Layne GeoSciences

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Mr. Glenn Dostal, P.E.
HDR Engineering
8404 Indian Hills Drive
Omaha, Nebraska 68114

REGARDING: RESULTS OF TASK 320 TEST DRILLING FOR LEWIS & CLARK RURAL WATER SYSTEM

Dear Mr. Dostal:

A preliminary test drilling program was recently conducted for the Lewis & Clark Rural Water System in Clay County, South Dakota. The purpose was to identify potential sites for construction of several Ranney Collector wells to develop a total combined water supply of approximately 30 million gallons per day (MGD) from ground water enhanced by induced infiltration of surface water.

LOCATION

The test holes were drilled in the unconsolidated glacio-fluvial aquifer system along the Missouri River south-southwest of the City of Vermillion, in Vermillion Township, Clay County, South Dakota. Sites U, V and W are on the north bank of the river, east of the Clay State Recreation Area on properties owned by Bottolfson and Heine in Sections 27 and 28 of T92N-R52W (South Dakota Survey). Sites B, D and F are on the east bank of the river, west of the State Route 19 extension on property owned by the State of South Dakota Department of Transportation in Sections 35 and 36 of T92N-R52W (South Dakota Survey). Site A is about 4000 feet east of the Missouri River, approximately along the section line between Sections 26 and 25, T92N-R52W.

FIELD PROCEDURES

Field reconnaissance was conducted to stake test hole locations and determine site access requirements. Then, a total of seven (7) test borings were drilled to total depths ranging from 75 to 120 feet. The borings were drilled using mud-rotary methods with a 94mm core sampling system. Four (4) of the boreholes were reamed to a larger diameter and completed as observation wells (Sites U, W, B and D). On-site geologist supervision was provided during drilling of the first borehole.

Borehole SP and resistivity logs were also obtained. Where possible, the borings were drilled into bedrock in order to provide a sump for drill cuttings to increase the potential to log full depth of the borehole and to provide maximum definition by comparison of rock and unconsolidated deposits.

Soil samples were obtained at five (5) feet intervals and change in formation from drill cuttings and/or the 94mm core barrel sampling system. Drilling logs were maintained that included formation description and depth of changes, relative penetration resistance, sample recovery, drilling mud loss, and water levels. Selected soil samples were dry sieved and gradation analysis was performed.

The observation wells were constructed with 10-feet of 4-inch diameter Schedule 40 PVC slotted screen with flush-threaded PVC riser extending at least 2 feet above grade. The annular space between the casing and borehole was sealed with bentonite chips from a depth of 20 feet to grade and the wells were completed with a protective surface casing and locking cap. Abandonment of boreholes that were not completed as observation wells was conducted by collapsing the borehole and placing bentonite chips from a depth of 20 to 30 feet to grade.

TEST DRILLING RESULTS

The test holes encountered bedrock, the Graneros Shale, at decreasing depths from west to east of 99, 98, and 94 feet below grade at Sites U, V and W, respectively. Along Mulberry Bend, bedrock was encountered at decreasing depths from north to south of 111, 110, 95 and 75 feet below grade at Sites A, B, D and F, respectively. The unconsolidated deposits overlying the bedrock were comprised of a generally downward coarsening sequence of interbedded clays, silt, sand, gravel and cobbles. Lithologic well logs, resistivity logs, and sieve analysis data and graphs are attached. Sieve analysis results are summarized in Table 1. Test boring results are also described below.

Site U

Unconsolidated deposits encountered in TH1 at Site U were generally comprised of fine to medium sand interbedded with layers of clay and silt; little coarse sand and gravel was encountered. The coarsest and most permeable materials at Site U were encountered in two horizons: the upper horizon, from about 52 to 62 feet below grade, has a 40% retained grain size of 0.033 to 0.055-inches; the lower horizon, from about 85 to 99 feet has a 40% retained grain size of 0.066 to 0.080-inches. These horizons are separated by a 23-feet thick section of gray clay and gray sandy, clayey silt.

Site V

Deposits encountered at TH2 in Site V were finer than Site U, with essentially no gravel except for the bottom 2 feet. Two main sand horizons were encountered, one at 11 to 58 feet and one at 84 to 97.5 feet, however sieve analyses indicated that the 40% retained grain size was only 0.010 to 0.020-inches. No observation well was installed at this site.

Site W

In TH3 at Site W, a thick sequence of fine sand was encountered from grade to bedrock at a depth of 94 feet; no clays were indicated. The 40% retained grain size ranged from 0.008 to 0.020 and the material was very uniform with a uniformity coefficient of 2 to 4.

Site B

Surficial deposits encountered in TH4 at Site B were comprised of fine brown sand to 5 feet and clay to a depth of 10 feet below grade. This was underlain by gray sand to a depth of 50 feet. Coarse sand and gravel was encountered from 50 to 85 feet. Below 85 feet the drilling was reported to be difficult. Coarse gravel, some sand and a few cobbles were reported from 85 to 102 feet; and immediately overlying bedrock, from 102 to 110 feet, broken gravel, cobbles and boulders were encountered. From 50 to 55 feet the 40% retained grain size was 0.055-inches; from 55 to 100 feet the 40% retained size was 0.100 to greater than 0.200-inches. From 100 to 110 feet, only wash samples could be obtained and the 40% retained size was 0.150 to 0.195-inches.

Site D
TH-5 at Site D found soil materials similar to Site B, except that bedrock was encountered at a shallower depth and the thickness of coarser sand and gravel deposits was less. Surficial deposits were comprised of fine sand to 4 feet, brown clay to 9 feet and very fine silty sand to 25 feet below grade. From 25 to 70 feet below grade was gray sand with a 40% retained grain size of 0.020-inches or less. Based on the sieve analysis, coarse sand and gravel with a 40% grain size of 0.185-0.193-inches was encountered from 70 to 80 feet. Overlying the bedrock, from 80 to 95 feet, coarse sand and broken angular gravel was encountered with a 40% size of greater than 0.200-inches.

Site A
Surficial deposits encountered in TH-6 at Site A were comprised of interbedded clay and sand to a depth of 50 feet (gray clay from grade to 9 feet, brown to gray sand from 9 to 26 feet, clay from 26 to 27 feet, and sand from 27 to 50 feet). A thick layer of clay to laminated sandy, silty, clay was encountered from 50 to 82 feet below grade. Sand with a 40% retained grain size of 0.017 to 0.041 was found from 82 to 100 feet and the driller reported that this formation was "tight". Immediately overlying bedrock, coarse sand and broken gravel with a 40% size of .151 to .164-inches was encountered from 102 to 111 feet below grade. No observation well was installed at this site.

Site F
Unconsolidated deposits encountered in TH7 at Site F were comprised of interbedded layers of clay (ranging from 1 to 9 feet thick) and sand (ranging from 3 to 14 feet thick) throughout the section. Bedrock was at a depth of 75 feet below grade. No observation well was installed at this site.

Assuming a static water level at 10 to 23 feet below grade, saturated aquifer thickness is estimated at 86 to 81 feet at the north sites and 87 to 65 feet along Mulberry Bend. At Sites B and D, it is anticipated that centerline of laterals would be at approximately 85 feet below grade and that the design pumping level would be at least 10 feet above the laterals. Therefore, average aquifer thickness (considering both pumping and static conditions) is estimated at 77.5 to 85 feet.

CONCLUSIONS

The coarsest and most well sorted aquifer materials and the thickest section of these materials were encountered at Site B; followed by Site D. Therefore, Sites B and D (and Site C by inference) are believed to be the most favorable sites for water supply development. Sites W and U are considered marginal because of the generally fine grained aquifer materials, and at Site U, because of the intervening clay layers. The least favorable site was Site F, because of the large amount of silt and clay throughout the section, followed by Sites V and A.

Estimated Collector Yield

Utilizing the following equation by Mikels and Klaer:

$$Q = \frac{(K)\ (m)\ (s)}{229 \ln [(2a)/r)]}$$

Based on the available data, including qualitative review of the drillers logs and soil sample grain size analyses, and general experience, the following parameters are estimated for Sites B and D (and are assumed to be the same for Site C), where:

K = Hydraulic Conductivity ..... 1800 - 2000 gpd/ft^2
m = Average Saturated Aquifer Thickness ..... 77-85 feet
s = Adjusted Drawdown ..... 42 feet
a = Distance to a Line Source of Recharge ..... 1000 feet
r = Effective Radius of Collector ..... 60 feet

Therefore, by substitution, it is estimated that a single Ranney Collector Well installed adjacent the Missouri River in the vicinity of Sites B, C and D may yield approximately 10.4 to 12.8 MGD, depending upon seasonal river stage, ground water temperature and recharge conditions.

It is anticipated that Site W would have to be gravel packed and that the potential yield of Site W is probably half that of Sites B and D.

RECOMMENDATIONS

Recommended Aquifer Testing

Prior to collector design and construction, it is recommended that aquifer testing be conducted at Sites B, C and D in order to confirm hydraulic characteristics of the aquifer, recharge potential and ultimately, collector well yield and optimum design. Aquifer testing should include a four-hour variable-rate step test, a minimum 12-hour recovery period, a 72-hour constant-rate pumping test and a 24-hour recovery test. It is anticipated that the variable-rate test will be conducted at four (4) successively higher rates, such as 600, 800, 1000 and 1200 gpm, with each held constant for a one hour period. It is anticipated that the constant-rate test will be conducted at approximately 1000 gpm (the minimum acceptable is 800 gpm; the maximum is probably 1200 gpm). Whichever rate is selected for the constant-rate test must be kept stable at +/- 2%.

Test Pattern Layout

At each aquifer test site, a total of six observation wells should be installed (including the initial observation well) in a T or L pattern. There should be two lines of wells that are perpendicular to and toward the river (R-line) and parallel to the river (P-line). The temporary test production well should be installed at the apex of the two lines. A sketch of optional test patterns and well spacings has been previously submitted.

Observation Well Construction and Design

The observation wells should be drilled and installed to a depth of 85 to 90 feet and equipped with 10-feet of 20-slot 2-inch diameter Schedule 40 flush threaded screen and riser; natural pack design is acceptable. A surface seal should be emplaced from a depth of at least 20 feet to grade in the annulus between the riser and borehole; the pvc riser should have a thumb-screw type water tight cap; surface completion should include a 5-feet steel protective casing with locking cap, cemented into place. All well construction should be conducted in accordance with State regulations.

River Stilling Well and Well Points

A river stilling well should be installed at a distance of approximately 50 feet upstream from the test discharge, however, actual location may be adjusted depending upon field conditions. Up to three well points should be installed in the river. Well point location and installation should be directed by the supervising geologist, but will depend in large part on safety considerations. If possible, a triangular pattern is preferred, however, a parallel pattern close the river bank is also acceptable and may be the only safe option. The well points should be equipped with 2-feet of screen or mesh and should be driven so that the top of the screen is three to five (3-5) feet below the river bottom. The well points should be tested to be sure that they are open to the aquifer and not the river.

Test Production Well Design and Construction:

It is recommended that the temporary test production well be drilled utilizing either A) reverse rotary methods with only clear fresh water with no drilling fluid additives, or B) cable tool drilling using the pull-back method of screen installation. Preliminary recommended test well design is the same for both Sites B and D, as summarized below.

If installed natural pack, the test well(s) should be equipped with 15 feet of nominal 12-inch diameter 0.100-inch (100 slot) well screen installed at a depth interval of 75 to 90 feet below grade. If gravel packed, the well may be equipped with 20 feet of 12-inch diameter 100 slot screen from 70 to 90 feet below grade and the gravel pack material should be Luther Maddox AA. The well screen should be wire-wound; it may be stainless or carbon steel. Minimum borehole diameter for a gravel packed well should be 18 inches. Final design of the temporary test production well(s) will depend upon results of drilling, soil sampling and sieve analysis at each test well location.

CLOSURE

Results of the initial test drilling program for the Lewis and Clark Rural Water Supply System indicate that it may be possible to develop the required water supply from three (3) Ranney Collector Wells along Mulberry Bend at Sites B, C and D. Test drilling at Site C will be required to confirm physical characteristics of the aquifer and aquifer testing at all three sites is recommended to determine hydraulic characteristics, infiltration capacity and yield.

Please do not hesitate to contact me if you have any questions. Thank you for the opportunity to participate in this important project.

Respectfully Submitted,

Layne Christensen Company

Kathryn Epp, CPG
Project Manager/Sr. Hydrogeologist

Enclosures
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TABLE 1
SUMMARY OF SIEVE ANALYSIS RESULTS
LEWIS & CLARK RURAL WATER SUPPLY PROJECT
CLAY COUNTY, SOUTH DAKOTA

Depth Interval below grade (feet)	SITE U - TH1			SITE V - TH2			SITE W - TH3			SITE B - TH4			SITE D - TH5			SITE A-ALT - TH6		
	Retained 40% (Inches)	Retained 90% (Inches)	Unif. Coef.	Retained 40% (Inches)	Retained 90% (Inches)	Unif. Coef.	Retained 40% (Inches)	Retained 90% (Inches)	Unif. Coef.	Retained 40% (Inches)	Retained 90% (Inches)	Unif. Coef.	Retained 40% (Inches)	Retained 90% (Inches)	Unif. Coef.	Retained 40% (Inches)	Retained 90% (Inches)	Unif. Coef.
25-30							0.010	0.005	2.0									
30-35	0.014	0.008	1.8	0.016	0.005	3.2	0.020	0.005	4.0							0.027	0.007	3.9
35-40	0.021	0.008	2.6	0.019	0.008	2.4	0.018	0.007	2.6							0.034	0.013	2.6
40-45				0.019	0.005	3.8	0.016	0.005	3.2							0.032	0.013	2.5
45-50	0.017	0.008	2.1	0.021	0.005	4.2	0.02	0.006	3.3	0.017	0.005	3.4	0.014	0.004	3.5	0.520	0.013	40.0
50-55	0.033	0.008	4.1	0.022	0.012	1.8	0.007	0.003	2.3	0.011	0.005	2.2	0.017	0.004	4.3			
55-60	0.055	0.007	7.9	0.016	0.005	3.2	0.015	0.005	3.0	0.055	0.01	5.5	0.021	0.013	1.6			
60-65							0.008	0.004	2.0	0.103	0.014	7.4	0.009	0.003	3.0			
65-70							0.015	0.006	2.5	0.139	0.043	3.2	0.018	0.005	3.6			
70-75							0.016	0.005	3.2	0.140	0.047	3.0	0.185	0.013	14.2			
75-80	0.012	0.005	2.4	0.010	0.005	2.0	0.018	0.007	2.6	0.200	0.015	13.3	0.193	0.057	3.4			
80-85	0.015	0.006	2.5	0.010	0.006	1.7	0.016	0.006	2.7	0.150	0.027	5.6	>.200	0.094	2.1	0.017	0.007	
85-90	0.066	0.014	4.7	0.016	0.006	2.7	0.019	0.009		0.179	0.044	4.1	>.200	0.098	2.0	0.022	0.009	
90-95	0.080	0.018	4.4	0.068	0.003	22.7										0.041	0.011	
95-100										>.200	0.060	3.3				0.040	0.010	
100-105										0.195	0.053	3.7				0.151	0.040	
105-110										0.150	0.056	2.7				0.164	0.054	

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FIELD BORING LOG

Boring Number: Site D TH-5

Project: Lewis & Clark Rural Water Supply Project
Location: Site B D 2
Drilling Method: Mud-Rotary with 94-mm core sampler
Job No. _____ **Date:** 5/4-7/01
Driller: Duane Trask
Drill Fluid: Potable water with bentonite

Depth (Feet) From	Depth (Feet) To	Description	Sample Type & No.	Depth (Feet)	Recovery (Inches)
0	4	SAND, brown, fine	wash	0-5	na
4	9	CLAY, brown, silty	wash	5-10	na
9	25	SAND, brown, very fine, silty (powdery)	wash	10-15	na
25	50	SAND, gray, fine-medium-coarse	94 mm	15-20	30"
50	60	SAND, gray, fine-coarse, few fine gravel (<10%)	94 mm	20-25	30"
60	63	SAND, gray, fine-medium-coarse	94 mm	25-30	30"
63	75	SAND, gray, fine-medium-coarse, few coarse-very coarse gravel	94 mm	30-35	30"
		SAND, gray, coarse, and broken, angular, medium GRAVEL, drilled	94 mm	35-40	30"
75	95	rough (ruined drill bit)	94 mm	40-45	30"
95	100	BEDROCK, limestone	94 mm	45-50	30"
			94 mm	50-55	30"
			94 mm	55-60	30"
			94 mm	60-65	30"
		resisitivity log to 86 feet; hole wouldn't stay open below this	94 mm	65-70	30"
			94 mm	70-75	30"
		depth interval mud viscosity mud loss	wash	75-80	na
		0-25' 29 6"	wash	80-85	na
		25-50' 30 11"	wash	85-90	na
		60-75' 30 9"	wash	90-95	na
		75-95' 34 18"			

WELL CONSTRUCTION / MATERIALS

Set 10 feet of Sch 40 PVC 4" diameter flush threaded screen from 75 to 85 feet below grade; set 78 feet of flush threaded riser from 75 to +3 feet.
Developed by surging, bailing and pumping.

WATER LEVEL OBSERVATIONS

After Completion _____ (Feet)

SIEVE ANALYSES
SITE D - TH-5
Location: Vermillion, South Dakota
Project Name: Lewis & Clark Rural Water Supply Project

SIEVE SIZE			Weight	Cum. Wt.	Cum % Ret.	Weight	Cum. Wt.	Cum % Ret.	Weight	Cum. Wt.	Cum % Ret.	Weight	Cum. Wt.	Cum % Ret.	Weight	Cum. Wt.	Cum % Ret.
no.	mm	inches	Depth Interval:		45-50	Depth Interval:		50-55	Depth Interval:		55-60	Depth Interval:		60-65	Depth Interval:		65-70
4	4.750	0.185		0.0	0.0%		0.0	0.0%		0.0	0.0%		0.0	0.0%		0.0	0.0%
8	2.360	0.093		0.0	0.0%		0.0	0.0%		0.0	0.0%		0.0	0.0%		0.0	0.0%
16	1.300	0.051	20.00	20.0	3.9%	25.00	25.0	4.9%	72.00	72.0	14.3%	14.00	14.0	2.8%	137.00	137.0	27.2%
20	0.833	0.033	5.00	25.0	4.9%	5.00	30.0	5.9%	25.00	97.0	19.2%	7.00	21.0	4.2%	12.00	149.0	29.6%
30	0.600	0.023	17.00	42.0	8.3%	10.00	40.0	7.9%	71.00	168.0	33.3%	17.00	38.0	7.6%	25.00	174.0	34.5%
50	0.300	0.012	209.00	251.0	49.4%	318.00	358.0	70.6%	257.00	425.0	84.2%	88.00	126.0	25.1%	92.00	266.0	52.8%
100	0.130	0.005	196.00	447.0	88.0%	85.00	443.0	87.4%	49.00	474.0	93.9%	280.00	406.0	81.0%	203.00	469.0	93.1%
200	0.075	0.003	37.00	484.0	95.3%	52.00	495.0	97.6%	20.00	494.0	97.8%	67.00	473.0	94.4%	24.00	493.0	97.8%
Pan + wash past 200			24.00	508.0	100.0%	12.00	507.0	100.0%	11.00	505.0	100.0%	28.00	501.0	100.0%	11.00	504.0	100.0%

SIEVE SIZE			Weight	Cum. Wt.	Cum % Ret.	Weight	Cum. Wt.	Cum % Ret.	Weight	Cum. Wt.	Cum % Ret.	Weight	Cum. Wt.	Cum % Ret.	Weight	Cum. Wt.	Cum % Ret.
no.	mm	inches	Depth Interval:		70-75	Depth Interval:		75-80	Depth Interval:		80-85	Depth Interval:		85-90	Depth Interval:		90-95
4	4.750	0.185	201.00	201.0	39.9%	219.00	219.0	43.0%	271.00	271.0	54.0%	269.00	269.0	54.0%	341.00	341.0	68.3%
8	2.360	0.093	53.00	254.0	50.4%	194.00	413.0	81.1%	182.00	453.0	90.2%	186.00	455.0	91.4%	122.00	463.0	92.8%
16	1.300	0.051	48.00	302.0	59.9%	50.00	463.0	91.0%	28.00	481.0	95.8%	25.00	480.0	96.4%	17.00	480.0	96.2%
20	0.833	0.033		302.0	59.9%		463.0	91.0%		481.0	95.8%		480.0	96.4%		480.0	96.2%
30	0.600	0.023	82.00	384.0	76.2%	20.00	483.0	94.9%	8.00	489.0	97.4%	7.00	487.0	97.8%	6.00	486.0	97.4%
50	0.300	0.012	82.00	466.0	92.5%	15.00	498.0	97.8%	6.00	495.0	98.6%	6.00	493.0	99.0%	5.00	491.0	98.4%
100	0.130	0.005	29.00	495.0	98.2%	8.00	506.0	99.4%	4.00	499.0	99.4%	3.00	496.0	99.6%	4.00	495.0	99.2%
200	0.075	0.003		495.0	98.2%		506.0	99.4%		499.0	99.4%		496.0	99.6%		495.0	99.2%
Pan + wash past 200			9.00	504.0	100.0%	3.00	509.0	100.0%	3.00	502.0	100.0%	2.00	498.0	100.0%	4.00	499.0	100.0%