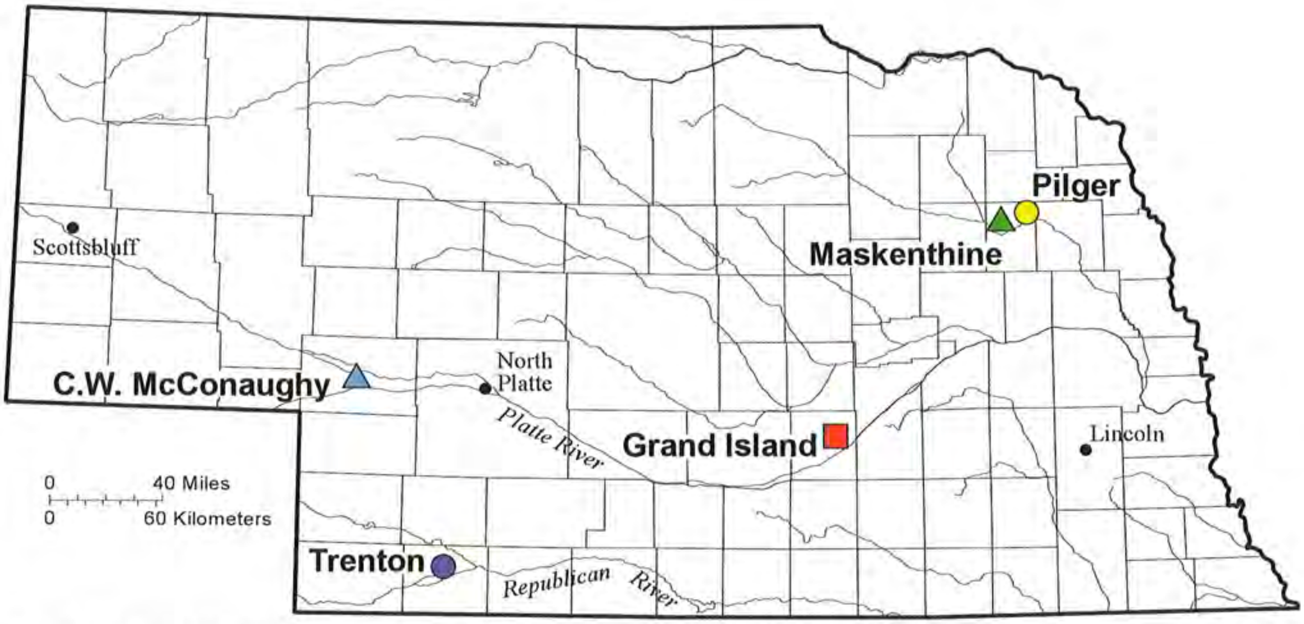

Figure 1. Location of grout study sites. Sites shown with a circle used bentonite slurry, bentonite chip and cement grout products; site shown with a square used bentonite slurry, bentonite chip, cement and bentonite thermal grout products; sites shown with a triangle used only bentonite thermal grout products.

The Technical Team performed site evaluations to ensure that each site met the specified criteria and that no man-made or abnormal natural contaminants existed. The evaluations included test drilling, sediment analyses, water analyses, and installation of a water table well on each of the five sites.

2.2 Grout Observation Well Drilling and Construction

The Technical Team designed the grout observation wells to replicate domestic well installations most typically constructed in Nebraska with the exception that full length grout was specified. The wells were spaced approximately 50 feet apart, depending on site access. The three participating industry suppliers provided the grouting materials, drilling fluid products, clear casing, couplers, clear screens, centralizers, and end caps. NDHHS supplied flush-mount covers, J-plugs, locks, and dye tube assemblies. The NGTF Technical Team provided field documentation of the drilling and installation operations. The drilling process was designed to provide optimum borehole gauge and stability. Minimum standards were required for all drilling and well construction equipment. Figure 2 depicts a generic grout observation well diagram.

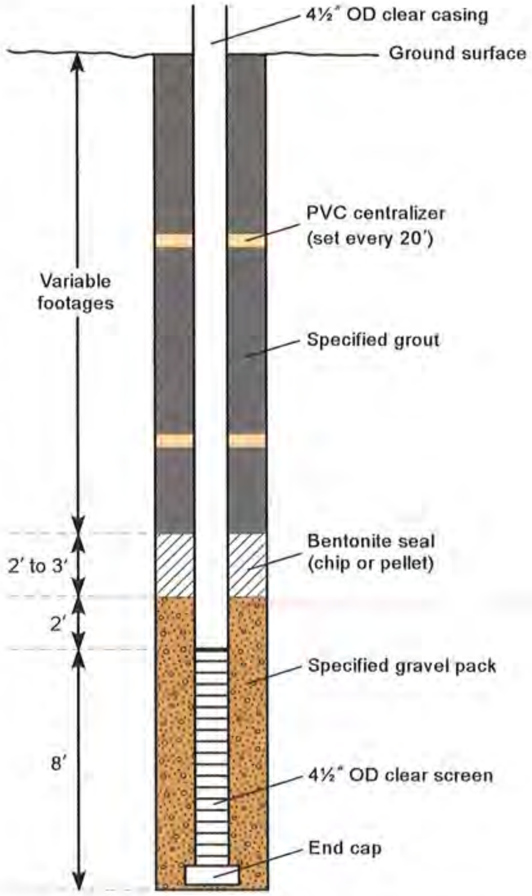

Figure 2. Diagram of grout observation well.

The observation well boreholes were 9 to 10 inches in diameter and sufficiently straight to allow for installation of the casing and the 1-inch tremie pipe required for grout placement. Optimum drilling fluid properties were a maximum density of 9 pounds per gallon, a minimum Marsh Funnel viscosity of 40 seconds per quart, a maximum sand content of 2 percent by volume, a maximum fluid loss of 15 cubic centimeters, and a pH between 8.5 and 9.5. These optimum fluid properties were adjusted based on individual site geology.

For all installations except heat loops, the 4.5-inch outside diameter (OD) Schedule 40 clear casing and slotted screen were installed in the boreholes at the target depths (Fig. 3). Centralizers were set every 20 feet. Gravel pack was poured or tremied into the annulus from the bottom of the borehole to about 2 feet above the top of the screen. The top of the filter pack was tagged with a weighted tape to ensure proper placement. A 2- to 3 feet, ⅜″ chip bentonite seal was placed above the filter pack. Then the specified grout was placed above the seal according to NGTF's specifications.


Figure 3. Installation of clear PVC casing with tremie pipe.

For the geothermal heat loop installations the borehole was 10 to 10.5 inches in diameter to allow for installation of the loop pipes, the clear access casing, and the tremie pipe required for grout placement. Geothermal heat loop variations included installation of the ¾″ loop pipes and a 2⅞″ OD clear access casing for down-hole viewing. Figure 4 shows the design of the geothermal heat loop installations.

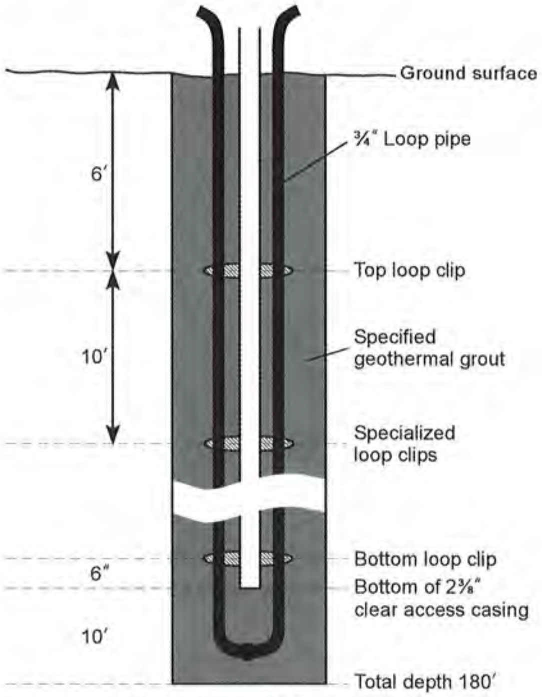

Figure 4. Geothermal heat loop diagram.

2.3 Grout Materials and Installation Details

A total of 63 grout observation wells were installed over a three year period. The Technical Team specified that the wells constructed the first year use full length bentonite slurry grouts with variable percent solids content. During the second year bentonite chip grouts were specified for the Pilger, Grand Island, and Trenton sites. Geothermal bentonite grout and geothermal bentonite grout containing sand were installed in heat loop fields at the Maskenthine, Grand Island, and Lake McConaughy sites that same year. The Technical Team used cement-based grouts as the sealing material in the grout observation wells constructed the third year. These wells were installed at the Pilger, Grand Island, and Trenton sites. Figures 5 through 9 show the locations of the grout observation wells and the water table wells at each of the five sites. Tables 1 through 5 outline the construction details of the observation wells at each site.

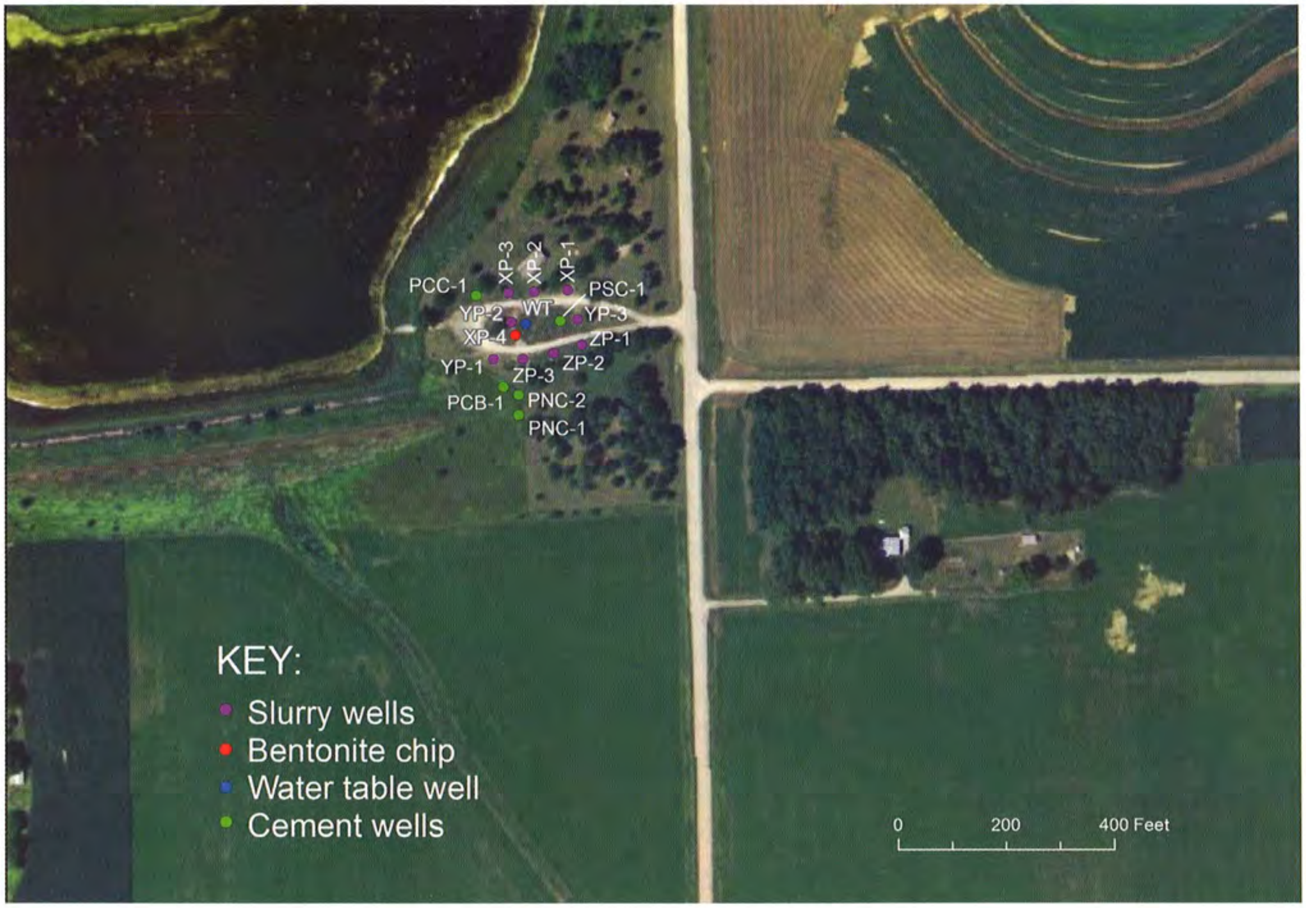

Figure 5. Well locations at the Pilger study site.
Aerial photography: USDA Farm Service Agency, 2003.

TABLE 1
CONSTRUCTION DETAILS OF GROUT OBSERVATION WELLS AT THE PILGER SITE

Well ID	Date installed	Bit size	Grout interval	Grout type	Specified grout
		In	Ft bgs		
XP-1	12/03/02	8.5	0 - 63	Bentonite	< 20% solids
XP-2	12/04/02	8.5	0 - 53	Bentonite	= 20% solids
XP-3	12/05/02	8.5	0 - 51	Bentonite	> 20% solids
YP-1	1/03/03	8.5	0 - 51	Bentonite	= 20% solids
YP-2	1/04/03	8.5	0 - 65	Bentonite	> 20% solids
YP-3	1/05/03	8.5	0 - 65	Bentonite	> 20% solids
ZP-1	12/16/02	8.5	0 - 51	Bentonite	< 20% solids
ZP-2	12/17/02	8.5	0 - 60	Bentonite	= 20% solids
ZP-3	12/18/02	8.5	0 - 65	Bentonite	> 20% solids
XP-4	7/24/03	10	2 - 61	Bentonite	Chip
PNC-1	10/11/04	9	0 - 58	Cement	Neat 7 gal H_2O
PNC-2	10/12/04	9	0 - 58	Cement	Neat 6 gal H_2O
PCB	10/12/04	9	0 - 56	Cement	Bentonite
PSC	10/13/04	9	0 - 56	Cement	Sand
PCC	10/13/04	9	0 - 40	Cement	Concrete

Figure 6. Well and loop locations at the Maskenthine study site.
Aerial photography: USDA Farm Service Agency, 2003.

TABLE 2
CONSTRUCTION DETAILS OF GROUT OBSERVATION LOOPS
AT THE MASKENTHINE SITE

Well ID	**Date installed**	**Bit size**	**Grout interval**	**Grout type**	**Specified grout**
		In	**Ft bgs**		
XM-5	10/17/03	9.5	0 - 180	Geothermal-sand	60%
XM-6	10/18/03	9.5	0 - 180	Geothermal	20%
YM-5	10/15/03	9.5	0 - 180	Geothermal-sand	60%
YM-6	10/16/03	9.5	0 - 180	Geothermal	20%
ZM-5	10/13/03	9.5	0 - 180	Geothermal-sand	60%
ZM-6	10/14/03	9.5	0 - 180	Geothermal	20%

Figure 7. Well and loop locations at the Grand Island study site.
Aerial photography: USDA Farm Service Agency, 2003.

TABLE 3
CONSTRUCTION DETAILS OF GROUT OBSERVATION INSTALLATIONS AT THE GRAND ISLAND SITE

Well ID	Date installed	Bit size	Grout interval	Grout type	Specified grout
		In	Ft bgs		
XG-1	11/19/02	8.5	0 - 45	Bentonite	< 20% solids
XG-2	11/20/02	8.5	0 - 45	Bentonite	= 20% solids
XG-3	11/20/02	8.5	0 - 45	Bentonite	> 20% solids
YG-1	11/23/02	8.5	0 - 45	Bentonite	= 20% solids
YG-2	11/24/02	8.5	0 - 45	Bentonite	> 20% solids
YG-3	11/24/02	8.5	0 - 45	Bentonite	> 20% solids
ZG-1	11/21/02	8.5	0 - 45	Bentonite	< 20% solids
ZG-2	11/22/02	8.5	0 - 46	Bentonite	= 20% solids
ZG-3	11/22/02	8.5	0 - 45	Bentonite	> 20% solids
ZG-4	7/21/03	10	2 - 52	Bentonite	Chip
GNC-1	10/04/04	9	0 - 42	Cement	Neat 7 gal H_2O
GNC-2	10/05/04	9	0 - 40	Cement	Neat 6 gal H_2O
GCB	10/06/04	9	0 - 42	Cement	Bentonite
GSC	10/05/04	9	0 - 43	Cement	Sand
GCC	10/07/04	9	0 - 44	Cement	Concrete
XG-5	9/26/03	9.5	0 - 175	Geothermal-sand	60% solids
XG-6	9/27/03	9.5	0 - <200	Geothermal	20% solids
YG-5	9/24/03	9.5	0 - 200	Geothermal-sand	60% solids
YG-6	9/25/03	9.5	0 - 200	Geothermal	20% solids
ZG-5	9/22/03	9.5	0 - <200	Geothermal	20% solids
ZG-6	9/23/03	9.5	0 - <200	Geothermal-sand	60% solids

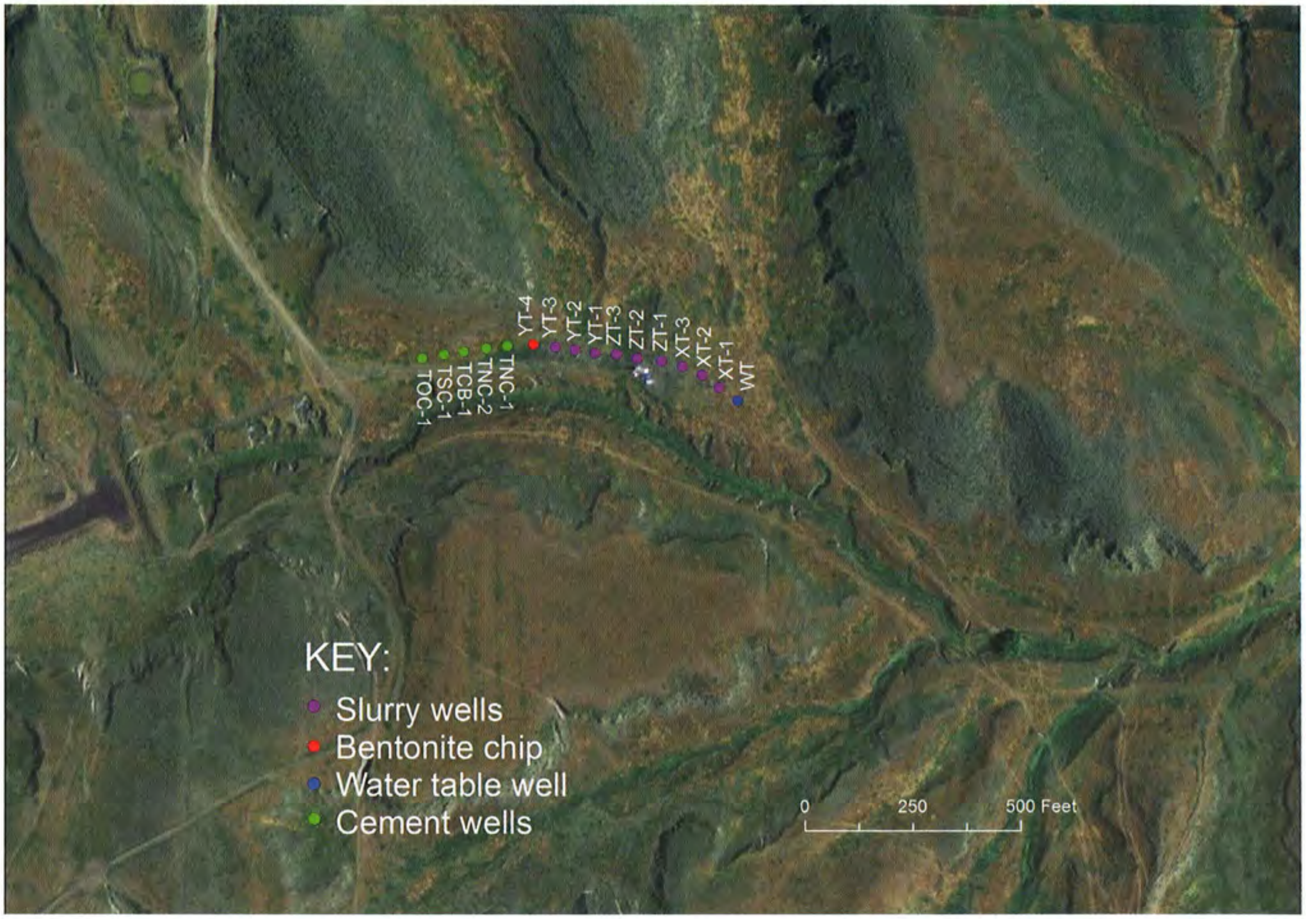

Figure 8. Well locations at the Trenton study site.
Aerial photography: USDA Farm Service Agency, 2003.

TABLE 4
CONSTRUCTION DETAILS OF GROUT OBSERVATION WELLS AT THE TRENTON SITE

Well ID	Date installed	Bit size	Grout interval	Grout type	Specified grout
		In	Ft bgs		
XT-1	10/31/02	10	0 - 74	Bentonite	< 20% solids
XT-2	11/01/02	10	0 - 76	Bentonite	= 20% solids
XT-3	11/02/02	10	0 - 76	Bentonite	> 20% solids
YT-1	11/06/02	10	0 - 76	Bentonite	= 20% solids
YT-2	11/07/02	10	0 - 76	Bentonite	> 20% solids
YT-3	11/09/02	10	0 - 76	Bentonite	> 20% solids
ZT-1	11/04/02	10	0 - 74	Bentonite	< 20% solids
ZT-2	11/05/02	10	0 - 75	Bentonite	= 20% solids
ZT-3	11/05/02	10	0 - 76	Bentonite	> 20% solids
XT-4	7/17/03	10	2 - 75	Bentonite	Chip
TNC-1	9/27/04	9	0 - 76	Cement	Neat 7 gal H_2O
TNC-2	9/28/04	9	0 - 75	Cement	Neat 6 gal H_2O
TCB	9/28/04	9	0 - 75	Cement	Bentonite
TSC	9/29/04	9	0 - 78	Cement	Sand
TCC	9/30/04	9	0 - 78	Cement	Concrete

Figure 9. Well and loop locations at the Lake McConaughy study site.
Aerial photography: USDA Farm Service Agency, 2003.

TABLE 5
CONSTRUCTION DETAILS OF GROUT OBSERVATION LOOPS
AT THE LAKE McCONAUGHY SITE

Well ID	Date installed	Bit size	Grout interval	Grout type	Specified grout
		In	Ft bgs		
XL-5	9/11/03	9.5	200	Geothermal-sand	60% solids
XL-6	9/12/03	9.5	200	Geothermal	20% solids
YL-5	9/08/03	9.5	200	Geothermal-sand	60% solids
YL-6	9/09/03	9.5	200	Geothermal	20% solids
ZL-5	9/03/03	9.5	200	Geothermal-sand	60% solids
ZL-6	9/04/03	9.5	200	Geothermal	20% solids

The Technical Team designed the 2002 bentonite slurry grout observation wells so that each participating bentonite industry supplier oversaw the drilling and installation of 3 observation wells at three sites for a total of 27 wells. Grout products ranged from 15-30 percent active solids; two installations had less than 20 percent solids, three had 20, and four had more than 20 percent solids. The bentonite slurry grouts were mixed in a variable speed paddle-type grout mixer and pumped from the mixer directly into the tremie pipe and down the borehole. The bottom of the tremie remained a minimum of 10 feet within the grout column during placement operations. The slurry was pumped into the annulus from the top of the bentonite seal to the ground surface.

Three bentonite chip grout observation wells were installed in 2003, one at Pilger, one at Grand Island, and one at Trenton. The three NGTF industry suppliers all used Wyoming sodium bentonite for this grout material. The ⅜″ chip bentonite grout was poured into the annular space above the filter pack and, when necessary, it was hydrated according to industry representatives' specifications.

The Technical Team installed six geothermal bentonite grout observation boreholes in 2003 at Maskenthine, Grand Island, and Lake McConaughy for a total of 18 boreholes. The boreholes were spaced 10 to 20 feet apart and were each approximately 200 feet in depth. Each industry supplier oversaw the drilling and construction of two loop installations, one containing bentonite geothermal grout with 20 percent solids and the other containing geothermal grout with the addition of sand to produce a slurry with 60 percent solids. The loop pipes and the tremie pipe were placed the full depth of each borehole. The 2" inside diameter (ID) clear-access casing was set a minimum of 20 feet above the bottom of the borehole. Special clips (centralizers) were attached to both inflow and outflow lengths of the loop pipe and the clear-access casing every 10 feet. Figure 10 shows an example of the geothermal loop installations.

Figure 10. Example of geothermal loop installation.

Five cement-based grout observation wells per site were installed at the Pilger, Grand Island, and Trenton sites in 2004. There were two neat cement grout mixes, one with 7 and one with 6 gallons of water per bag of cement. The unit proportions of the cement-sand mix were 1 bag of Portland Cement, 188 pounds of sand, and 7 gallons water. However, this mix was very difficult to pump so the amount of sand was reduced to 150 pounds for all installations. The unit proportions of the cement-bentonite grout were 1 bag of cement, 2.5 pounds of bentonite, and 7.5 gallons of water. The specifications for each unit of concrete grout were 1 bag Portland Cement, 282 pounds of aggregate, and not more than 7 gallons of water. These grouts were pumped from the mixer directly into the tremie pipes and down the boreholes. Only concrete grout was mixed off-site and poured into a hopper attached to the tremie pipe.

2.4 Grout Sampling

Although the Grout Task Force had not developed any laboratory testing protocol for the grout material, the task force considered it prudent to obtain a sample of each grout should testing be deemed important at a later date. The samples were obtained directly from the top of the borehole for all slurry grouts. The slurry grouts were sampled when the weight of the grout exiting the borehole measured within 10 percent of the weight of an equal sample taken from the mix tank. The bentonite chip and the concrete grouts were poured into sample containers that were filled with drilling fluid in an effort to simulate down-hole conditions. Each sample container was given an ID number that correlated with the ID number of the well. No additional testing has been performed on the grout samples at this time, but this can be done in the future if needed.

2.5 Surface Completion – Dye Reservoir

The grout in each well cured for at least twenty-four hours prior to the installation of the steel protective cover and dye reservoir. Figure 11 shows the surface completion diagram and dye reservoir for the observation wells. The upper 4 feet of each borehole was enlarged to a diameter of four feet to allow for emplacement of a protective cover and concrete pad. The protective cover was centered over the casing in the enlarged borehole. The dye tube was placed 6 inches above the top of the bentonite slurry grout and embedded in sand pack. Then a layer of bentonite chip seal was placed and hydrated.

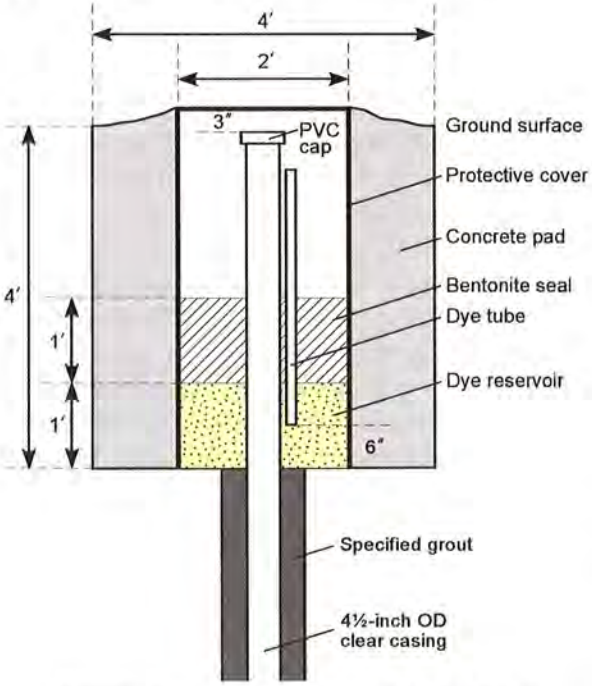

Figure 11. Surface completion diagram for grout observation wells.

For the heat loop installations, the grout was removed from the borehole to a depth of approximately 5 feet. An effort was made to leave the borehole intact through the bottom foot. The dye tube was installed a minimum of 3 inches above the top of the bentonite grout and embedded in sand. A bentonite chip seal was placed and hydrated above the sand. The loop pipe was laid in the trench and attached to the header. The protective cover was then put into the enlarged borehole and filled with gravel to a depth of approximately 2.5 feet below the ground surface. A bentonite chip seal was then placed inside the cover and properly hydrated (Fig. 12).

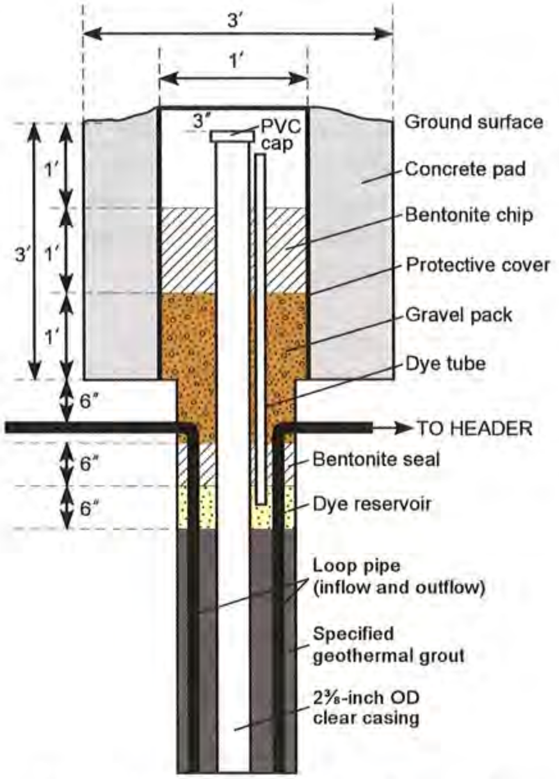

Figure 12. Surface completion diagram for geothermal grout loops.

2.6 Site Monitoring

There were three elements involved in site monitoring, including water level measurements, video surveys, and dye tests. First, we recorded water level variations from the water table well at each of the five study sites. We installed pressure transducers in all five wells to measure water levels every 8 hours. Second, the Technical Team designed down-hole video camera surveys to observe the changes in the nature of the grout material over time in an attempt to confirm that static conditions existed prior to the performance of dye tests. NDHHS performed an initial inspection at least twenty-four hours after placement of the grout. The second video inspection was performed 30 days after the initial inspection and a third survey approximately 90 days after the well was installed. Subsequent camera surveys were conducted on a semiannual basis.

NDHHS/Water Well Standards Program supplied the down-hole video camera (Fig. 13). Down-hole video equipment was disinfected prior to it being used in the well. Key information noted on a clipboard was videoed prior to each camera survey. Original recordings were in Digital 8 format. New camera equipment allowed for recordings in VHS format that were transferred to DVD's.

Figure 13. Down-hole camera survey equipment.

Grouts are used in the annular space of a well to inhibit the downward movement of any potential surface contaminant through this space and into the aquifer. The camera surveys only allowed the viewing of the grout nearest the clear casing. No assessment could be made of the potential connectivity of void spaces using only the camera survey. Therefore, the NGTF decided to perform a dye test and use the down-hole video camera to determine any movement of the dye. These tests, the third element in the monitoring, were scheduled to occur about 2 years after installation of the observation wells, depending on camera survey results.

The NGTF Technical Team adapted the dye test techniques used by the Ohio Department of Health (May 2000). Surface completion diagrams (Figs. 11 and 12) show the configuration of the dye reservoirs. The dye was non-toxic food grade quality. In dye tests performed between 2004 and 2006, we used a yellow-green fluoresein dye. NDHHS personnel swabbed the dye tubes to eliminate the possibility of any obstructions in the tube that could alter the results of the dye test. Then a clear hose was attached to the dye tube and connected it to the 220-gallon dye tank (Fig. 14).

Figure 14. Dye testing.

Field personnel placed the tank in the bed of a pickup truck to aid in maintaining a positive artificial head. NDHHS personnel then lowered the camera into the well and opened the valve from the tank. The movement of the camera depended on detection of the dye. Near the end of the 1-hour test, the camera was lowered to the bottom of the well and then slowly raised to detect the maximum depth of penetration of the dye after approximately one hour. In 2006 the technical team decided to also video each of the wells twenty-four hours later to assess longer term dye movement. NDHHS personnel recorded the results of the dye tests on a dye test form provided by the NGTF.

3.0 ANALYSIS PROCEDURES

3.1 Visual Assessment

The purpose of the visual assessment was to review down-hole videos and to assign a numerical rating to the condition of the annular seal at one-foot depth intervals. Preliminary analyses indicated that all grout materials exhibited voids above the water table and were mainly intact below the water table. Therefore, the visual assessments were performed only for the portion of the grout column within the unsaturated zone. The Technical Team selected videos to review based on a target date of at least 90 days after well installation. Numerical ratings were assigned for each one-foot interval based on the following coding system: 0 = No data, 1 = Good, 2 = Cracks, and 3 = Voids and cracks. The rating code 0 was used in instances where no survey was completed for that interval or when the interval was above the grout column.

The visual assessment of the bentonite slurry grouts conformed to the rating code system originally adapted for this study. We assigned the rating codes to depth intervals with greater confidence compared to the other grouts included in this study. Greater confidence in code assignments with bentonite grouts can also be attributed to consistent visual characteristics of the seal materials at the individual sites when compared to cement grout installations. The visual assessment of cement product wells proved to be challenging. The use of different cameras, varied camera views, excessive condensation, and apparent discoloration of the casing were factors that made this analysis difficult.

One of the most difficult conditions to assess was the detachment of the cement-based grouts from the casing. The cement-based grouts also had many small openings that were termed by the NGTF as inconsistencies that needed to be accounted for in the assessment of these grouts. Therefore we expanded the coding system to account for these additional grout characteristics. The revised rating system for cement-based grouts was 1 = Good, 2 = Cracks or small inconsistencies, and 3 = Voids or detachment from casing.

The results of the camera survey assessment are presented in this publication as average ratings. In order to focus on the material and not specific products, average ratings were calculated for each grout recipe when more than one installation used this recipe. Site average ratings were also calculated for comparison between sites.

3.2 Original Dye Tests – 2004-2006

The Technical Team based the results presented in this publication on observations made in the field at the time of the test. NDHHS field personnel recorded these observations on the dye test field forms and included time, depth, and dye detection notes. When the results appeared anomalous, some of the videos were reviewed on a larger screen to confirm the results. No attempt has been made at this time to review all of the videos on a larger screen with more resolution.

The Technical Team used the maximum depth at which the dye was detected as the primary means to compare the performance of different grout materials at each site. In instances where different products were used but mixed in the same proportions, the average maximum depth of dye was calculated in order to focus on the material and not on the individual products or drilling practices of the industry supplier. Average maximum depth of dye detection was considered when comparing the performance of the grout types to the different hydrogeologic conditions at the three to five sites. However, because the thickness of the unsaturated zone varied between 13 and 134 feet, the percentage of the unsaturated zone penetrated by the dye was calculated in an effort to lessen the impact of this variation. For the geothermal installations the water level at the time of the test was estimated from transducer data obtained from the water table well at each site.

3.3 2007 Dye Tests

After completion of all the initial dye tests, the NGTF raised questions related to the ability to replicate the results of these tests and the potential longer term dye movement in the installations prior to 2004. Therefore, in the summer of 2007, the NDHHS personnel retested all grout observation installations using the same procedures as used in the original tests. These tests also included a camera inspection twenty-four hours after the new dye was introduced. The dye used was changed to food grade Rhodamine WT to be sure that the test results were not impacted by the original dye tests. The one-hour dye test results of the 2007 tests were used to assess the ability to replicate the results of the original dye tests. The results of the 24-hour inspection of the bentonite slurry and chip installations were used to compare longer-term dye movement in these grouts as compared to the 2006 longer-term dye movement in the cement-based grouts.

3.4 Comparison of the Nature and Performance of Grouts

The Technical Team performed comparisons of the results of the visual assessment and the maximum depth at which dye was detected on all installations. The depth of dye detection from the original tests was plotted on individual visual rating graphs. To provide a means of comparison each installation was assigned to one of three groups. Group A was considered a good correlation between results. The maximum depth that dye was detected was within 3 feet of the lower visual ratings. Group B included cases where the dye was shallower than expected. The dye did not penetrate all sections of grout that were identified as cracks or cracks and voids. Group C included instances where the dye penetrated deeper than expected. In this group the dye penetrated areas of the grout that showed no inconsistencies. Figure 15 shows an example from each group.

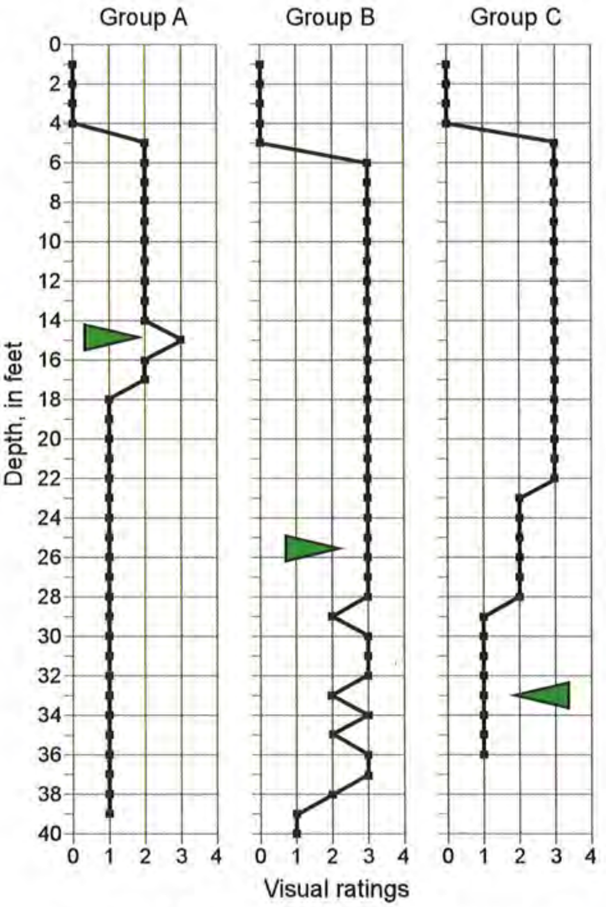

Figure 15. Comparison of visual assessment and dye test results. Arrow indicates maximum depth dye was detected.

4.0 OVERVIEW OF HYDROGEOLOGIC CHARACTERISTICS AT STUDY SITES

The sections in this chapter present a broad overview of hydrogeologic characteristics of each of the study sites. More detailed site descriptions were presented in the NGTF Project Report (July 2009). Myers (2005) presented additional stratigraphic details. The results of the individual site evaluations indicated that the sites met the design criteria and that there were few or no existing contaminants that would alter the grout performance. Details were presented in Phase II Task Completion Reports in June, 2002 and December, 2003. We calculated annual precipitation amounts from daily data obtained from the High Plains Regional Climate Center. These data are available on the University of Nebraska-Lincoln web site: http://www.hprc/data/historical (accessed April 22, 2009).

4.1 Northeastern Well Site - Pilger

The northeastern target was a hydrogeologic environment influenced by glaciation where a Pleistocene sand and gravel aquifer was present. The Lower Elkhorn Natural Resources District (NRD) agreed to allow the NGTF to use the Pilger Recreation Area in Stanton County. This study site is in the moist subhumid climatic zone and is referred to as the Pilger site. Figure 16 shows a generalized geologic cross-section based on core samples, rotary cuttings, and downhole geophysical logs from CSD test holes.

This area of Nebraska is known to have local or perched water systems. These systems occur when water moving through the unsaturated zone encounters a layer of reduced permeability that inhibits the downward movement of the water. These groundwater flow systems are highly variable. The amount of flow is dependent on relatively recent recharge.

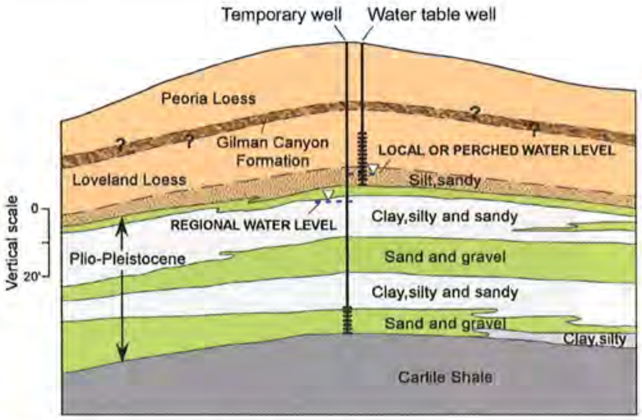

Figure 16. Generalized geologic cross-section of Pilger site. Site aquifer is composed of Plio-Pleistocene sand and gravel with intermittent layers of silty clay.

The water table well was screened from 26-46 feet through the sandy portion of the Loveland Loess. In April of 2002, the water level was 29 feet below ground surface. The temporary well installed in the test hole was screened in the deep aquifer from 67-77 feet. The water level in this well was 36.5 feet deep. The water in the lower sand and gravel aquifer is under confined pressure conditions. These conditions exist when the groundwater is being stored under pressure greater than the atmosphere exerts. When the overlying sediments are removed by drilling, the water level rises above the top of the aquifer.

The water table varied from 28-38 feet deep. The high water levels occurred in mid-summer and the low water levels were recorded in the late winter to early spring. In this NRD, hydrographs from wells that monitor regional aquifer systems impacted by seasonal pumping generally indicate that high water levels occur in late spring and low water levels occur in late summer. These temporal variations in the maximum and minimum seasonal water levels could indicate that the water table aquifer is local and is connected to a regional aquifer only through a leaky confining layer. This could explain the delay of a few months for irrigation pumping to impact the water levels and the additional 5 months needed for this system to fully recharge itself.

4.2 Northeastern Geothermal Site - Maskenthine

The Maskenthine Recreational Area was selected in the northeastern part of the state to install the heat loops. Test holes were drilled and cored in May of 2003. A generalized geologic cross section (Fig. 17) was developed for this site based on samples obtained from these test holes.

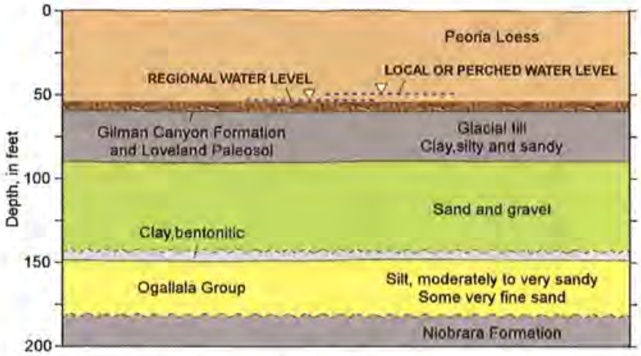

Figure 17. Generalized geologic cross-section of Maskenthine site.

The water table well was screened from 55-65 feet through the Gilman Canyon Formation, the Loveland Paleosol, and the upper portion of a glacial till. A pressure transducer monitored variations in water levels in the perched flow system for the period of July 2003 to January 2006. In these 2.5 years the water level varied a maximum of about 4 feet in the range of 50 to almost 54 feet.

4.3 Central Site – Grand Island

The central site target was an alluvial aquifer associated with a major river valley. The Nebraska Game and Parks Commission agreed to grout observation installations on its property in Hall County west of Grand Island. This central site is in the subhumid climatic zone and is referred to as the Grand Island site. A generalized geologic cross-section of this site (Fig. 18) was developed using registered well logs and grout observation well logs.

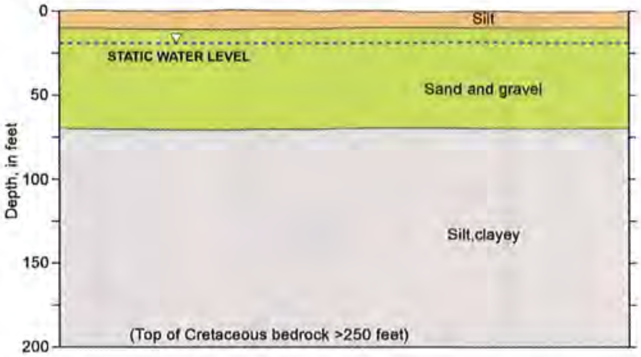

Figure 18. Generalized geologic cross-section of Grand Island site.

The water table well was screened at a depth of 12-22 feet below the ground surface. The temporary well installed in the test hole was screened at a depth of 45-55 feet. The water levels in these wells were the same indicating unconfined aquifer conditions. The water table varied from 13.5 to almost 22 feet during the study. The water table is generally at its highest in late May to early June and is about 2 feet lower in early to mid-August. The average annual precipitation recorded at the Grand Island Climate Station for the six years of this study was 24.75 inches. Annual precipitation amounts ranged from approximately 17 inches in 2002 to 39 inches in 2007.

4.4 Southwestern Well Site – Trenton

The southwestern site target was the Ogallala Aquifer and the semiarid climatic zone. A private landowner allowed the Grout Task Force to use part of his property in Hitchcock County, north of Trenton. This southwestern site is called the Trenton site. A generalized geologic cross-section of the Trenton site (Fig. 19) was based on core samples, rotary cuttings, and the downhole geophysical logs from CSD test-holes and driller's logs from the grout observation well installations.

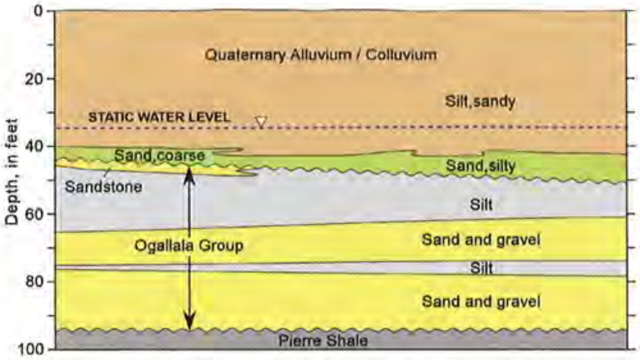

Figure 19. Generalized geologic cross-section of Trenton site.

The water table well was screened from 40-50 feet through the upper 3 feet of reworked Ogallala silt and sandstone clasts above the Ogallala Aquifer. In May of 2002, the water level was 34.5 feet below ground surface. The temporary well installed in the test hole was screened in the deep aquifer from 84-94 feet. The water level in this well was 34 feet deep. The similar water level readings indicated that there is a single aquifer system beneath this site. Pressure transducer data showed the water table varied by only one-foot during the period from July 22, 2003 to January 7, 2007. There were no indications of impacts due to seasonal pumping at this site based on the data. Monthly precipitation amounts from Palisade Weather Station indicate that the six-year average annual precipitation amount was 17.36 inches. Recorded annual precipitation totals ranged from 9.9 in 2002 to more than 26 inches in 2007.

4.5 Southwestern Geothermal Site – Lake McConaughy

The Lake McConaughy Visitor's Center was selected for the southwestern geothermal site. CSD drilled a test hole at this location in 2000 to a total depth of 190 feet. A generalized geologic cross section (Fig. 20) was developed for this site based on samples obtained from this test hole and from additional nearby CSD test holes.

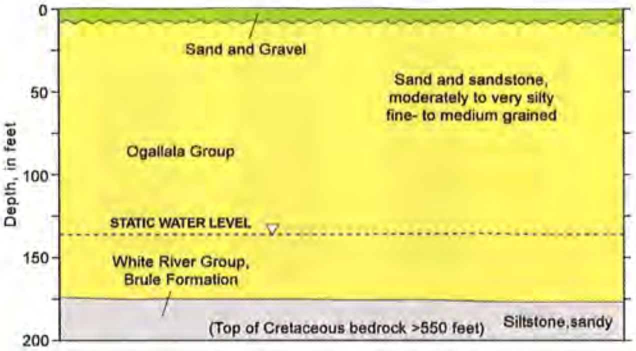

Figure 20. Generalized geologic cross-section of Lake McConaughy site.

The water table well was screened from 148-158 feet deep in the Ogallala Aquifer. Pressure transducer data indicated that the water table declined from 132 feet to 142 feet during the period from July 2003 through April 2007. No seasonal variations in water level depths occurred during this time frame. Monthly precipitation amounts recorded at the Kingsley Dam Station show that the six-year average annual precipitation was 17.68 inches. Annual precipitation varied from 12.6 inches in 2003 to approximately 24.5 inches in 2007.

5.0 DISCUSSION OF RESULTS

5.1 Drilling and Installation

It became evident to the Technical Team during the analysis of the bentonite slurry dye tests that there were some relatively large variations in the performance of the various products. To assess this variation, the percentage of the unsaturated zone penetrated by dye was calculated for all installations with 20 percent solids supported by the individual industry suppliers identified as X, Y, and Z (Fig. 21).

The Technical Team compared the various products and the only characteristic identified as potentially relevant was encapsulated verses disbursed grouts. No correlation of dye test results between the two types of bentonite grouts could be identified. Since the same contractor and equipment were used to install each supplier's products, the only variation we found was in the drilling fluids program that the

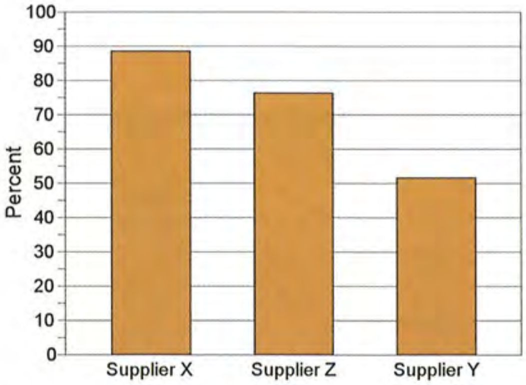

Figure 21. Percentage of the unsaturated zone penetrated by dye.

individual suppliers controlled. Supplier X was the most particular and performed numerous tests on the drilling fluids' properties so that specifications would be consistently met. The grout column installed by this supplier rarely subsided, whereas the other suppliers (Y and Z) often had to top off the grout the next day. This may indicate that the drilling fluids program that supplier X maintained developed a more effective wall cake in the borehole adjacent to the grout column. It is possible that this well-developed wall cake precluded the movement of dye away from the well and into the formation, allowing the dye to penetrate deeper than in installations overseen by the other suppliers.

In April 2009, the Technical Team noted that the cement grout infiltrated through the bentonite chip seal and into the filter pack (Fig. 22). Industry personnel indicated that this occurs when the water phase of the cement slurry grout is given off due to the hydrostatic head caused by the density of the grout column itself. This water is acidic and contains high concentrations of calcium that breakdown the chip seal when cement is in direct contact with it as shown in Figure 23. Cement industry representatives recommend placing at least 2 feet of blotter sand between the cement and bentonite chip to prevent the breakdown of the seal.

Figure 22. Infiltration of cement grout into the filter pack. (Numbers indicate depth of camera in feet.)

Figure 23. Failure of bentonite chip seal caused by cement grout.

5.2 Visual Assessment of Grout Nature in the Unsaturated Zone

The Technical Team observed inconsistencies in slurry wells ranging from small areas of spiral cracking to large open voids in the annular space. At least some form of visual inconsistency was observed in the slurry grouts throughout much of the unsaturated zone in all of the wells assessed. The grout ratings for the Pilger and Trenton observation wells were generally more comparable with rating code assignments of 2 and 3 for the majority of the unsaturated zone depth intervals as shown in Figure 24. The grout nature of

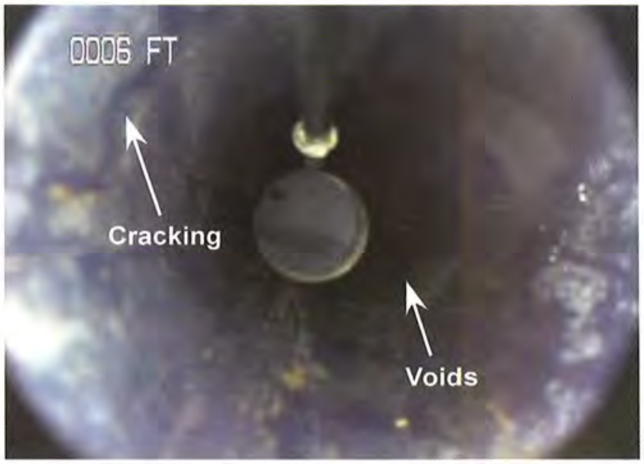

Figure 24. Cracking and voids in the Trenton bentonite slurry.

the Grand Island wells was more typically rated 1 and 2 (Fig. 25).

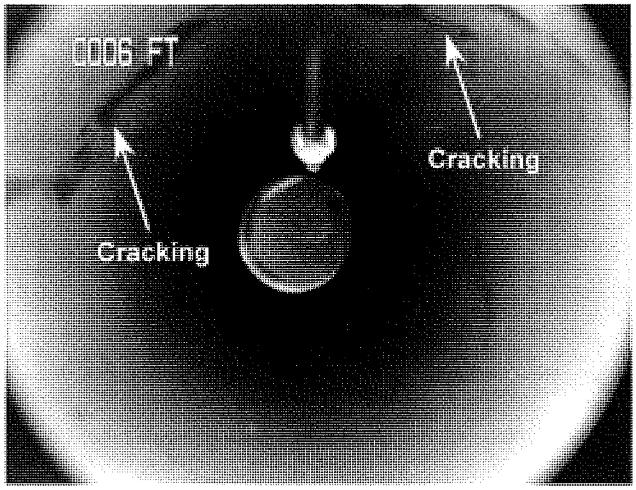

Figure 25. Small cracks in Grand Island bentonite slurry.

The results of the visual assessment of the bentonite slurry grout nature are shown in Table 6. The average ratings at the Pilger and Trenton sites indicate that the bentonite slurry grouts with higher percentages of solids have less cracking and fewer voids. This is also supported by the grout average rating of all the variable percent solids at the three sites. However, the results of the Grand Island grout assessments do not support this conclusion.

The results of the visual assessment of the chip well videos revealed few overall inconsistencies in all three wells. The grout seal at Pilger appeared well hydrated with a smooth texture. At the Trenton site the well seal also appeared to be in good condition overall with the exception of several small voided areas. The chip seal at this site did not appear to be as well hydrated as the seal at the Pilger site. It often appeared chunky or coarse in appearance above 27 feet. The grout column at the Grand Island site also appeared to exhibit a somewhat less hydrated appearance in some areas (Fig. 26).

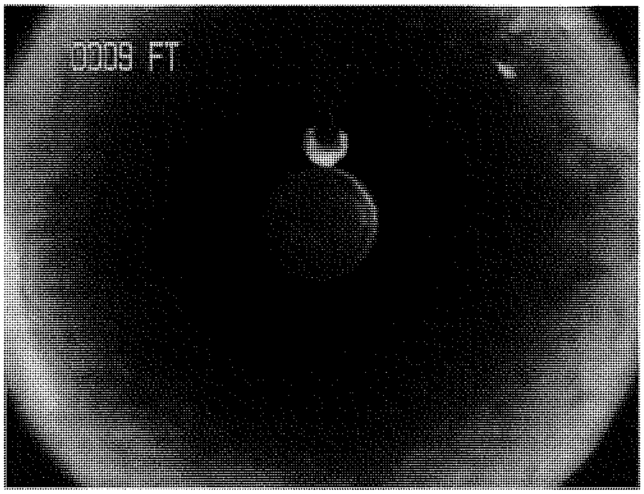

Figure 26. Grand Island bentonite chip grout.

TABLE 6
AVERAGE VISUAL RATINGS FOR ALL GROUTS

Grout type	Pilger or Maskenthine	Grand Island	Trenton or Lake McConaughy	Average visual rating
Bentonite < 20 % solids (3 wells per site)	2.7	1.4	2.7	2.3
Bentonite = 20 % solids (3 wells per site)	2.1	1.7	2.2	2.0
Bentonite > 20 % solids (3 wells per site)	1.9	1.6	2.0	1.8
Bentonite slurry average	**2.1**	**1.6**	**2.2**	**2.0**
Bentonite chip	**1.0**	**1.5**	**1.3**	**1.2**
Geothermal ~20% solids (3 per site)	2.8	2.6	2.9	2.8
Geothermal-sand ~60% solids (3 per site)	2.8	2.5	2.8	2.7
Geothermal slurry average	**2.8**	**2.6**	**2.9**	**2.8**
Neat cement with 6 gallons of water	1.6	1.4	1.3	1.4
Neat cement with 7 gallons of water	1.9	2.0	1.6	1.8
Cement with bentonite	1.3	1.9	1.6	1.6
Cement with sand	2.4	1.3	1.2	1.6
Concrete	1.6	2.5	2.0	2.0
Cement-based average	**1.8**	**1.8**	**1.5**	**1.7**

The geothermal bentonite grouts exhibited predominate cracking and voided areas throughout much of the unsaturated zone, as shown in Figure 27. In general, many of the grout seal conditions improved somewhat with depth. The average results of the visual assessment showed little variation in the appearance of these grouts between sites and between the geothermal grouts with or without sand added. The average ratings for the 20 percent and 60 percent solid grouts are the same for the Maskenthine site. At the Grand Island and Lake McConaughy sites there is only a slight improvement in the appearance of the grout column with the addition of sand as shown in Table 6.

Figure 27. Geothermal grout containing 20 percent solids.

Overall the cement wells appeared to show some inconsistencies through most of the unsaturated zone. However, it was difficult to consistently rate the occurrence of these due to the obstacles noted in Section 1 of Chapter 3. The detachment of the grout from the casing was one of the most difficult challenges to assess visually in the cement wells. Detachment may have occurred in many of the wells assessed with this grout type, but may not have been accounted for completely in all of the visual assessments. Figures 28 through 30 show examples of the nature of cement-based grouts.

The average results of the visual assessment of cement grouts (Table 6) show little overall variation in the appearance of grouts between the Pilger, Grand Island, and Trenton sites based on the site average ratings. The Pilger and Grand Island sites had average

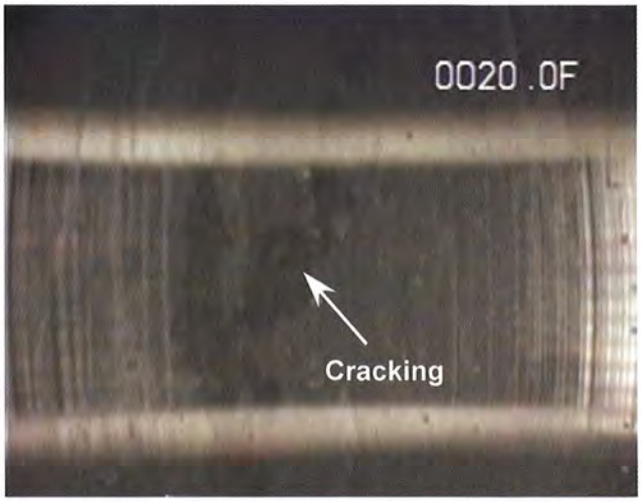

Figure 28. Cracking in cement-based grout.

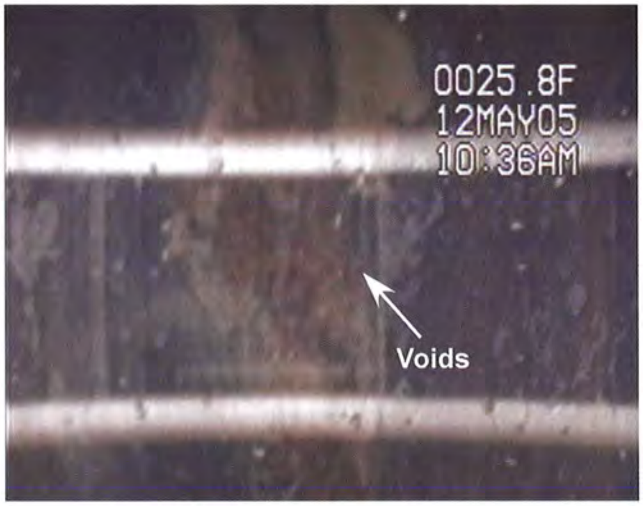

Figure 29. Voids in cement-based grout.

Figure 30. Neat cement appears detached from casing.

ratings of 1.8, whereas the Trenton site average was 1.5. These results would indicate that the cement based grouts appeared more consistent in the Trenton environment.

Comparison of the appearance of the two different neat cement mixes indicates that the grout with 6 gallons of water per bag of cement is more consistent than the mix with 7 gallons of water per bag. This is supported by the results on the individual sites and the average rating of all three sites. Comparison of the cement with sand grout ratings from site to site shows a wide variation of appearance. This grout rating was the worst at the Pilger site, with a rating of 2.4, and yet it was rated the best of the grouts at the Trenton site, a rating of 1.2.

The average ratings for the different cement grout recipes indicate that concrete grout is visually more inconsistent then other cement grouts. This could be a seal performance issue or be related to the inclusion of coarse aggregate that would make this grout appear to have a coarser texture. Other considerations with concrete grout are mixing and placement methods. During placement of this grout at the Trenton site there were larger than specified aggregates and clots of unmixed or dried cement. Therefore, off-site bulk mixing of grout material by contractors with little knowledge of well construction should be questioned.

We used average ratings to compare the observed nature of the varied grout materials at the Pilger, Grand Island, and Trenton sites. The results are presented in Table 7. Bentonite chip grout appeared the most intact. The average ratings for cement-based grouts were generally low, except for the concrete grout. The average rating of the bentonite slurry grout with more than 20 percent solids is comparable to most of the cement-based grouts.

The geothermal grouts had the lowest visual ratings. Some of the loop installations used the same mix as the 20 percent solids bentonite slurry wells installed in 2002. However in the loop installations with the same grouts appeared less intact at the same site. This would indicate that geothermal loop installations cannot be compared to the 4-inch well installations.

5.3 Grout Performance - Original Dye Tests

We based grout performance on the assessment of the maximum depth that dye was detected. Surface completion for this study is not typical of standard well completions. In order to compare the various grouts using dye tests, a 1-foot thick layer of sand pack was placed directly on top of the grout column within the protective steel cover (Chapter 2, Section 5). Additional head was obtained by placing the 220-gallon dye tank in the back of a pickup truck to ensure movement of dye through any permeable areas of the grout column. This engineered surface completion design that created artificial head must be kept in mind when considering dye penetration depths.

TABLE 7
OVERALL AVERAGE VISUAL RATINGS

Grout type	Visual rating (All installations)
Bentonite chip	1.3
Neat cement with 6 gallons of water	1.4
Cement with bentonite	1.6
Cement with sand	1.6
Bentonite slurry >20%	1.8
Neat cement with 7 gallons of water	1.8
Bentonite slurry =20%	2.0
Concrete	2.0
Bentonite slurry <20%	2.3
Bentonite geothermal-sand ~60%	2.7
Bentonite geothermal ~20%	2.8

The maximum depth of dye detection is based on data recorded on dye test field forms completed during the dye tests. Figure 31 shows dye in a void within a bentonite slurry grout. Figure 32 shows the yellow-green dye in the dye reservoir. As is evident from these video clips, detecting the dye from a single picture is difficult. However, the dye is more easily detected when viewing video sequences.

Figure 31. Dye detected in a void in bentonite slurry grout column.

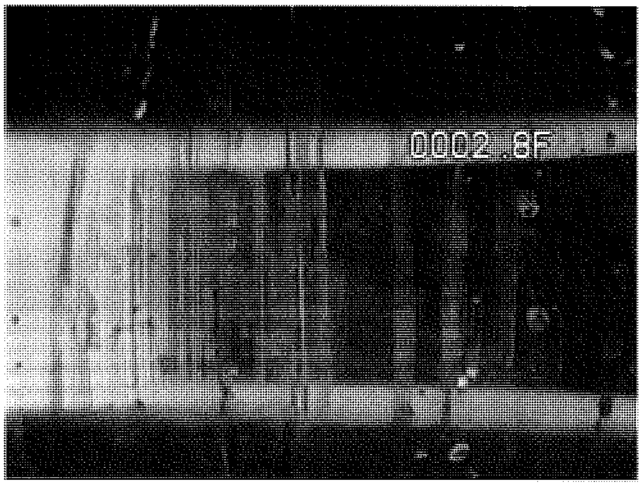

Figure 32. Dye detected in dye reservoir.

Dye was detected below the dye reservoir in all of the bentonite slurry wells except for two at the Trenton site. Review of the field notes recorded during the drilling process indicated that of the 27 wells only these two wells lost circulation due to surface cracks during drilling operations. Since more than 100 and 180 gallons of dye were used during the one-hour tests, it is probable that the dye moved away from the annular space through these surface cracks.

The results of the dye tests at the Pilger site indicate that the performance of the bentonite slurry grout improves with increased solids content (Table 8). However, the results at the Grand Island and Trenton sites do not fully support this conclusion. When the average maximum depth of dye detection for all the installations are calculated for each percentage of solids, the results again indicate that an increase in solids content improves grout performance. These differences in results may be related to lack of control inherent in field studies or possibly related to the variable bentonite slurry products used in this study. Both hypotheses could be supported by the range of maximum dye detection for each category of solids at the individual sites.

We calculated the percentage of the unsaturated zone that the dye penetrated for each well in order to compare grout performance between sites. The water level recorded at the time of the dye test was used for calculations at the Grand Island and Trenton sites, which resulted in site averages of 63% and 92%, respectively. For the Pilger site the water level in the shallow aquifer was used to calculate this percentage because the water table conditions would impact all the grout installations. The average percentage of the unsaturated zone penetrated by dye at this site was 81%.

These results indicate that conditions at the Trenton site are the worst for bentonite slurry grouts. Whereas, site conditions at Grand Island would be considered most favorable. Based on findings by Myers(2005) the particle size and moisture content of unsaturated zone sediments are the two primary factors related to the visual nature of bentonite slurry grout. Since the sediments above the water table are predominantly silt-sized at both the Trenton and Pilger sites, it is probable that the drier climate in the Trenton area is intensifying the harshness of the environment at that study site.

The bentonite chip well at Grand Island had a cracked casing and dye entered the well so the test was inconclusive. We detected no dye in the chip well at the Pilger site, but we detected dye to a depth of 24 feet at the Trenton site. Given the unfavorable conditions identified for bentonite slurry grouts at both Pilger and Trenton, the potential exists that there was a construction problem with the chip well at Trenton. However, field documentation did not indicate any construction problems.

Dye was detected below the reservoir in all but one geothermal installation at Lake McConaughy. No reason for this anomalous result has been determined at this time. Average results of maximum depth of dye detection for the geothermal grout and geothermal grout with sand are shown in Table 9.

The average results from the Lake McConaughy site indicate that the addition of sand to the geothermal grout substantially improves the geothermal grout performance. However, both the Grand Island and Maskenthine site results show little variation in the average maximum depth of the dye between the two grout types. Field notes for both sites indicated numerous difficulties were experienced during both the drilling and construction of these loop installations, including connection between boreholes. These problems may have impacted the results of the dye tests.

At the Maskenthine site, the Technical Team designed the depth of the loops to be shallower (180 feet) because the upper portion of the Niobrara Formation often contains dissolution fractures that can provide conduits for fluid flow between boreholes. However, to accommodate the landowner we moved the loop field downhill away from the owner's lawn. During two installations lost circulation occurred at about 165 feet and the previously installed loop started floating to the surface. It is probable that the connection between the boreholes was through these dissolution fractures in the Niobrara Formation.

The overall average percentage of the unsaturated zone penetrated by the dye for geothermal installations was 93, 92, and 45 for the Maskenthine, Grand Island, and Lake McConaughy sites, respectively. These averages might indicate that the Lake McConaughy site has the best environment because the dye only penetrated 45% of the unsaturated zone. However, the dye test videos from this site showed dye running down the annulus ahead of the camera through large voids and areas with no grout in the loop installations without sand. The average amount of the unsaturated zone penetrated by dye in these installations was 74% and for the geothermal grout with sand added it was only 16%. The overall average for this site is lower because the performance of the geothermal grout with sand was so good.

Except for the Lake McConaughy site, the results of the dye tests for geothermal grouts lacked consistency

TABLE 8

AVERAGE MAXIMUM DEPTH OF DYE DETECTION IN BENTONITE SLURRY GROUTS

Grout solids	**Pilger**	**Grand Island**	**Trenton**	**Average of all wells**
< 20 %	33 feet	13 feet	33 feet	26 feet
= 20 %	21 feet	15 feet	26 feet	21 feet
> 20 %	15 feet	9 feet	32 feet	19 feet
Site average	21 feet	12 feet	31 feet	21 feet

TABLE 9

AVERAGE MAXIMUM DEPTH OF DYE DETECTION IN GEOTHERMAL GROUTS

Percent solids	**Maskenthine**	**Grand Island**	**McConaughy**	**Average of all loops**
Geothermal ~20% solids	40 feet	21 feet	99 feet	53.3
Geothermal-sand ~60% solids	42 feet	20 feet	21 feet	27.7

when comparisons were made between the grout containing sand and the grout without the addition of sand. Possible causes of this lack of uniformity are the larger borehole diameter, impact of temperature variations, numerous problems encountered during drilling and installation operations, as well as the relatively large amount of tubing, centralizers, and clear-access casing that the grout had to flow around and between. One possibility that can be eliminated is that temperature variances during heating and cooling cycles caused problems with grout performance at these sites. The Grand Island loop field had been in use for over a year, whereas the Maskenthine loop field had never been used prior to running the dye tests.

Dye was detected in all cement-based grout installations either during the 1-hour or the 24-hour inspections with the exception of the cement-sand grout at the Grand Island site. Field notes and construction logs at this site did not indicate any possible explanation for this anomaly. Table 10, shows the maximum depth that dye was detected within one hour after the dye tank valve was opened and during the 24-hour inspection. Dye was detected in all types of cement-based grouts in at least one installation at the three sites. Only the neat cement recipes had dye below the reservoir in one hour at the Pilger, Grand Island, and Trenton sites. Comparison of the maximum average depth of dye penetration for the neat cement recipes indicates that the recipe with 7 gallons of water performed better than the recipe with 6 gallons of water. This result is the opposite of industry recommendations; however, no additional research to explain this apparently anomalous result has been performed at this time.

The cement sand grout performed the best overall and the cement bentonite grout was the worst overall. However, all the cement-based grouts have similar performances when the accumulated depths of each recipe are compared (Fig. 33).

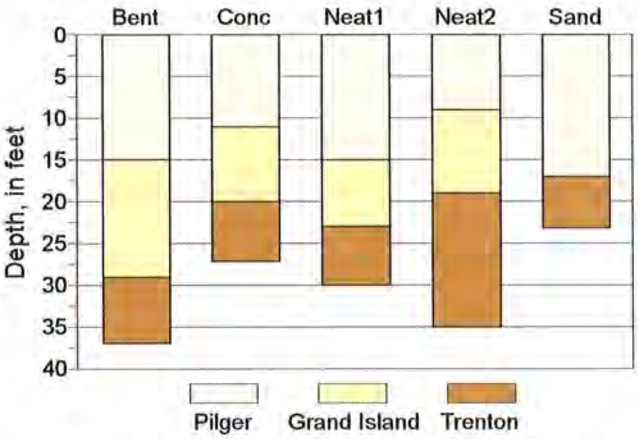

Figure 33. Accumulative maximum depth of detection for cement grouts.

We assessed grout performance between sites by calculating the percent of the unsaturated zone penetrated by the dye (Table 11). There is little difference in the average performance of cement grouts at the Pilger and Grand Island sites based on the site averages. However, variation is considerable and inconsistent between the results of the individual types of grout at each of the sites. Because of the apparent erratic performance results it is possible that cement-based grouts are less impacted by site conditions, but may be more sensitive to mixing and placement operations.

TABLE 10
MAXIMUM DEPTH OF DYE DETECTION IN FEET

Grout type	Pilger		Grand Island		Trenton		1-Hour average	24-Hour average	Average maximum depth*
	1-hr	24-hr	1-hr	24-hr	1-hr	24-hr			
Neat-6 gal	7	9	7	10	6	16	7	12	12
Neat-7 gal	5	15	5	8	7	7	6	10	10
Cement-bentonite	0	15	0	14	8	7	3	12	12
Cement-sand	7	17	0	0	6	0	4	6	8
Concrete	11	0	0	9	7	0	6	3	9
Site Average	6	11	2	8	7	6	5	8	8

* Based on the maximum depth from both the 1- and 24- hour videos

TABLE 11
AVERAGE PERCENTAGE OF UNSATURATED ZONE PENETRATED BY DYE IN CEMENT-BASED GROUTS

Cement grout	Pilger	Grand Island	Trenton
Neat-6 gal	53	26	51
Neat-7 gal	43	46	22
Cement-bentonite	74	45	26
Cement-sand	0	53	19
Concrete	54	45	22
Site average	45	43	28

We used the calculated average percentage of the unsaturated zone that dye penetrated to compare the performance of the various grout materials. The results are presented in Table 12. Note that maximum depth that the dye was detected in a 24-hour period was used in these calculations for the cement based grouts and that the water levels used for the geothermal grout installations are estimated. These data indicate that the cement with sand grout performed the best when all grouts are compared within a period of 1.5 to 2 years after installation of the material.

When comparing the average results of all bentonite slurry grouts used in the wells and in the geothermal installations, the bentonite slurry with 23 to 30 percent solids (>20%) out-performed the geothermal grout with 60 percent solids content. However, when the two different geothermal grouts are compared there is a difference of almost 20 percent between their performance ratings. Based on the geothermal comparisons, inclusion of sand in bentonite slurry grout enhances its performance. Comparison of these results between 20 percent solids grout in the well and the loop installations indicate that the similar or same grouts used in the well installations out-performed the grout in the geothermal loops by 11 percent. Based on these observations, it is probable that the grout performance results of the geothermal installations are not comparable with the results of well installations, as previously noted.

TABLE 12
OVERALL AVERAGE PERCENTAGE OF UNSATURATED ZONE PENETRATED BY DYE

Grout type	Average percentage
Cement with sand*	24
Neat cement with 7 gallons of water*	37
Concrete*	40
Bentonite chip (Pilger & Trenton wells)	40
Neat cement with 6 gallons of water*	44
Cement with bentonite*	48
Bentonite slurry >20%	65
Bentonite geothermal-sand ~60%**	67
Bentonite slurry =20%	75
Bentonite geothermal ~20%**	86
Bentonite slurry <20%	87

* Based on maximum depth of dye in one- and 24-hour videos.
** Water level estimated from water table well

5.4 Grout Performance - 2007 Dye Tests

The Technical Team used the one-hour dye test results of the 2007 tests to assess the ability to replicate the results of the original dye test. The results of the 24-hour inspection of the bentonite slurry grouts were used to compare longer term dye movement in these grouts as compared to the 2006 longer term dye movement in the cement-based grouts. This comparison was done in an effort to validate the use of the maximum depth that dye was detected in either inspection for the original dye test analyses. Figure 34 shows an image from a video clip in a grout interval where the dye could be seen flowing through a crack in the grout column.

Figure 34. Flowing rhodamine dye.

The results of the 2007 dye test at the Pilger site were very similar to the 2004 dye test. The maximum depth dye was detected within one hour in the 2007 tests was within a few feet for six of the nine installations. One well test showed the dye penetrated 6-feet less and two showed dye penetrated 5- and 9-feet more than in the 2004 dye tests. These results indicate that in 67% of the cases the dye tests were replicated and that 33% of the tests produced similar results. This also confirms that the grout column remained in a relatively stable condition.

The results of the 2007 dye tests at the Grand Island site were very different from the original dye test results. Dye was detected in only two of the wells within one-hour of starting the test. The variation of dye test results at this site may be due to the breakdown of the mud cake on the borehole wall. Since the unsaturated zone sediments at this site are typified by sand-sized particles, it would be relatively easy for the dye to move through this material and away from the annular space if the dye was not inhibited by a seal on the borehole wall.

The second dye test results at the Trenton site showed that the dye penetrated 10 to 33 feet deeper in six of the nine wells. The two wells that lost circulation during the drilling process showed dye between 10 and 15 feet deep in 2007. Figure 35 shows the total monthly precipitation at the Palisades Weather Station and the green arrows indicate when each dye test was performed. The total amount of rain recorded between installation of these wells and the original dye test was about 25 inches, with less than 9 inches recorded in the six-month period prior to the test. During the six months before the 2007 dye test was performed 16 inches of precipitation was received. These data

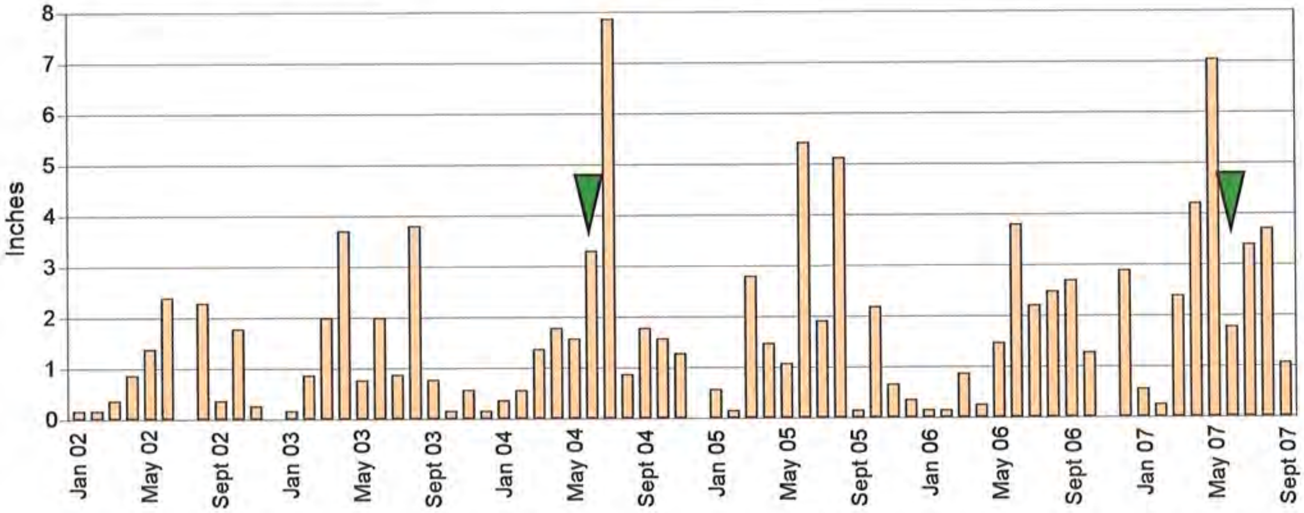

Figure 35. Comparison of monthly precipitation and dye test timing. Green arrow indicates date of dye test.

would support the supposition that the surface cracks sealed before the 2007 test was performed.

Dye was detected below the water table in four of the nine bentonite slurry wells at the Trenton site. The pretest field forms for these wells indicated that the grout had a number of cracks and voids between the static water level and the maximum depth that dye was detected, between 45-66 feet deep. Since the water level at this site did not vary, we compared water chemistry results between the Pilger and Trenton sites. There was little variation in key parameters. The only variation noted in this depth interval was a change in sediment size from mainly silt to sand and gravel below the maximum dye depth. However, this variation in geologic material did not impact the other five grout installations. Additional video viewing and research are needed before these results can be explained.

The 24-hour videos at the Pilger site showed dye remained in three of the wells. In two of the wells the dye moved an additional 6 to 7 feet deeper and in the third well the dye was detected at a level 2 feet higher. At the Grand Island site dye remained 2 feet higher in one of the two wells in which dye was detected during the test and dye was seen in another well that had no dye detected in one hour. At the Trenton site dye was detected twenty-four hours later in only the four wells where the dye had moved below the water table within one hour of opening the dye tank valve. In two wells the dye had moved 2 to 5 feet deeper and in the other two wells it remained at the same depth.

Overall, dye was detected twenty-four hours after beginning the test in 30 percent of bentonite slurry wells and it moved 2 to 7 feet deeper in 19 percent of the 27 grout observation wells. The results of the 2006 cement-based dye tests showed that the dye remained in 93 percent of the installations after twenty-four hours. In 67 percent of the installations the dye moved deeper twenty-four hours after the dye tank valve was open. These results suggest that most of the dye movement in bentonite slurry grouts occurs within a relatively short period of time whereas the maximum movement of dye in the cement-based grout takes longer. Additional field testing is necessary to more accurately define the optimal duration of video viewing during dye tests in order to assess the maximum depth of dye penetration in the various grout columns.

For the 2007 dye test of the bentonite chip well at Grand Island, a packer was set below the cracked casing so that the dye would not enter the well. No dye was detected in the chip wells at Pilger and Grand Island. At Trenton the dye was detected to a depth of 25 feet one hour after the test began. Twenty-four hours later no dye was detected. This dye test video was viewed on a large screen by the NGTF technical team in April 2009. The intervals where dye was detected in the field were reddish but this coloring appeared to be an iron oxide coating on the individual bentonite chips and not dye moving within the grout column. Additional video viewing would be required to confirm this explanation. Using the field results from Trenton, the average percentage of the unsaturated zone penetrated by dye for the three chip wells is 27%. When this result is substituted into Table 12, the performance of bentonite chip grout would rank second best using the results of three dye tests.

In general the performance of the geothermal grout material was worse at the Maskenthine site and the test results were very different from the 2005 test results. The Grand Island site grout performance was mainly improved and relatively similar to the 2005 dye test results. No additional analyses were performed on these data at this time. At the Lake McConaughy site the individual installation results of the 2007 dye test correlated reasonably well with the 2005 test result. The average depths of dye detection for the 20 percent solids grout were 99 and 124 feet and for the 60 percent solids the average depth was 21 and 26 feet for the 2005 and 2007 tests, respectively. The overall average results for this site, 60 feet in the original test and 69 feet in the second test, indicate that dye test results for some geothermal installations can be replicated relatively closely within a two year period.

No dye was detected in any of the cement-based wells during the 2007 dye test or the 24-hour inspection. At present the reason for this is not apparent. A number of possibilities exist including the potential that the micro-annular space between the casing and the grout was sealed by precipitation of calcium carbonate or fine sediment particles that were introduced with the dye in the original test. Another possibility could be that the red dye used in the 2007 tests was more difficult to detect than the yellow-green dye used in the original tests. Additional field work would need to be performed to substantiate any conclusion.

5.5 Comparison of Grout Nature and Performance

The Technical Team compared the results of the visual assessment and the maximum depth at which dye was detected on all installations. For the bentonite slurry grouts 63 percent of the results showed a good correlation between the visual assessment and performance of the grout (group A; Chapter 3, Section 4). This result could indicate that the method of visual assessment was relatively valid or that the one hour duration of the dye tests was reasonably sufficient to assess maximum depth of dye penetration. Dye was detected shallower than expected in 26 percent of the grouts. This could indicate that the dye test could possibly have been of longer duration or that there was no connection between the cracks and voids seen in the videos. Dye was seen deeper than expected in 11 percent of the grout observation wells. These 3 wells were all installed by supplier X; see section 1 of this chapter.

Two of the three bentonite chip grout results correlated well. The Trenton chip well in which dye was detected 24 feet deep was categorized as group C or indicated that the dye penetrated deeper than expected. The comparison between the results of the Pilger and Grand Island chip wells and the Trenton chip well again suggests the anomalous results of the dye test for the Trenton chip well.

We based the cement-based grout analysis on the 2006 one-hour dye test and the 24-hour inspection results. For the one-hour dye test results, 80 percent fell into group B, the dye was detected shallower then anticipated based on the visual ratings. The dye test and visual analysis results compared well in only one instance (7 percent). For the 24-hour inspection, the results correlated well in 33 percent of the cases and 53 percent of the comparisons showed dye remained shallower than expected. The increase from 7 to 33 percent of the grouts that showed good correlation between the monitoring techniques indicates that to properly assess cement grout performance the dye tests must be more than one hour in duration. These results could also indicate that the obstacles identified with the assignment of visual ratings were substantial enough to prevent an accurate visual assessment.

Comparison of the overall average results are presented in Table 13. The overall comparison is based on the performance and visual ranking (see Sections 2 and 3 of this chapter). We calculated the variation between the rankings by subtracting the performance rank from the visual rank. Therefore, a positive variation means that the grout performed better than it visually appeared and a negative variation means it performed worse than it appeared.

TABLE 13
OVERALL AVERAGE RESULTS

Grout type	Performance ranking	Visual ranking	Ranking variation
Cement-sand *	1	3.5	+2.5
Bentonite chip (All 3 wells)	2	1	-1
Neat cement -7 gallons H_2O *	3	5.5	+2.5
Concrete *	4	8	+4
Neat cement - 6 gallons H_2O *	5	2	-3
Cement-bentonite *	6	3.5	-2.5
Bentonite slurry >20%	7	5.5	-1.5
Geothermal-sand ~60%**	8	10	+2
Bentonite slurry =20%	9	7	-2
Geothermal ~20%**	10	11	+1
Bentonite slurry <20%	11	9	-2

* Based on maximum depth of dye in one- and 24-hour videos.
** Water level estimated from water table well

All cement grout comparisons had variations with a ranking of 2.5 or more. These variations showed both better and worse than anticipated performances. Based on these relatively large variations, the visual assessment ratings of the cement-based grouts are probably inaccurate either because of viewing difficulties or because this type of assessment is not appropriate for these grouts. Additional camera surveys would need to be performed and assessed prior to drawing any final conclusions.

The bentonite grout variations in rankings were much closer, a maximum of 2. The bentonite slurry in the geothermal installations performed better than it appeared, whereas in the well installations it performed worse than expected. It is possible that either the loop tubing or the centralizing clips were seen in the videos and interpreted as inconsistencies.

6.0 SUMMARY

6.1 Project and Management Design

A key element leading to the success of this study was the formation of the Nebraska Grout Task Force (NGTF) that included regulatory agency personnel, water well industry professionals, and grouting material manufacturers. The NGTF created administrative and technical teams to focus on the various aspects of this project. The administration team determined the broad scope of the study and obtained adequate funding to complete the project. The technical team developed the design details, provided on-site quality control and documentation, and analyzed the data.

The initial scope of this study was to evaluate the performance of varied percent solids content of bentonite slurry grouts over a 2-year period. The subsequent project expansions in this study tripled its duration, the required man-hours, and the volume of data collected. These project expansions complicated standard data collection and organization procedures and delayed the presentation of the results of the study. This could have been avoided by hiring a project coordinator to oversee and support all aspects of the project.

By adopting standards for minimum equipment requirements, the NGTF minimized variations in the drilling and completion phases of the grout observation installations. However, some deviations were encountered due to the open bid process that resulted in different contractors being awarded contracts for construction. These operations could have been more consistent if the bid process was structured so that one contractor was required to complete all installations. As evidenced in the bentonite chip grout wells, replication of installations would also improve the reliability of grout performance results. Given the inherent difficulty in controlling all aspects of field operations, such as the equipment cracking the casing during surface completion efforts, additional installations would have helped to substantiate the performance results.

When performing multiple down-hole camera surveys, standard procedures need to be developed in order to compare the visual nature of grout materials with more accuracy. These procedures need to include a maximum rate of camera movement, standard viewing angles, standard lighting type, and use of the same or similar down-hole camera equipment. Visual assessment of cements-based grouts requires a substantial amount of knowledge and experience with cement-based materials. Team members experienced with cement installations were much more capable of identifying inconsistencies and determining the probable causes of these irregularities than were inexperienced personnel. Comparison of the nature and performance of the grouts indicates that the rating system used in this assessment may not be applicable to cement-based grouts. Additional research is needed to refine a rating system for cement-based grouts.

An effort was made by the Technical Team to determine the amount of time necessary for the various grout types to reach equilibrium. We selected one well of each grout type and reviewed all four camera surveys and both dye test videos to assess the variability of the grouts through time. Little change in the nature of the bentonite slurry grouts was noted after the 90-day video and the bentonite chip grouts appeared to reach a static state within 30 days of installation. The cement-based grouts showed cracks in the grout column in the first day. The 30-day camera survey revealed very little change in the grout column except for additional evidence of the presence of a micro-annular space. Based on these observations the technical team proposes that dye tests can be performed 90 days after installation.

The results of the 24-hour dye test inspections performed on bentonite slurry grouts confirm that most of the dye movement occurs within a relatively short period of time. These results indicate that the one-hour test duration was reasonable, but that it could possibly be slightly longer. The comparison of the visual assessment and dye test results of the cement-based grouts suggests that more than one hour is required to determine the maximum depth of dye movement. Additional field testing is necessary to more accurately define the optimal duration of video viewing during dye tests to assess the maximum depth of dye penetration in grout columns. However, it is evident that different time spans are needed to compare different types of grout materials.

6.2 Drilling and Installation Methods

Results of this study indicate that sealing the borehole wall through the grout interval during the drilling process reduces the performance of bentonite slurry grouts. This was supported in the discussion of the drilling and installation, the 2004 and 2007 dye tests results at the Trenton site, and 2007 dye test results at the Grand Island site. The comparison of the visual assessment and dye test results also supports this conclusion. If site conditions require the use of drilling fluid additives to control fluid loss through the grout interval, then an effort needs to be made to break this wall cake down and to allow any potential surface contaminants to move away from the annular space.

As noted in the discussion of the visual assessment of the bentonite chip grout, the Pilger site grout exhibited a smooth appearance whereas the grouts at Trenton and Grand Island appeared to have a chunky texture. Industry suppliers indicated that this texture was probably due to incomplete hydration of the bentonite chips. The chips should be placed slowly into the annular space in order to allow for the complete hydration of a chip seal in the unsaturated zone. Thinning the drilling fluid with fresh water prior to placement might allow the chips to hydrate more completely, although this hypothesis was not field tested in this study.

Many drilling and installation problems occurred during the construction of the Maskenthine and Grand Island loop fields. In some cases there was a connection between boreholes that caused the previously installed loops to float during the drilling of the subsequent borehole. The designs of geothermal loop installations need to account for variable geologic conditions. At the Maskenthine site, it is likely that in at least two of the installations this connection was caused by dissolution fractures in the upper part of the Niobrara Formation. Loop field designs need to address site geology by either reducing the depth and increasing the number of loops or increasing the spacing between loops to reduce the potential for connection between boreholes in certain geological environments.

Review of some of the cement-based grout wells showed the infiltration of the grout through the bentonite chip seal and into the filter pack. Cement industry representatives recommend placing at least 2 feet of blotter sand between the cement and bentonite chip to prevent the breakdown of the seal. During placement of the concrete grouts there were larger than specified aggregates and clots of unmixed or dried cement. Off-site bulk mixing of grout material by contractors with little knowledge of well construction should be eliminated. Variation between the dye test results of the individual cement grouts at each of the sites was significant in most cases, but there appeared to be no consistency related to the performance between the sites. Because of the apparent erratic performance results it is possible that cement based grouts are less impacted by site conditions and may be more sensitive to mixing and placement operations.

6.3 Hydrogeologic Conditions

The results of this study demonstrated that bentonite slurry grouts appear to be most sensitive to the variable hydrologic conditions at the three study sites. Both visual and performance results indicated that the Trenton site conditions had the worst impact and the Grand Island site conditions had the least impact on these grouts. Based on the results of the 2005 study of the three original sites by Myers, sediment particle size and moisture content have the largest impact on bentonite slurry grouts.

The Trenton site is in the semi-arid climatic zone and the unsaturated zone sediments there are dominated by silt-sized particles. The sediments above the water table at the Pilger site are also dominated by silt-sized particles, however this site is in the moist subhumid climatic zone. The results of analyses of moisture content of cores, collected in the summer of 2003 at these sites, indicated that the upper 13 feet contained a maximum of 10% moisture and from 13- and 22-feet deep the moisture content was between 15%-20% at the Trenton site. The moisture content at the Pilger site was 15%-20% in the top 13 feet and 20%-30% from 13 to 20 feet deep. The moisture content of the unsaturated zone sediments at the Grand Island site was less than 15 percent; however the sediments were dominated by sand-sized particles.

The performance of cement-based grouts was impacted less by site conditions as noted in the discussion of dye test results. There was some indication that these grouts performed better at the Trenton site, based on site average results of all five grout recipes. However, due to inconsistent results noted earlier in these discussions no definitive conclusions can be made at this time about the impact of the site conditions on cement-based grouts.

6.4 Grout Compositions

During the early stages of the study it became apparent to the technical team that there was a substantial difference in the nature of the grout column above and below the water table. The bentonite slurry grouts exhibited cracks and some voids in the unsaturated zone. Below the water table there was little evidence of cracking, however there were some anomalies that appeared to be related to the placement of the grout. The bentonite chip grouts showed few inconsistencies above and below the water table, with the exception of the Trenton site well. The cement-based grouts appeared cracked above and below the water table. There was also evidence of areas where the grout failed to bond to the casing thus creating a micro-annulus. Additional video viewing and possible field investigations are needed to objectively assess the variability of grout column above and below the water table.

The performance results indicate that increased solids content enhanced grout performance at one of the three study sites. This is also supported by the overall average depth of dye detection of all installations with the same solids content. The variation of drilling fluid programs noted previously may have impacted the average percent solids results of the dye test. The results of the visual assessment at two of the study sites and the overall average results of this assessment indicate that an increase in solids content in bentonite slurry grouts improves their performance somewhat. However, the variation of visual and performance results between grouts with solids content between 16 and 30 percent was not substantial.

Results of this study suggest that grout performance cannot be compared when the installations are different. This was noted in the discussion of both visual and performance results of bentonite slurry with 20% solids content in wells and geothermal loop installations. Since the impact of temperature variations due to the utilization of the geothermal system can be ruled out, the major variation between the types of installations is the configuration of the area that the grout is expected to seal. In the grout observation wells the grout sealed a 2- to 2¾-inch annular space free of obstructions except for centralizers every twenty feet. In the geothermal installations the grout interval was an open 9½- to 10-inch borehole with two ¾-inch loops, centralizing clips every ten feet, and a 2-inch clear casing for viewing the grout.

The average depth of dye detection for the Lake McConaughy site and the average results of all geothermal installations with 20 percent solids content and 60 percent solids content indicated that the addition of sand to bentonite slurry grouts helps maximize their performance. The results at the Grand Island and Maskenthine sites, however do not support this conclusion. The numerous difficulties encountered during drilling and installation of the loops at these sites may have caused these contradicting results. Additional geothermal loop installations would be needed to validate the results from the Lake McConaughy site installations.

No dye was detected in two of the three chip grout installations tested in 2007. The dye test field forms of the Trenton well indicated that dye was detected to a depth of 24 feet however, the technical team determined these results were inconclusive based on a review of this video. Additionally, the comparison of the nature and performance of the grout indicated that the dye penetrated deeper than expected in this well. Based on these analyses, it is probable that the dye test results for the Trenton chip installation are inaccurate and not indicative of bentonite chip grout. Additional video review and possibly additional bentonite chip installations would be necessary to corroborate this conclusion.

The results of the original dye tests performed on cement-based grouts suggest that the cement with sand performed the best and the cement with bentonite performed the worst overall. However, there was not a substantial difference in the accumulative maximum depth of dye detection for all the cement-based grouts. In the 2007 dye test no dye was detected in any of the cement-based grout videos. Possible explanations for this lack of detection include the potential that the micro-annular space between the casing and the grout was sealed by precipitation of calcium carbonate or that fine sediment particles were introduced with the dye in the original test. Another possibility could be that the red dye used in the 2007 tests was more difficult to detect than the yellow-green dye used in the original tests. Additional field work would need to be performed to validate any conclusion.

We used the calculated percentage of unsaturated zone penetrated by dye to rate the performance of each grout. The results of the original dye tests and the 2007 tests of the Grand Island chip well indicate that the sand cement and bentonite chip grouts performed the best overall with 24% and 27%, respectively. The results for the other cement-based grouts were grouped together with 37%-48% of the unsaturated zone penetrated. The results for the bentonite slurry with more than 20 percent solids and the geothermal grouts with sand were between 65% and 67%. The average percentage of the unsaturated zone that was penetrated by the dye in the wells with bentonite slurry containing 20 percent solids was 75%. These data also suggest that the bentonite slurry with less than 20 percent solids and the geothermal grout without sand performed the worst with 86% and 87%, respectively.

There remain a number of unresolved questions identified in the discussion of the results of this study, Chapters 5 and 6. For example, the conflicting findings of the 2004 and 2007 dye tests at the Trenton site demonstrate the need for additional research related to longer-term assessment of the various grout columns. However, since grout is designed to seal the annular space to protect the quality of groundwater, the NGTF decided to focus on the unsaturated zone. In 2006 the NGTF began the design of a second field study that included testing of new annular seal materials above the water table.

7.0 UNSATURATED ZONE STUDY - DESIGN AND PROGRESS

This study was initiated based on the results of the 2004 through 2006 dye tests that showed dye movement through the unsaturated zone in all grout types tested. The NGTF technical team was directed to develop and test potential annular seal materials that may be resistant to the physical and chemical differences in the unsaturated zone. The objective of this unsaturated zone study was to identify materials that divert water away from the borehole in the unsaturated zone. Further, these materials were to be economical as well as easily placed using standard grouting equipment.

This study was designed to include different drilling techniques and annular fill placement methods. In 2008, twelve installations were drilled using standard mud rotary techniques, 4 were done using auger drilling equipment, and 2 were completed using direct push technology. Twelve slurry annular fill materials were placed through a tremie using a grout mixer. Dry annular fill materials were mixed on the surface and placed into a funnel connected to the tremie pipe. Two fill materials were placed by allowing the material to freefall from the surface.

The Technical Team selected the original study sites at Pilger, Grand Island, and Trenton for installation of these wells because site evaluation data were readily available. The annular fill materials used granular bentonite, chip bentonite, cement, sand, pea gravel, and additives in different combinations. Drill cuttings were placed in one well to assess the performance of this fill material because it is often used as an annular fill material in smaller diameter well installations in Nebraska. Some of the materials tested were still in the experimental stages of development.

Installation of the unsaturated zone grout observation wells began in April and was completed in August of 2008. Additionally, clear-access casing was installed in one geothermal loop installation in both the eastern and western portions of the state. The eastern loop installation was constructed in September 2007 in Lincoln and the western loop installation was constructed in October 2008 near Big Springs. NDHHS personnel performed camera surveys on all installations 24-48 hours after well installation. Thirty and sixty days later the second and third camera surveys were performed. Dye tests were performed 90 days after the grout observations were completed.

Analysis of the unsaturated zone study camera surveys and dye test videos has begun, but is incomplete at this time. It is the hope of the NGTF that results of these analyses will provide water well industry professionals with information leading to formulation of better grout materials that protect our groundwater resources.

8.0 REFERENCES

Myers, W.F., 2005, Water Well Annular Seal Conditions and Stratigraphic Characteristics of the Unsaturated Zone: Case Studies from Nebraska: Lincoln, University of Nebraska, M.S. Thesis. 110 pp.

NGTF Technical Team, 2002, Grout Task Force: Phases I and II Task Completion Report. 101 pp.

NGTF Technical Team, 2003, Grout Task Force: Phases I and II Task Completion Report. 69 pp.

High Plains Regional Climate Center, http://www.hprcc.unl.edu/data/historical/. (Accessed April 22, 2009)

Ohio Department of Health, Bureau of Local Environmental Heath Services, 2000, Dye Testing Wells. 6pp.

Olafsen-Lackey, S., Myers, W.F., Christopherson, T.C., Gottula, J., 2009, Nebraska Grout Task Force Project Report; In-Situ Study of Grout Materials 2001-2006 and 2007 Dye Testing: University of Nebraska, Conservation and Survey Division, Reprint Series OFR-104. 98 pp.

9.0 ACKNOWLEDGMENTS

The Water Well Standards and Contractors Licensing Board was created in 1986 by adoption of the Water Well Standards and Contractors Licensing Act. The board includes of 6 members from the ground water industry, 3 members from government regulatory agencies and a representative from the Conservation and Survey Division of the University of Nebraska. When water wells in Nebraska are registered, a part of the registration fee is deposited in the Water Well Standards and Contractors Licensing Board fund. This fund was the source of 65 to 70 percent of funds used for this grout research study, including the cost of this publication.

The grout industry suppliers, WyoBen, Inc, Cetco, and Baroid, provided a large amount of the drilling and construction materials as well as a substantial amount of time during the design and construction phases of this project. The drilling crews from Sargent Irrigation, Layne-Western, and Loop-Tech worked long hours under adverse weather conditions and a substantial amount of scrutiny.

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