Drought Assessment and Local Scale Modeling of Osceola County Rural Water District

Water Resources Investigation Report 11

The University of Iowa
IOWA GEOLOGICAL SURVEY
IIHR Hydroscience & Engineering

Drought Assessment and Local Scale Modeling of Osceola County Rural Water District

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Iowa Geological Survey
Water Resources Investigation Report 11

IOWA GEOLOGICAL SURVEY

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EXECUTIVE SUMMARY

The Iowa Geological Survey (IGS) completed a drought assessment to evaluate current and future groundwater availability for the Osceola County Rural Water District (OCRWD) wellfield near May City, Iowa. In addition, a calibrated groundwater flow model was constructed to provide OCRWD with various strategies to enhance and increase both aquifer storage and induced recharge. For the purposes of this summary report the aquifer will be referred to as the Ocheyedan aquifer. The current users include the Osceola County Rural Water District North Wellfield (OCRWD), and approximately twenty-three irrigation wells.

OCRWD has limited additional groundwater and wellfield expansion potential under current conditions in the northern half of its wellfield. Well D-1 obtains a majority of its water production from induced recharge, and Wells H-1 through H-4 obtain almost half of their water production from induced recharge. Critical streamflow conditions occurred during the fall of 2014 in the vicinity of the H-Series wells. Adding additional wells near Well D-1 or the H-Series wells could result in a sharp increase in drawdowns and an overall decrease in water production during a moderate to severe drought.

The groundwater flow model was used to estimate the percentage of water obtained from induced recharge. Based on model results, well D-1 had the highest percentage of induced recharge at 70 percent or 362,000 gallons per day (gpd). This was followed by the H-Series sub-wellfield, which had 44 percent or 672,000,000 gpd. The CD-Series and the RS-Series sub-wellfields had relatively small percentages (19%, 304,000 gpd) and 0.6%, 6,500 gpd). Wells D-3 and the RS-Series wells are located between 1,200 and 4,800 feet from the Ocheyedan River. This greatly reduces the induced recharge that can occur in these sub-wellfields.

Based on model results, a proposed low-head dam downgradient of the H-Series production wells would raise the river stage approximately 3 feet immediately behind the dam during low flow conditions. Increases in water table elevations from a potential low-head dam range from over 2 feet in wells H-3 and H-4, to 1 to 1.5 feet in wells H-1 and H-2. The estimated increase in groundwater storage would allow the H-Series wells to maintain water production even during a severe drought. Induced recharge would increase from 44% (without the low-head dam) to 67% with the low-head dam. Adding additional production wells in the H-Series sub-wellfield may be possible.

Based on model results, a proposed low-head dam downstream of the CD-Series wells would raise the river stage approximately 3 feet immediately behind the dam during low flow conditions. Based on the model simulation, increases in water table elevations range from 1 to 1.5 feet in wells C-1R and C-2R, to 0.5 to 1 foot in wells D-2R2 and D-4R1. Based on the model results, well D-3 would not benefit from the proposed low-head dam. The increase in groundwater storage created by a low-head dam would benefit the CD-Series sub-wellfield. Induced recharge would increase from 19% (no low-head dam) to 56% (with a proposed low-head dam).

Based on model results, a proposed low-head dam and cutoff channel would increase the induced recharge available to the CD-Series wells from 19% (no low-head dam or cutoff channel) to 72% (low-head dam and cutoff channel). Based on model results, increases in water table elevations range from 1.5 to 2 feet in wells C-1R, C-2R, and D-4R1, to 1 to 1.5 feet in wells D-2R2, and D-4R1, and between 0.5 and 1 foot in well D-3. The combination of a proposed low-head dam and cutoff channel not only increases the induced recharge, but is more effective at increasing overall groundwater storage compared to a low-head dam alone.

Based on model results, a proposed earthen berm near Well D-1 would increase the water table elevation approximately 2 feet. The potential increase in groundwater storage would allow well D-1 to maintain water production even during a severe drought.

A possible strategy for the RS-Series wells might involve the decommissioning of one or more of the nearby irrigation wells. Based on model results, approximately 0.25 and 0.5 feet of upwelling would occur in the R and S-series wells if the irrigation wells were not used during the peak summer months. Most of this well interference is created by the pumping of Karmen Schoelerman’s well.

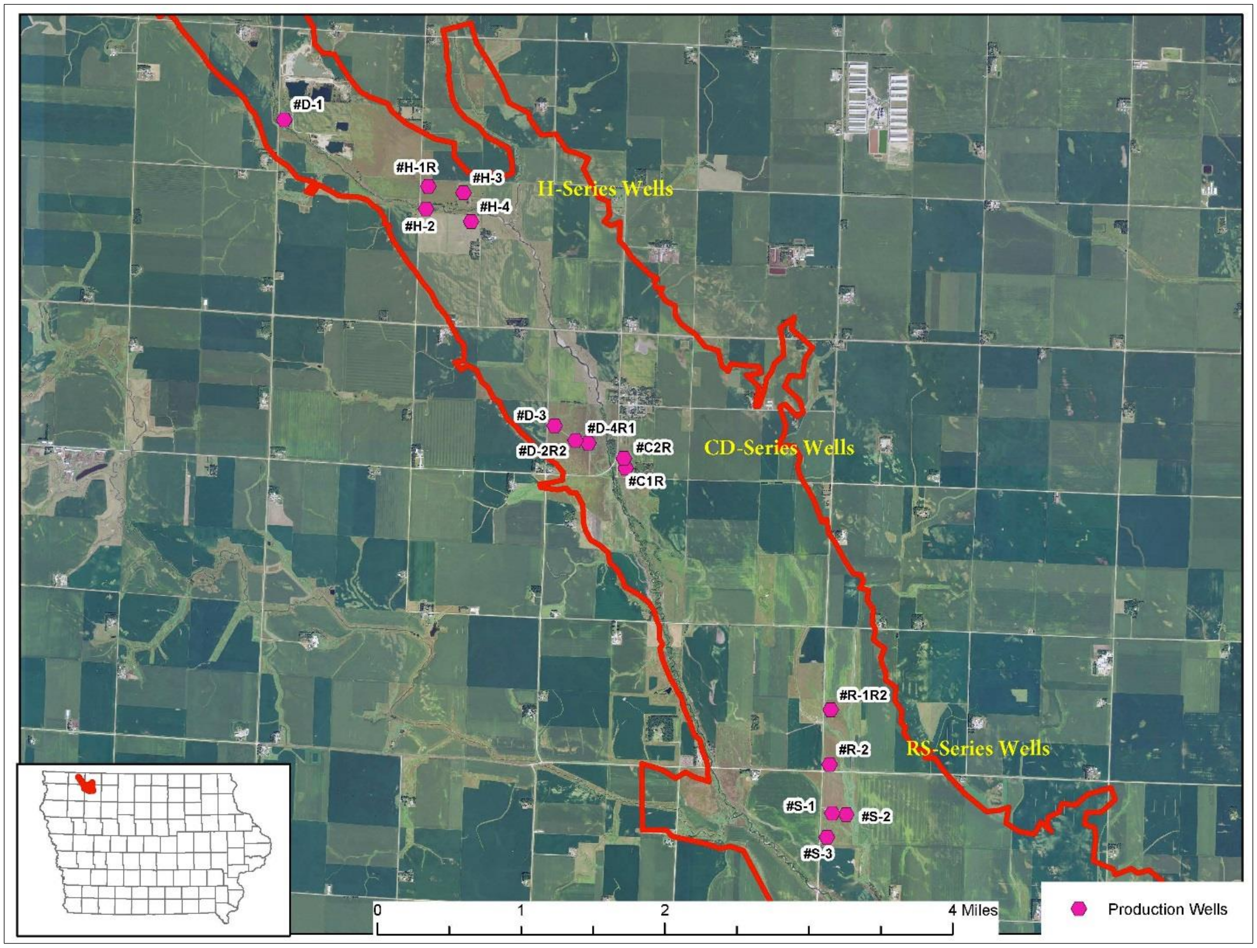

Figure 1. Osceola County Rural Water Model Area and Location Map

INTRODUCTION

The purpose of this study is to evaluate current and future water use and groundwater availability for the Osceola County Rural Water District (OCRWD) near May City, Iowa under moderate to severe drought conditions. To help predict future availability, a calibrated groundwater flow model was constructed. The model was also used to evaluate various strategies to enhance and increase both aquifer storage and induced river recharge.

For the purposes of this report, the aquifer will be referred to as the Ocheyedan aquifer. The current users include OCRWD (Figure 1), and approximately 23 irrigation wells. Previous investigations along the Ocheyedan River have been conducted by Hickok, E.A. and Associates (1979), Thompson (1986), Leggette Bradshears & Graham, Inc. (2007), and Gannon and Vogelgesang (2014). The current investigation uses hydrologic and hydrogeologic data that were collected during the 2012, 2013, and 2014 drought years.

CLIMATE

The climate of northwest Iowa is classified as sub-humid. Based on data compiled by Iowa State University (Mesonet, Iowa State University, 2015), the average annual precipitation in the four county study area ranges from 27 inches per year near Sutherland to 29 inches per year in Primghar.

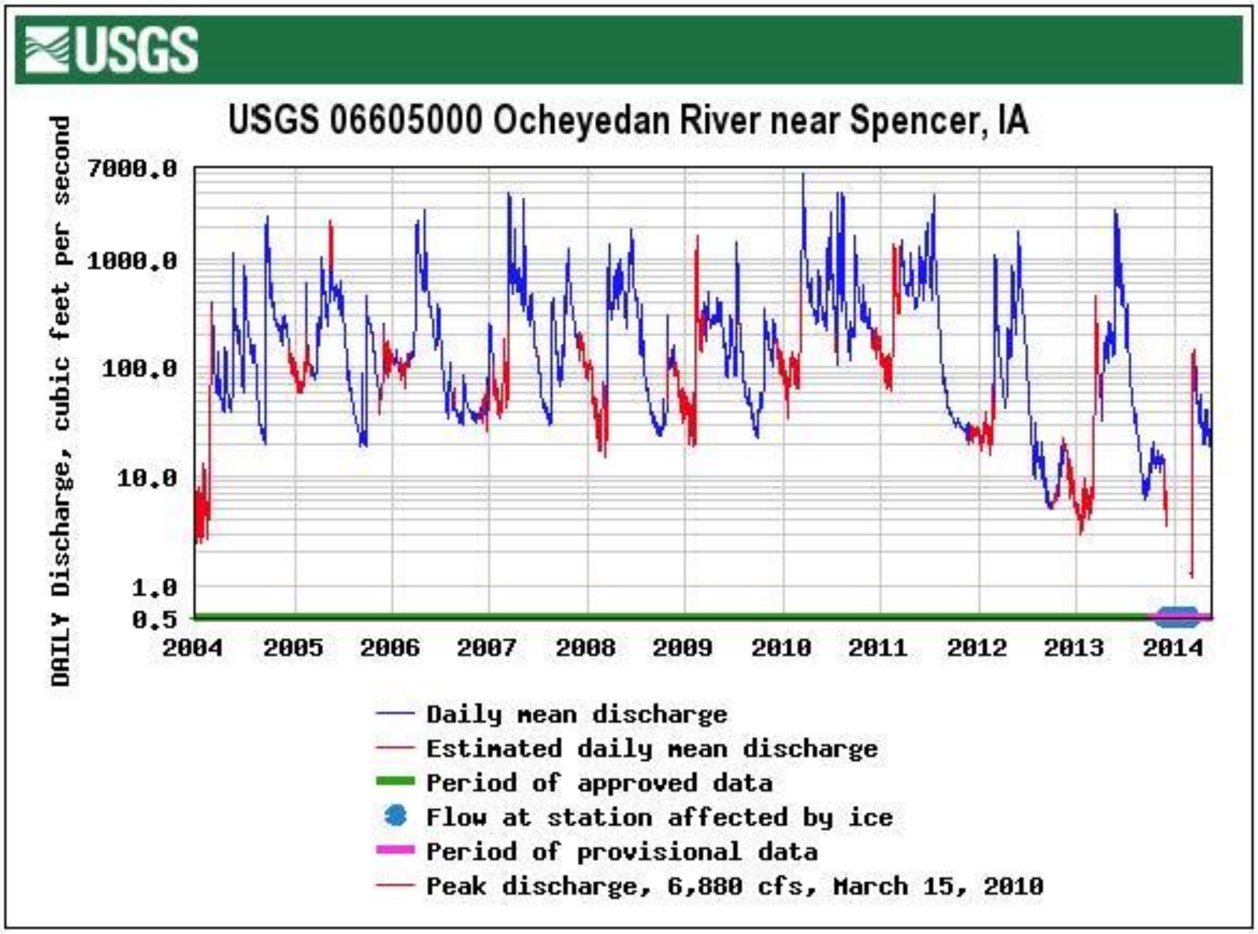

Figure 2. Daily average streamflow at USGS streamgage 06605000 on the Ocheyedan River near Spencer (2004 to 2014).

The study area has historically experienced moderate to severe droughts. Table 1 shows the historical minimum annual precipitation amounts for a select number of cities in the study area (Mesonet, Iowa State University, 2015). These minimum annual precipitation amounts range from 12.70 inches in Milford in 1958 to 15.41 inches in Sheldon in 1958.

Location	Minimum Inches (Year)
Milford	12.70 (1958)
Primghar	14.96 (1958)
Sheldon	15.41 (1958)
Sibley	14.38 (1976)
Spencer	14.41 (1958)
Sutherland	14.80 (1976)

Table 1. Minimum annual precipitation for select communities in Osceola, O'Brien, Clay, and Dickinson counties.

SURFACE WATER

Two gaging stations operated by the United States Geological Survey (USGS) show streamflow trends over time in the study area. Average daily discharge in the Ocheyedan and Little Sioux rivers near Spencer are shown in Figures 2 and 3. The lowest average daily discharge observed at the Ocheyedan River gage was 5 cubic feet per second (cfs) on September 23 to 24, 2012. The lowest average daily discharge observed at the Little Sioux River gage was 12 cfs, which was observed for several days

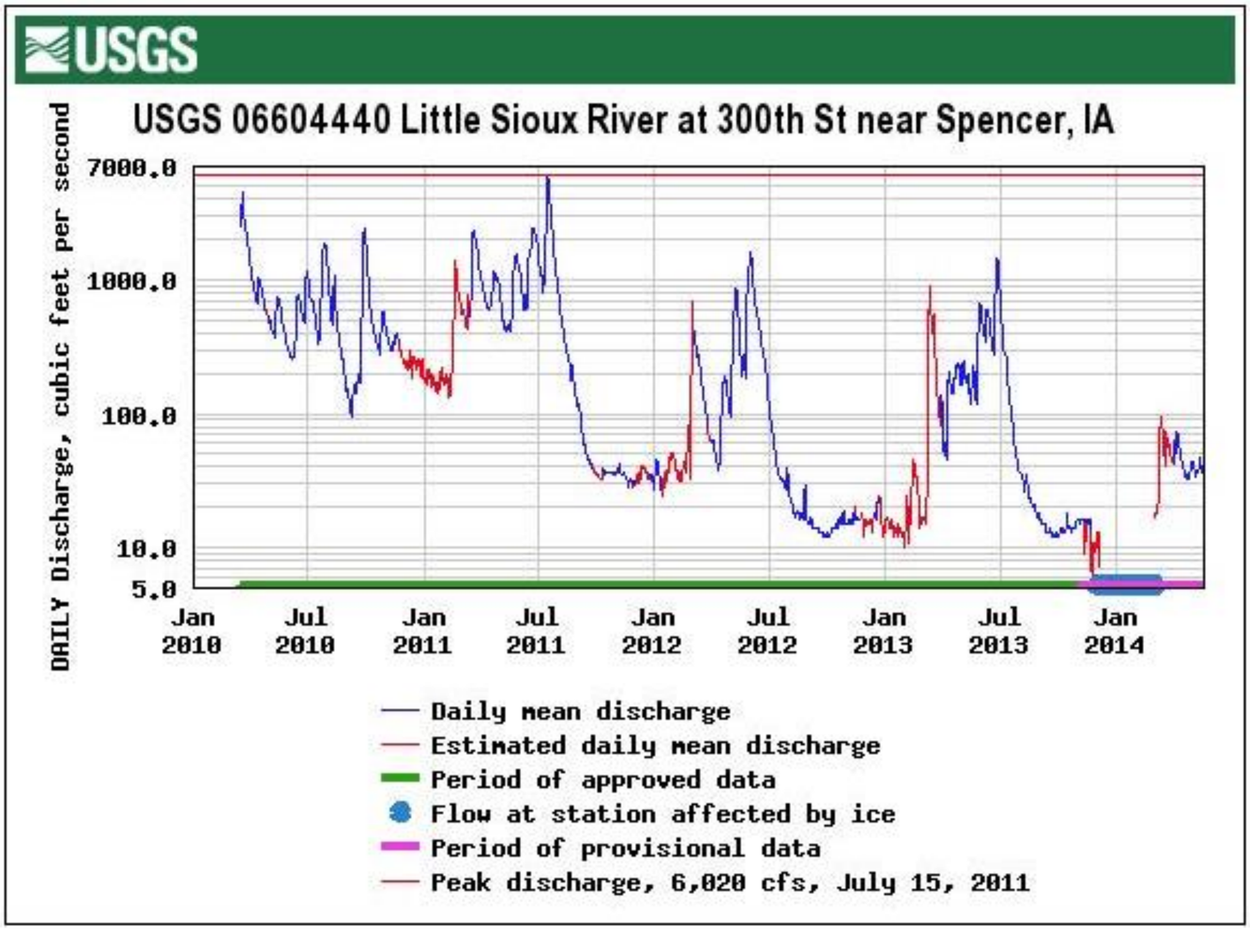

Figure 3. Daily average streamflow at USGS Streamgage 06604440 on the Little Sioux River near Spencer (2010 to 2014). USGS began collecting streamflow in 2010.

in late September and early October, 2012 and 2013.

The Iowa Administrative Code (IAC) [567] Chapter 52.8 has rules that protect consumptive water users during moderate to severe droughts for rivers with watersheds greater than or equal to 50 square miles. The Ocheyedan River watershed is approximately 434 square miles, but is not included in Chapter 52.8(3). The protective low-flow value at the Linn Grove gage on the Little Sioux River is used for the Ocheyedan River, Stony Creek and the Upper Little Sioux River. These rules involve the concept of protective low-flow in streams and rivers. The protective low-flow value is defined as the discharge in cubic feet per second that is equal to or exceeds this discharge 84 percent of the time over a certain period of time (generally 10 years or more). When streamflow measurements drop below the protective low-flow value, withdrawals from irrigation wells and surface water intakes within 0.125 miles from the river must cease pumping. The protective low-flow value for the Linn Grove gage is reported as 42 cfs (IAC [567] 52.8). The streamflow at the Linn Grove gage has fallen to 42 cfs or lower during the periods September through March of 2012 and 2013, and September through March of 2013 and 2014 (Figure 4). These are the only two periods of below protective flow from 2004 to 2014 at the Linn Grove gage.

For the project study area, river stage readings were collected at ten bridges that span the

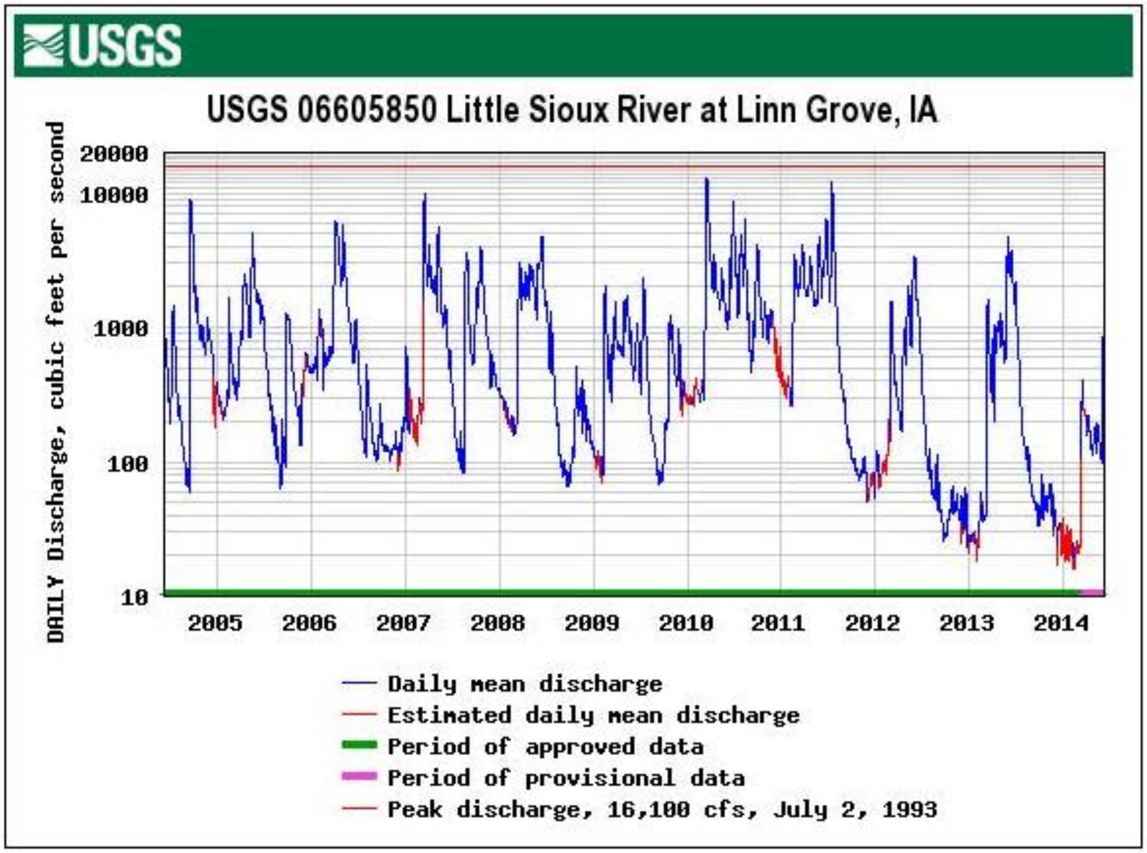

Figure 4. Daily average streamflow at USGS Streamgage 06605850 on the Little Sioux River at Linn Grove (2005 to 2014).

Location	Bridge Elevation (ft)	Depth to River (ft)	Stage Elevation (ft)
G-1	1456	16	1440
G-5	1432	18	1414
G-8	1410	18	1392
G-2	1456	19	1437
G-3	1449	20	1429
G-4	1435	16	1419
G-6	1422	21	1401
G-7	1416	17	1399
G-9	1404	15	1389
G-10	1414	16	1398

Table 2. River stage elevation data for the Ocheyedan River gathered on May 27, 2014.

Ocheyedan River and the Little Ocheyedan River as shown on Figure 5 and Table 2. Datum elevations for the ten bridges were obtained from Osceola County Engineers Office or from LiDar elevation data. Readings were obtained on May 27, 2014, and represent moderate to severe drought conditions. The average daily streamflow on the Ocheyedan River at Spencer on May 27, 2014 was 12 cfs, which is much lower than the median daily value for May 27th of 300 cfs. The lowest average daily streamflow measurement on the Ocheyedan River at Spencer during the 2012 to 2014 drought was 5 cfs. This occurred on September 23 and 24, 2012.

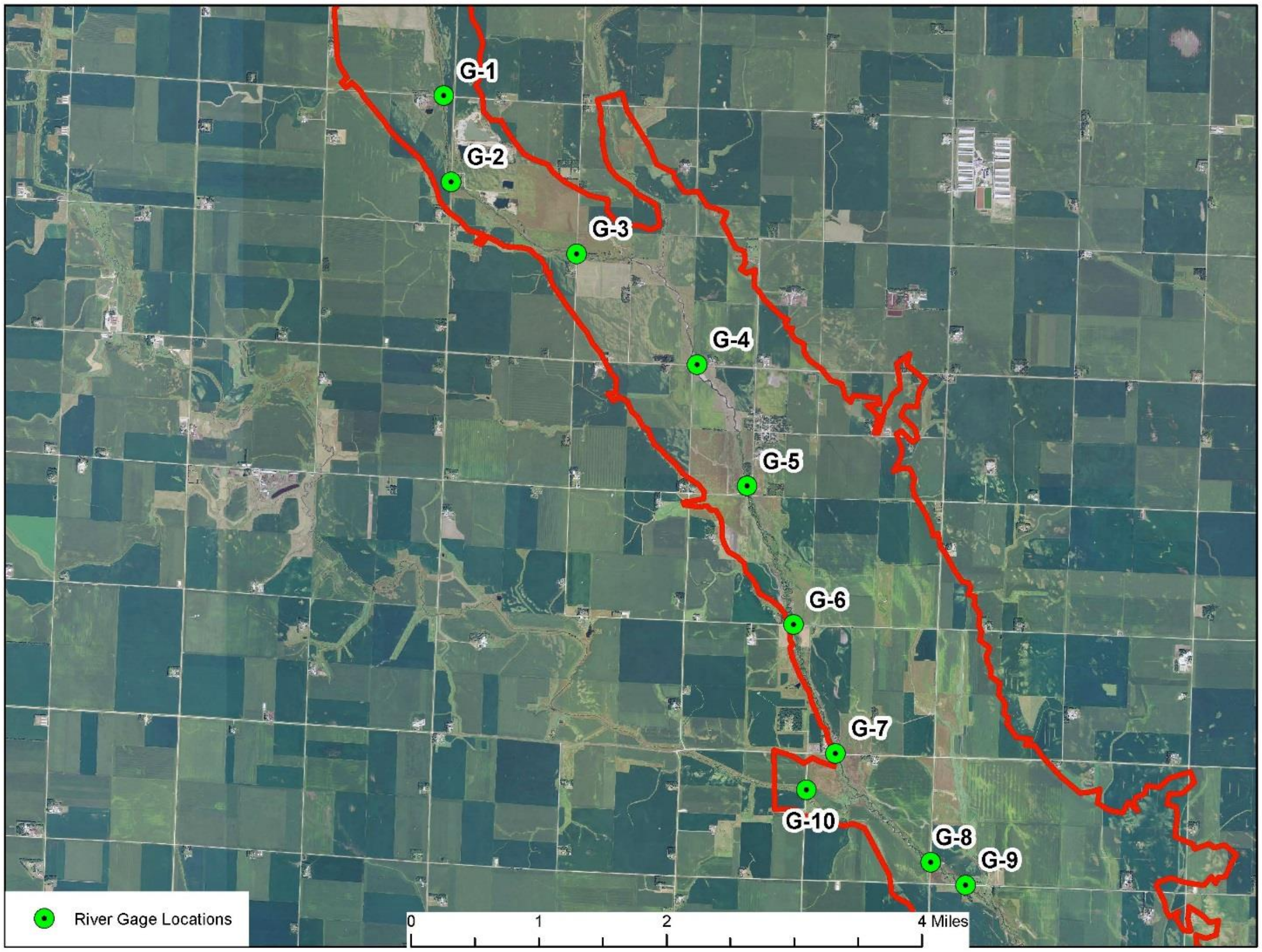

Figure 5. Ocheyedan River stage measurement locations.

GEOLOGY

Glacial melt-water from the Wisconsinan-age deposited various thicknesses of alluvial sediments along the modern day Ocheyedan River valley and its tributaries. The thickness of alluvial deposits along the Ocheyedan River ranges from less than 10 to over 50 feet, but averages approximately 30 feet. The alluvial deposits are not uniform or homogeneous, but include silt, clay, sand, gravel, cobbles, and boulders. The yields that can be expected in wells screened in these sediments depend on the thickness of alluvium, the grain size or texture, and interconnectedness of the various sand and gravel units.

Based on existing data from 34 striplogs and drilling logs, and surface geophysics, the distribution of sand and gravel thickness was estimated and is shown on Figure 6. The locations of all existing information were confirmed before use. Based on Figure 6, over 40 feet of sand and gravel occurs near the OCRWD wells H-1, H-3, H-4, D-2R D-3, D-4, C-1, and R-1R. The sand and gravel is overlain by fine-grained sediments consisting of clay, silt, and silty-sand.

There are no known bedrock exposures in the study area (IGS-GeoSam Database). The bedrock surface lies beneath an average of 260 feet of glacial tills and alluvium (IGS-GeoSam Database). The bedrock surface primarily consists of Cretaceous-age sedimentary rocks belonging to the Dakota Formation. The primary lithologies are shales and very fine to medium grained sandstones (Witzke, *et al.*, 1997).

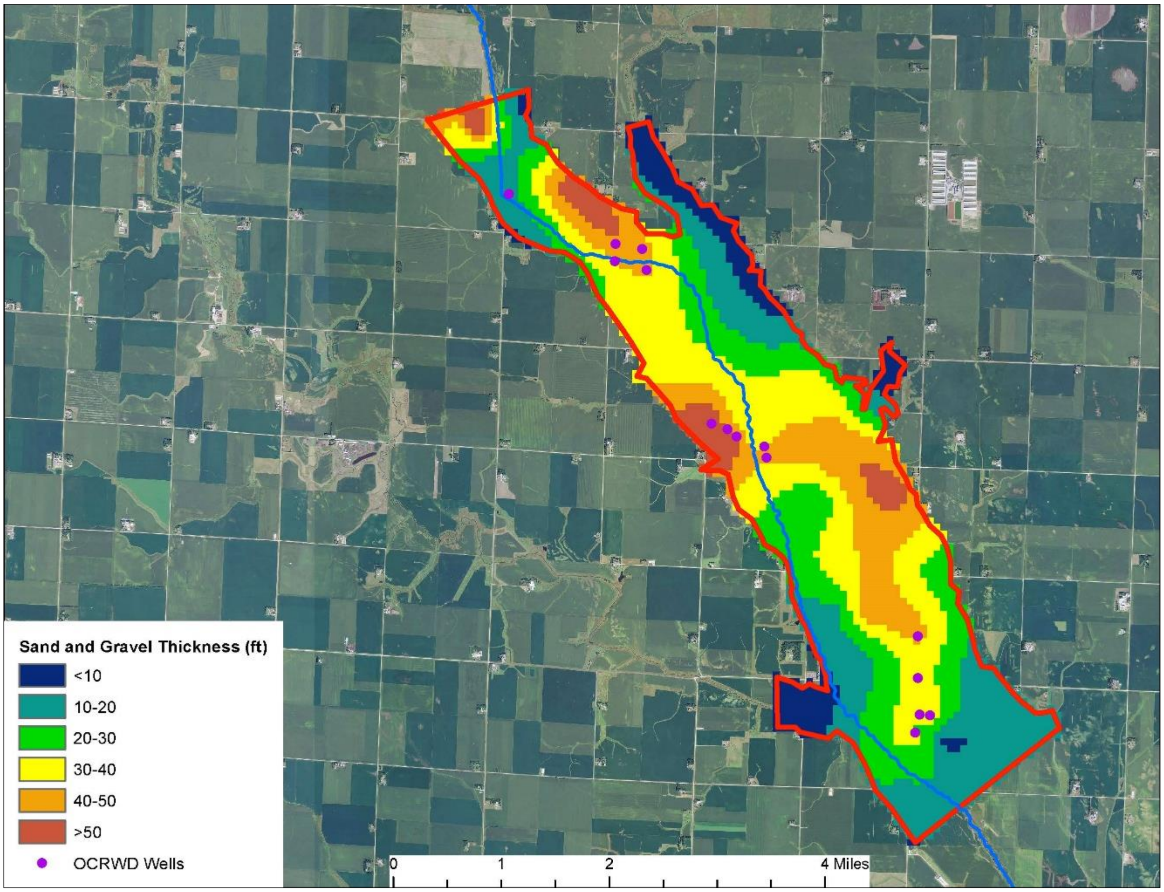

Figure 6. Sand and gravel thickness (isopach) map of the model area.

Monitoring Point	Ground Elevation (ft)	SWL* (ft)	Groundwater Elevation (ft)
OCRW H-1	1440	14.1	1,425.9
OCRW H-2	1438	17.4	1,420.6
OCRW R-1	1410	13.0	1,397.0
OCRW R-2	1408	13.2	1,394.8
OCRW C-1	1420	15.5	1,404.5
OCRW C-2	1420	16.5	1,403.5
OCRW D-1	1450	14.8	1,435.2
OCRW D-2	1424	16.8	1,407.2
OCRW D-3	1422	11.4	1,410.6
OCRW D-4	1428	11.5	1,416.5
OCRW S-1	1404	18.0	1,386.0
OCRW S-2	1404	17.4	1,386.6
OCRW S-3	1404	14.3	1,389.7
Jeff Monster	1430	13.0	1,417.0
Karmen Schoelerman	1406	4.0	1,402.0
Larry Ten Lkey	1412	9.5	1,402.5
Ron Petersen	1418	6.5	1,411.5
Rossman Farms	1408	4.0	1,404.0
SWL= Static Water Level in the fall of 2013 or spring of 2014			

Table 3. Groundwater elevation data collected in the fall of 2013 and the spring of 2014, which were used to evaluate the groundwater table surface.

HYDROLOGY

Assuming groundwater table conditions are a reflection of the ground surface, regional groundwater flow is toward the Ocheyedan River and its tributaries in a general southerly and southeasterly direction. Water level data from 18 wells were used to evaluate the groundwater surface (Table 3). The water level data was obtained from the Iowa Department of Natural Resources Water Use database, and from OCRWD measurements, and represent drought conditions during the fall of 2013 and the spring of 2014. All of the OCRWD wells were surveyed for location and elevation by DGR Engineers, Inc. Using the groundwater elevation data in Table 3, and the surface water elevations in Table 2, a groundwater elevation map was contoured as shown on Figure 7. Relatively large zones of depression occur in the groundwater surface near

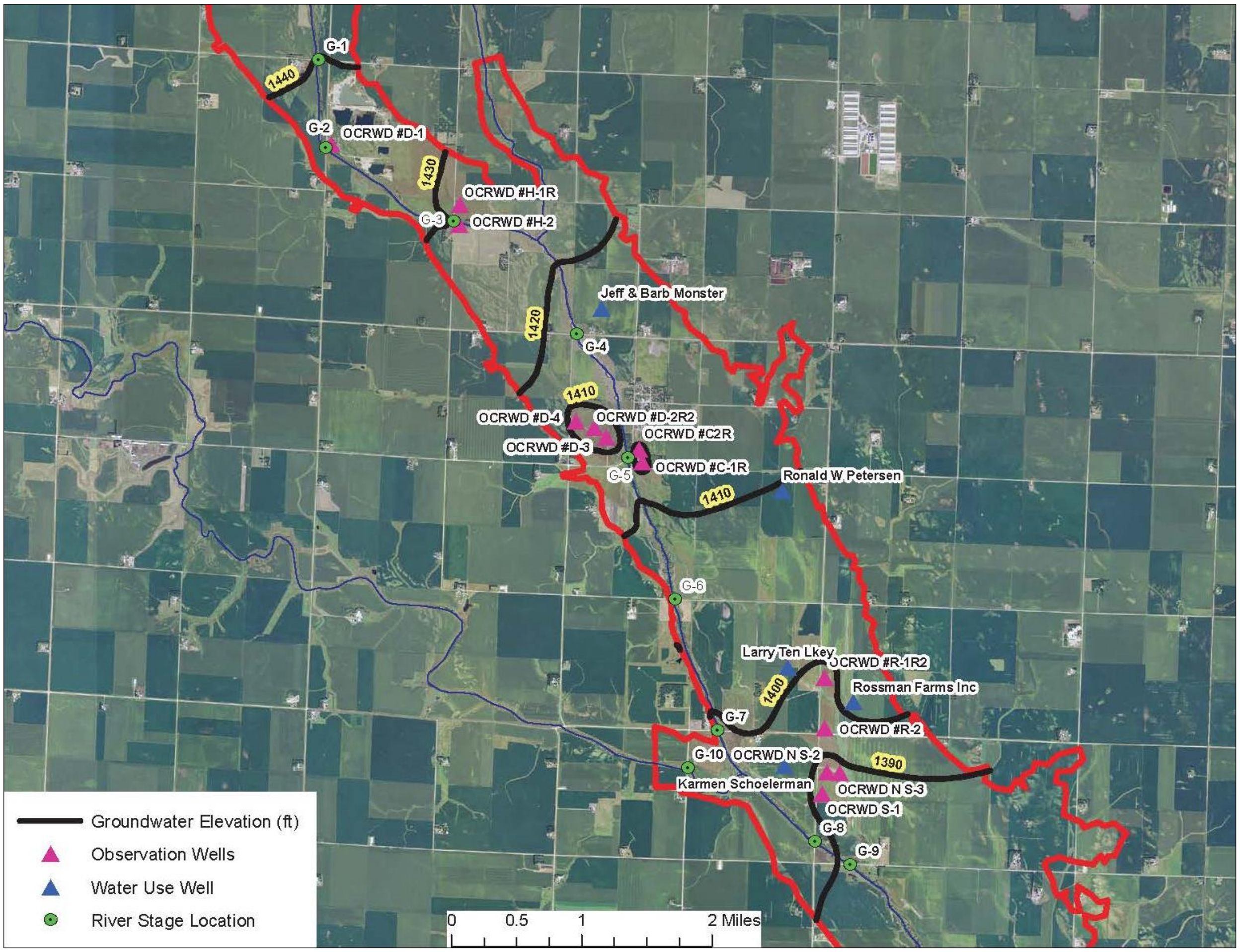

Figure 7. Observed groundwater elevation contours for Osceola County Rural Water District and surrounding area.

OCRWD wells as a result of the high pumping rates.

Based on the groundwater contour elevations, surface water from the Ocheyedan River flows toward OCRWD wells. Without this induced recharge, high capacity production wells would not be able to sustain their pumping rates during prolonged droughts.

Groundwater recharge sources include precipitation, induced recharge from surface water, and seepage from glacial drift and terraces along the valley wall. It is difficult to measure the groundwater recharge based on annual precipitation data. In Iowa much of the groundwater recharge occurs in the early spring and fall. The actual amount of groundwater recharge depends on the intensity and distribution of the precipitation events, and when they occur seasonally. Based on previous studies (Gannon, 2006 and Gannon, 2011), the annual rate of precipitation recharge during a moderate to severe drought was estimated to be 4 inches/year, and 0 inches during June 1 through August 31.

Public Wells

OCRWD has 15 active public wells screened in the Ocheyedan aquifer as shown in Figure 1. In addition to the public wells, there are approximately 23 water-use wells that are used primarily for irrigation. Annual water-use was obtained from the Iowa DNR Water-Use database

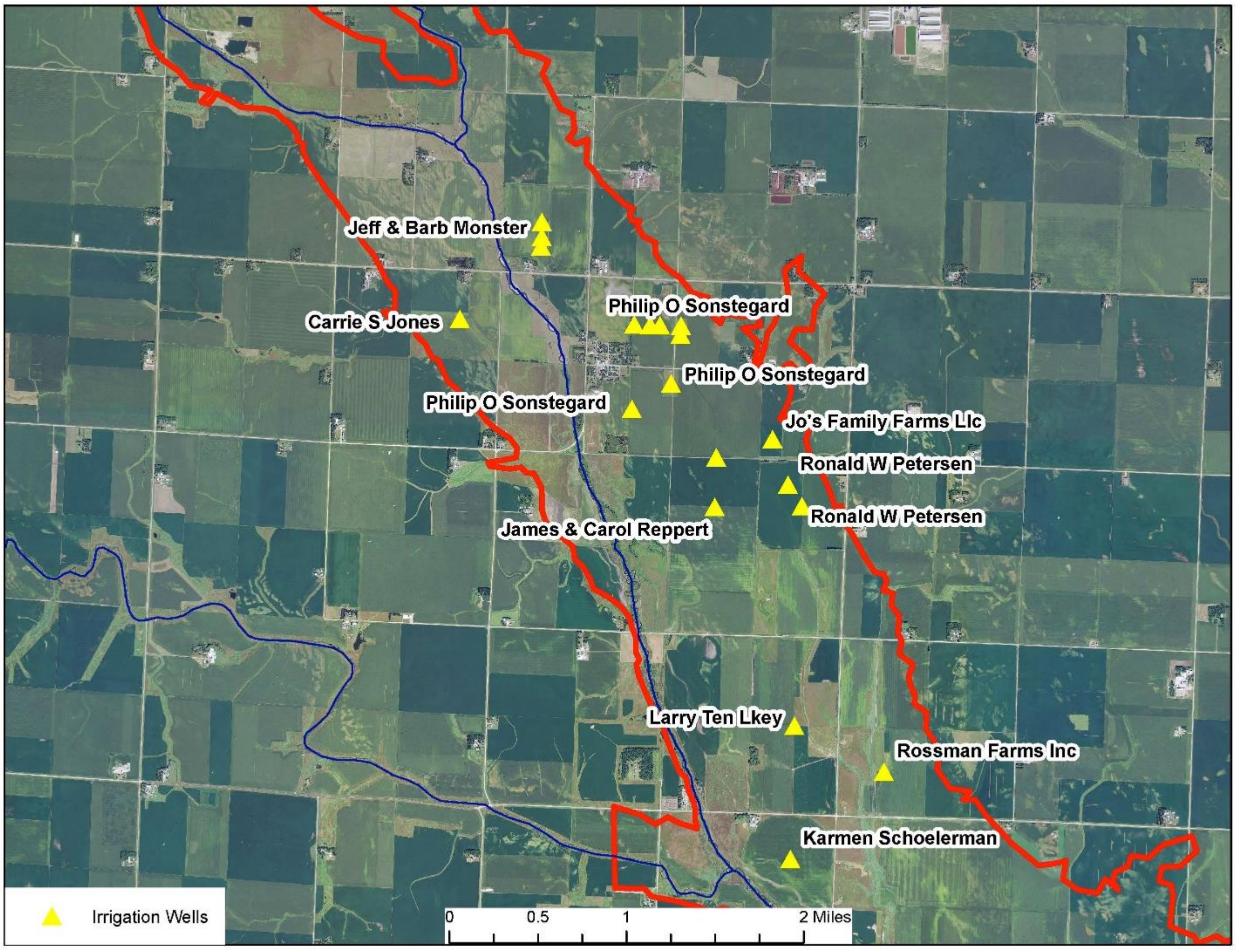

Figure 8. Irrigation wells found within the model area.

Permit Held	Number of Wells	Average Q (GPD)	Peak Q (GPD)	Maximum Historical Q (MGY) (year)	Allocated Q (MGY)
Osceola County RW	13	3,394,521	3,780,935	1,239 (2013)	1,700
James Reppert	1	0	0	0	52
Jeff Monster *	3	361,111	400,000	32.5 (2012)	45.6
Sonstegard Farms *	13	1,504,444	1,811,000	135.4 (2013)	251.6
Karmen Schoelerman *	1	395,556	400,000	35.6 (2007)	45.6
Larry Ten Lkey *	2	666,667	967,000	60 (2012)	182.5
Ron Petersen *	2	588,889	1,051,000	53 (2013)	48.9
Rossman Farms *	1	205,556	448,400	18.5 (2012)	44.3
* = Based on a 90 day Irrigation Season					
Q = Discharge (gallons per day)					

Table 4. Permitted water use and actual water use for public, and irrigation wells in the model area.

and from OCRWD and is listed in Table 4. Total water usage for the study area, not including private wells, is estimated at 2.1 billion gallons per year (7.1 million gallons per day), with a peak usage of 8.8 million gallons per day (Table 4). Well interference likely occurs between the irrigation wells and the public wells, especially OCRWD wells C-1, C-2, R-1, R-2, S-1, S-2, and S-3.

Irrigation Wells

Most of the land use in the vicinity of the Ocheyedan aquifer is in row crop agriculture. A large percentage of the corn acreage is irrigated due to the sandy soils in the valley. Approximately 23 irrigation wells were identified in the valley as shown in Figure 8. Annual and daily usage rates are available for the irrigation wells (Mike Anderson, IDNR-

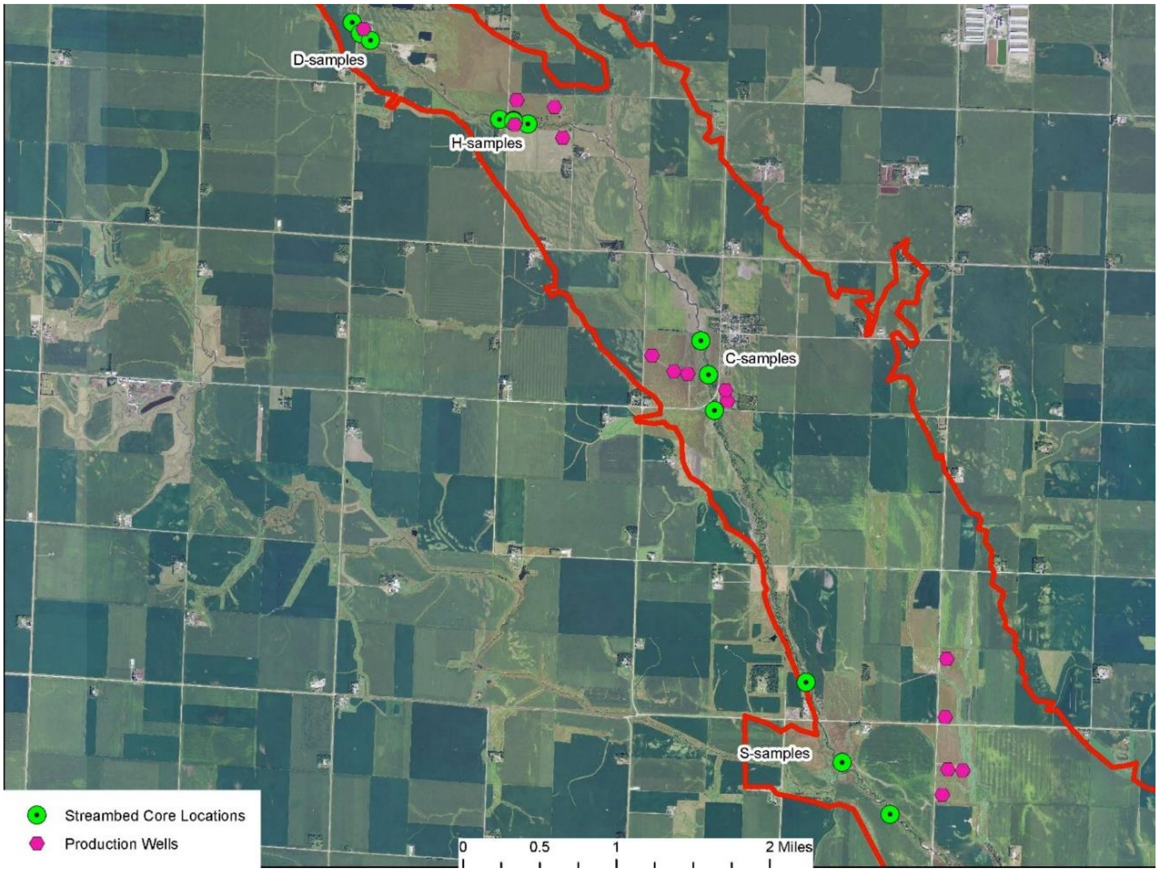

Figure 9. Streambed sample locations in the Ocheyedan River.

Water Supply Engineering Section), and are found in Table 4.

Pump Test Results

Hydraulic properties are used to define and characterize aquifers and include specific yield or storage, transmissivity, and hydraulic conductivity. The most reliable aquifer properties are those obtained from controlled aquifer tests with known pumping rates, pumping duration, accurate well locations, and accurate water level measurements. A total of 14 pump tests were conducted within the model area using the OCRWD production wells and 14 OCRWD observation wells. In-Situ pressure transducers and data loggers were used to collect the water levels. AquiferTest software (Schlumberger, Inc.) was used to analyze the 14 aquifer pump tests, and the results are shown on Table 5 and Appendix A.

Transmissivity values indicate the rate at which water is transmitted through the aquifer when considering factors such as the hydraulic gradient and aquifer thickness. Based on aquifer test results, the transmissivity of the aquifer was found to range from 20,600 feet^2/day near OCRWD well C-1, to 316,000 feet^2/day near OCRWD well D-3.

Hydraulic conductivity values indicate the rate at which water can move through a permeable medium. Hydraulic conductivity was calculated by dividing the transmissivity by the overall aquifer thickness. Hydraulic conductivity in the study area was found to range from 514 feet/day near OCRWD well C-1 to 7,360 feet/day near OCRWD well D-3.

Sediment Sampling

Streambed sediment samples were collected from the Ocheyedan River as shown in Figure 9. A constant head permeability test was run on each sample to calculate the vertical hydraulic conductivity value. The laboratory method used to calculate permeability was taken from the

Well	Transmissivity	Aquifer Thickness	Hydr. Cond. (ft./day)	Specific
ID	ft^2/day	Feet	Pump Test Results	Yield
D-1 OB 1	133,000	31	4,300	0.000003
D-1 OB2	73,800	31	2,380	0.100
H-1 OB 1	91,800	39	2,360	0.003
H-1 OB 2	126,000	39	3,240	0.001
H-1 WN-1	83,400	39	2,140	0.020
H-2 OB 1	16,900	26	652	0.150
D-2 OB 2	119,000	40	3,000	0.0007
D-3 OB 2	131,000	43	7,360	0.009
D-3 OB 3	316,000	43	3,050	0.0004
D-4 OB 1	31,100	48	648	0.020
C-1 OB 1	20,600	40	514	0.002
C-1 OB 2	23,700	40	594	0.004
C-2 OB2	22,900	40	572	0.990
S-3 OB 1	20,600	32	644	0.050

Table 5. Aquifer pump test results for OCRWD production wells.

Sample ID	$H-H_1$	Q (mL/minute)	Length (cm)	Area (cm^2)	K (m/sec)	K (ft/day)
SC	70.5	610	15.24	45.58	0.00048217	137
SS	77.5	575	15.24	45.58	0.000413452	117
SN	71	640	15.24	45.58	0.000502321	142
CC	75.5	600	15.24	45.58	0.000442857	126
HW	66	650	15.24	45.58	0.000548819	156
CS	60.5	750	15.24	45.58	0.000690821	196
CN	84.5	60	15.24	45.58	3.95689E-05	11
HCC	62	750	15.24	45.58	0.000674107	191
HCS	103.5	250	15.24	45.58	0.000134604	38
HE	85.5	475	15.24	45.58	0.00030959	88
HCN	65	690	15.24	45.58	0.000591555	168
DC	72.5	590	15.24	45.58	0.000453496	129
DN	70	590	15.24	45.58	0.000469692	133
DS	65.5	725	15.24	45.58	0.000616817	175
					Average K =	129
					Std Dev. =	53

Table 6. Laboratory permeability test results for the Ocheyedan River sediment.

permeability handbook of the American Society of Testing Materials (ASTM, 1967). The results of these permeability tests are shown in Table 6. Values range from 11 to 199 feet/day, with an average value of 129 feet/day. Grain size was measured using Gradistat Version 8.0, and the results are shown in Table 7 and Appendix B. Most of the samples are dominated by gravel and very coarse sand. The vertical hydraulic conductivity values were used as inputs in the river boundary within Visual MODFLOW.

Streamflow Measurements

Streamflow measurements were collected on October 22, 2014, at five cross sectional locations along the Ocheyedan River as shown on Figure 10. Measurements were made using a Marsh-McBirney FLOWMATE 2000, and the results are shown in Table 8 and Appendix C. The difference in streamflow measurements H-1 (upstream of H-Series wells) and H-2 (downstream of H-Series wells) were used to estimate the rate of river recharge or induced recharge in wells H-1, H-2 (inactive during the

SAMPLE	V. Cr. Gravel	CR. GRAVEL	MED. GRAVEL	FINE GRAVEL	V.F. GRAVEL	V.CR. SAND	CR. SAND	MED. SAND	F.SAND	V.F. SAND	SILT
CC	0%	1%	3.30%	14.90%	32.60%	31.60%	15.40%	1.30%	0.20%	0.20%	0%
CH	14.70%	9.50%	6.70%	7.90%	13.10%	17.30%	14.40%	10.30%	5.30%	0.90%	0.10%
CS	15.20%	17%	15.30%	10.80%	9.10%	17.60%	14%	0.80%	0.10%	0%	0.10%
DN	0%	0.10%	0.90%	2.30%	14%	51.20%	29.90%	1.40%	0.20%	0%	0%
DC	22.10%	17.30%	13.10%	13.10%	11.50%	11.70%	9.70%	1.20%	0.20%	0.10%	0%
DS	9.70%	16.50%	19.20%	16.60%	13.70%	13.40%	9%	1.40%	0.30%	0.10%	0.10%
HC-C	41.50%	10.10%	9.20%	10.70%	13.80%	11.90%	2.50%	0.20%	0.10%	0%	0%
HC-E	0.30%	1.40%	2.30%	2.60%	3.80%	15.80%	65%	8.10%	0.50%	0.10%	0.10%
HC-N	20.50%	13.30%	10.60%	9%	12.60%	17.40%	9.60%	4.80%	1.80%	0.30%	0.10%
HC-S	12.50%	7.40%	12.70%	19.70%	22.10%	16.50%	7.10%	1.20%	0.60%	0.10%	0.10%
HC-W	12.50%	7.40%	12.70%	19.70%	22.10%	16.50%	7.10%	1.20%	0.60%	0.10%	0.10%
SC	15.20%	17%	15.30%	10.80%	9.10%	17.60%	14%	0.80%	0.10%	0%	0.10%
SN	18.30%	25.10%	20.10%	13.70%	10.10%	5.60%	4.50%	1.60%	0.80%	0.20%	0%
SS	0.50%	6%	11.90%	20.60%	19.70%	21.60%	16.60%	1.90%	0.90%	0.20%	0.10%

Table 7. River sediment grain size results.

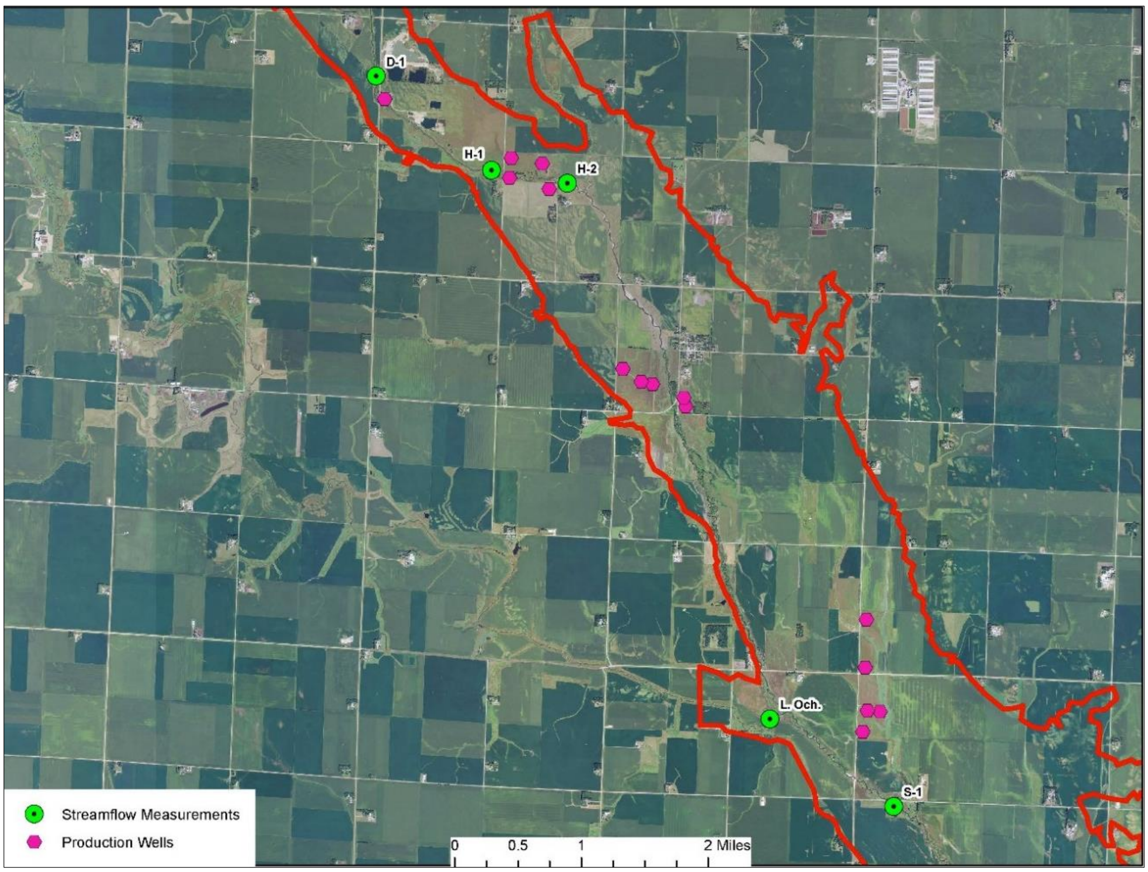

Figure 10. Streamflow measurement locations along the Ocheyedan River and Little Ocheyedan River.

Location	Streamflow (cfs)
D-1	1.42
H-1	1.17
H-2	0.09
L. Ocheyedan River	5.48
S-1	12.59

Table 8. Ocheyedan River streamflow results for October 22, 2014.

measurement), H-3, and H-4. It is assumed that the loss in streamflow is the result of the induced recharge or river recharge caused by the pumping of the H-Series wells. Based on the results of the streamflow measurements, approximately 1.08 cubic feet per second (cfs) of water from the Ocheyedan River recharges the sand and gravel aquifer in the vicinity of the H-Series wells. This

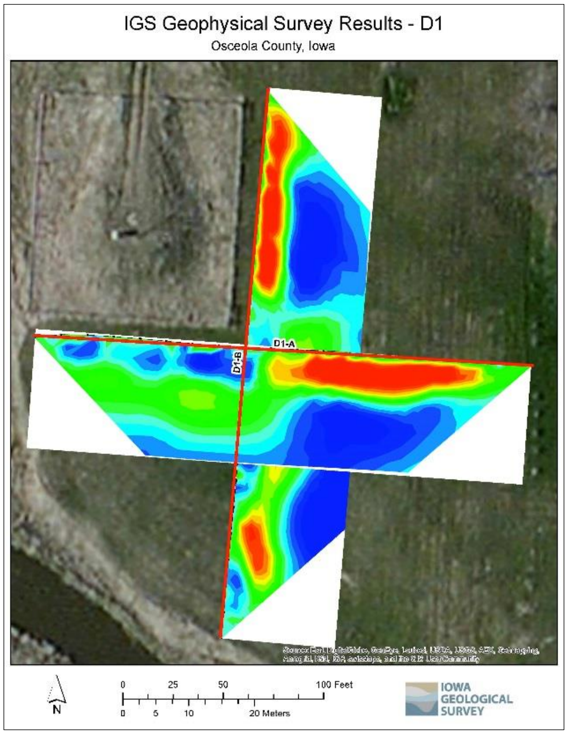

Figure 11a. Geophysical cross sectional locations and electrical resistivity profiles near Well D-1.

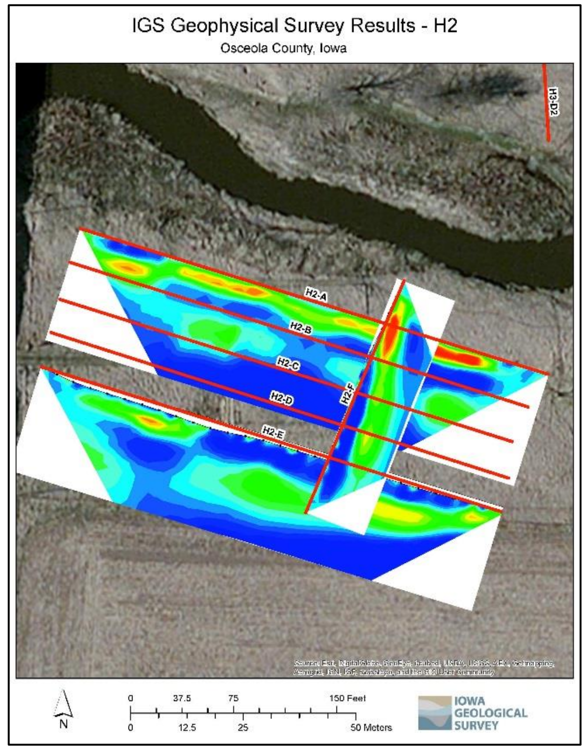

Figure 11b. Geophysical cross sectional locations and electrical resistivity profiles near Well H-2.

streamflow data was also used in the calibration of the groundwater flow model discussed later in the report.

GEOPHYSCIAL INVESTIGATION

A geophysical investigation was conducted to gather additional information related to aquifer characteristics. An Advanced Geosciences Inc. (AGI) SuperSting R8, 8-channel electrical resistivity (ER) meter was used to collect all geophysical measurements. Field measurements were obtained by introducing a direct current into the ground through current electrodes and measuring resulting voltages through multiple potential electrodes. An array of fifty-six stainless steel electrode stakes were spaced approximately twenty feet apart, driven approximately one foot into the ground, and connected via electrode cables and a switch box to a central ER meter.

Thirteen geophysical lines were completed in the summer and fall of 2013 (Figures 11a, 11b, and 11c). Transects were oriented in a perpendicular arrangement to determine how geologic materials vary in either direction.

Field data were obtained using dipole-dipole configurations; chosen to maximize data collection by utilizing all channels to acquire data. Measure time was set at 3.6 seconds and measurements were stacked (averaged) twice, unless the standard deviation of all channels was less than 2%. In that case, a third measurement was taken and included in the average. To quantify error, overlapping data were collected in areas already covered by normal measurement.

Data were processed using AGI EarthImager 2D version 2.4.0 software. A smooth model inversion method was used. The inversion mesh was fine for the near-surface region in each transect and coarsened with depth. Resistivity values below 1 Ohm-m or above 10,000 Ohm-m were removed as these values are typically representative of erroneous data. Inversion was stopped after once root-mean-squared (RMS)

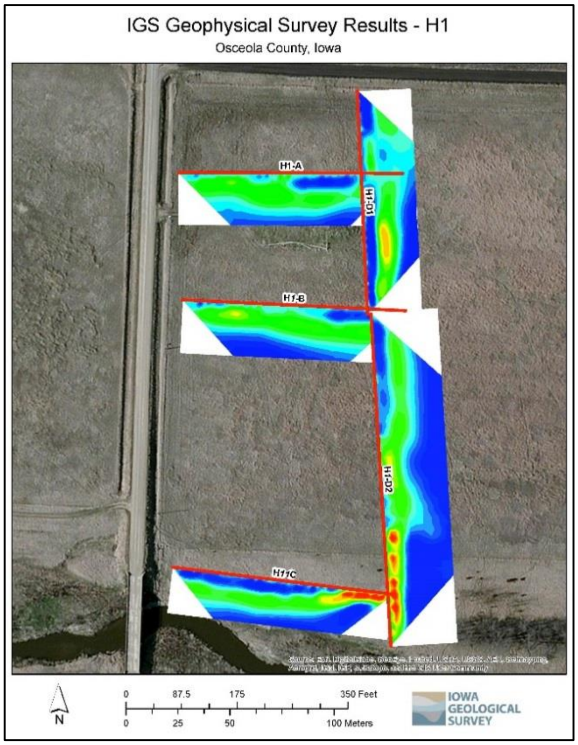

Figure 11c. Geophysical cross sectional locations and electrical resistivity profiles near Well H-1.

values were at or below 5%, and L2 norm ratio values were less than 2.

Models provide information on how the subsurface responds to electrical influence. Model results can be indicative of a number of variables including, mineralogy, water saturation, compaction and available pore space, dissolved ions in pore fluid, as well as other geologic, biologic, and chemical factors. Interpretation of these data must be in the context of additional site information.

Electrical resistivity tomography uses direct current as a means of modeling the subsurface. Generally, coarse grained material is more resistive to electrical charge than fine grained material. This is especially important in alluvial aquifer settings where coarse grained material usually produces more groundwater. Drilling log records were analyzed from several test holes drilled in the well field and were used in the interpretation of the geophysical data.

Final geophysical models for each transect are included in Appendix D and Figures 11a, 11b, and 11c. Each model was corrected for land surface elevation using LiDAR elevation data. The reds and yellows in the models correlate well to known sand and gravel units identified in neighboring boreholes. The models showing the greatest potential for sand and gravel were near the current well H-1 and D-1. Electrical resistivity has been found to be successful at identifying coarse material but cannot differentiate between "clean" or "dirty" sand and gravel (i.e.: sand or gravel mixed with clay or silt). The results of the geophysical investigation were used to further refine the aquifer thickness (Figure 6).

GROUNDWATER MODELING

The model software Visual MODFLOW version 2011.1 was used to simulate the groundwater flow in the alluvial aquifer in the study area under severe drought conditions. A three-layered model was used for the simulation. Borehole logs were obtained from the IGS GeoSam database, and elevation data were obtained from LiDAR (2-foot contour intervals). The model boundary conditions and inputs include the following:

- Layer 1 includes the alluvial silt and fine sand. The horizontal hydraulic conductivity for layer 1 was 100 feet/day, which is representative of fine sand. The vertical hydraulic conductivity value was assigned a value 1/10 of the horizontal hydraulic conductivity.
- Layer 2 includes the sand and gravel aquifer. The horizontal hydraulic conductivity value was calibrated within the model using the pump test results. The vertical hydraulic conductivity value was assigned a value 1/10 of the horizontal hydraulic conductivity.
- Layer 3 is primarily silty clay (glacial till or shale). The horizontal hydraulic conductivity was assigned a value of 0.01 feet/day. The vertical hydraulic conductivity value was assigned a value

Well	Observed (m)	Simulated (m)	Observed (ft)	Simulated (ft)	Difference (ft)
D-1 (OB2)	438.51	438.09	1438.31	1436.94	1.38
H-1 (OB1)	435.85	435.44	1429.59	1428.24	1.34
H-1 (OB2)	436.03	435.48	1430.18	1428.37	1.80
H-2 (OB1)	435.96	435.35	1429.95	1427.95	2.00
H-3 (OB2)	435.37	435.04	1428.01	1426.93	1.08
H-4 (OB2)	435.14	434.7	1427.26	1425.82	1.44
D-2 (OB2)	430.84	431.97	1413.16	1416.86	-3.71
D-3 (OB1)	431.59	432.14	1415.62	1417.42	-1.80
C-1 OB1)	431.05	430.95	1413.84	1413.52	0.33
C-1 (OB2)	431.12	431	1414.07	1413.68	0.39
C-2 (OB2)	430.91	431.16	1413.38	1414.20	-0.82
R-1 (OB1)	426.68	426.21	1399.51	1397.97	1.54
R-1 (OB2)	426.83	426.2	1400.00	1397.94	2.07
R-2 (OB2)	425.78	425.65	1396.56	1396.13	0.43
S-1 (OB2)	425.09	425.36	1394.30	1395.18	-0.89
S-2 (OB2)	425.02	425.37	1394.07	1395.21	-1.15
S-3(OB2)	424.53	425.16	1392.46	1394.52	-2.07

Table 9. Simulated versus observed water levels used for steady-state (non-pumping) model calibration.

1/10 of the horizontal hydraulic conductivity.

- The uplands were considered no-flow boundaries. This was represented by de-activating the grids outside the alluvial aquifer boundary. This was estimated using Natural Resource Conservation Service (NRCS) soils data and LiDAR elevation data.
- The Ocheyedan River was represented by using a river boundary. The surface water elevations from Table 2 were used to represent drought conditions. A water level depth of 1 foot was used.
- Vertical conductivity of the streambed measured using 14 sediment samples collected from the Ocheyedan River (Table 6 and Figure 9). The model represented baseflow (summer) conditions, and the stage was kept the same throughout the simulated time period.
- General head boundaries were used in the numerous sand and gravel pits in the area. These general head values were obtained from LiDAR elevation data.
- General head boundaries were used to represent the benches or terraces along the valley wall. Groundwater elevations were estimated from the closest well or observation point.
- OCRWD wells and irrigation wells were included in the model simulation. Usage was obtained from the IDNR water use database and OCRWD (Table 4).
- Specific yield value was 0.3, and specific storage varied with aquifer thickness.
- Average annual recharge was calibrated for drought conditions (4 inches per year). During the summer drought conditions (90 day period) 0 inches of recharge were used.
- The total number of rows and columns were 214 by 182. The grid size varied from 5 feet to 220 feet.

Water Level and Drawdown Calibration

The model was initially run to simulate non-pumping conditions. The model was calibrated using static water levels obtained from OCRWD. Table 9 compares simulated values to observed water levels for 17 observation wells. Based on the model results, the root mean square error was 1.6 feet or 3.562%, and the residential mean was

Well ID	Observed Drawdown (ft)	Simulated Drawdown (ft)	Hydr. Cond. (ft./day) Model Calibration	Hydr. Cond. (ft./day) Pump Test Results
D-1 OB 1	0.632	0.656	2,000	4,300
D-1 OB2	0.266	0.328	1,600	2,380
H-1 OB 1	0.486	0.49	2,360	2,360
H-1 OB 2	0.326	0.36	3,240	3,240
H-1 WN-1	0.301	0.24	2,500	3,240
H-2 OB 1	0.4	0.45	650	652
D-2 OB 2	0.548	0.46	3,800 and 6,000	3,000
D-3 OB 2	0.24	0.25	6,000	7,360
D-3 OB 3	0.4	0.43	1,700	3,050
D-4 OB 1	1.2	1.19	500	648
C-1 OB 1	1.2	1.18	750	514
C-1 OB 2	0.7	0.64	100 and 250	594
C-2 OB2	1.4	1.38	1,100	572
S-3 OB 1	2.1	1.97	1,000	644

Table 10. Simulated versus observed drawdown data for transient (pumping) model calibration.

-0.2 feet. Root mean square errors of 5% or less are normally considered acceptable.

The model was also used to simulate pumping or transient conditions using pump test results from the 14 on-site pump tests. Hydraulic conductivity values were adjusted to match the simulated drawdown to the observed values. Figures 12, 13, 14, and 15 show the simulated drawdown values for the aquifer pump tests in each of the 4 sub-wellfields. The simulated versus observed drawdowns are shown in Table 10. Most of the model calibrated hydraulic conductivities correlate closely to the pump test results. Exceptions include Well D-1 (2,000 versus 4,300 ft/day), D-2 (6,000 versus 3,000 ft/day), and D-3 (1,700 versus 3,000 ft/day).

Streamflow calibration

The water balance in Visual MODFLOW was used to estimate the induced recharge or river recharge near OCRWD H-Series sub-wellfield. The model was first run using the pumping rates provided by OCRWD for production wells H-1, H-2 (inactive), H-3 and H-4 on October 22, 2014. A second model run was simulated with all of the H-Series wells turned off. Based on the mass balance model results, approximately 672,000 gallons per day (1.04 cfs) of river water recharged the aquifer when the wells were turned on versus when the wells were turned off.

The observed difference in streamflow measurements H-1 and H-2 on October 22, 2014, (Figure 10 and Table 8) was 1.08 cfs. If we assume the decrease in streamflow was caused by the induced or river recharge created by the pumping of OCRWD wells H-1, H-3, and H-4, the measured induced recharge of 1.08 cfs compares closely with the simulated value of 1.04 cfs.

On October 22, 2014, the pumping rates in OCRWD wells H-1, H-3, and H-4 were 250 gpm, 425 gpm, and 425 gpm, respectively, for a total withdrawal or pumping rate of 1,100 gpm (2.45 cfs). Dividing the measured induced recharge of 1.08 cfs by the total pumping rate of 2.45 cfs, gives an estimate of the percentage of the water production supplied by the Ocheyedan River, which is approximately 44 percent. In other words, 44 percent of the water production in wells H-1, H-3, and H-4 on October 22, 2014 originated from the Ocheyedan River. The percentage of induced recharge is probably much higher during the summer peak usage period. In addition to the higher summer usage, OCRWD well H-2 was shut off for maintenance during October of 2014,

Figure 12. Simulated drawdown near well D-1 used in model calibration in Table 10.

which probably reduced the percentage of induced recharge.

It is important to note that on October 22, 2014, the induced recharge to OCRWD wells H-1, H-3, and H-4, reduced the streamflow on the Ocheyedan River from 1.17 cfs upstream of the H-Series wells, to 0.09 cfs downstream of the H-Series wells. Even with well H-2 shut off, the three remaining active H-Series wells had maximized the river recharge available to maintain water production (critical flow). On October 22, 2014, the critical flow appears to have been reached along the Ocheyedan River in the vicinity of the H-Series sub-wellfield. Adding any additional wells near current wells H-1 through H-4 would likely exceed the critical streamflow necessary to maintain water production during a moderate to severe drought. Adding a low-head dam or similar structure downstream of wells H-3 and H-4 may be advantageous to increase groundwater storage, raise the available head or drawdown in the H-Series wells, increase the available induced recharge from the Ocheyedan River, and allow for the possibility of additional wells in the H-Series sub-wellfield. The potential benefits of a low-head dam will be evaluated using the calibrated groundwater flow model. This will be discussed in the OCRWD Wellfield Model Simulations Section of this report.

OCRWD Wellfield Model Simulations

The calibrated groundwater flow model was used to evaluate the potential benefits of various induced recharge strategies. Each of the four sub-wellfields were modeled at a local scale, and the strategies are meant to be conceptual in nature. The final design of any proposed strategy will

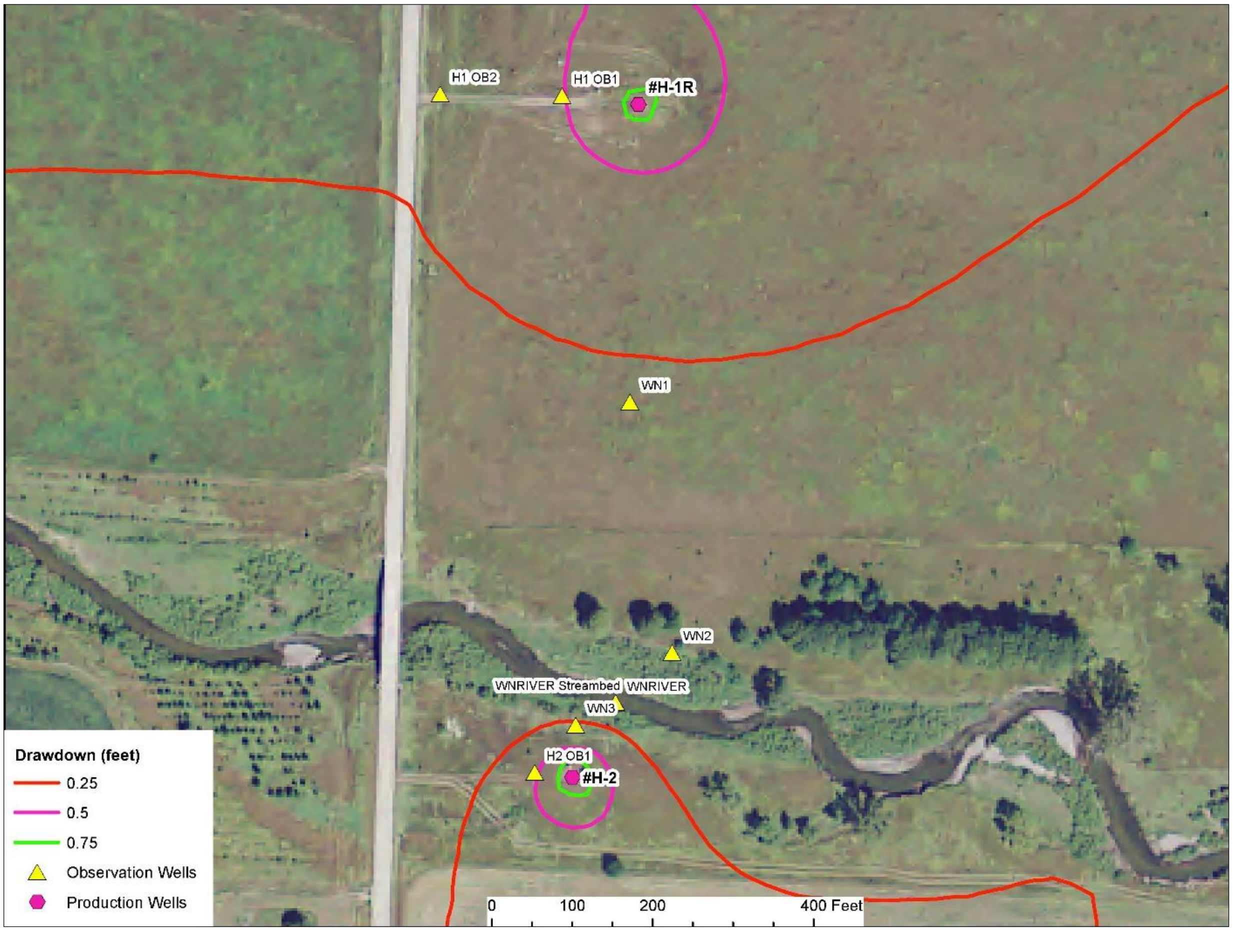

Figure 13. Simulated drawdown near H-Series wells used in model calibration in Table 10.

need to be completed by a profession engineer licensed in the State of Iowa. OCRWD will also need to work closely with the United State Army Corps of Engineers (USACE), the Osceola County Soil and Conservation District, the Osceola County Engineers office, and the Iowa Department of Natural Resources (IDNR), prior to implementation of any proposed strategy. Required permits will also need to be obtained prior to implementation.

Induced Recharge Evaluation

Induced recharge or river recharge occurs when the pumping water elevation within a production well drops below the adjacent river stage elevation, and surface water begins to move from the river toward the well. The amount of induced recharge is based on many variables. The most important variables include river stage, the vertical hydraulic conductivity of the river sediments, the horizontal conductivity of the aquifer material between the river and the well, the pumping rate in the well, the horizontal distance between the river and the well, and the amount of precipitation recharge that has occurred over the last 3 to 6 months.

The groundwater flow model was used to estimate the percentage of water obtained from induced recharge. The model was first run using the pumping rates provided by OCRWD. A second model run was simulated with all of the active OCRWD wells turned off. Based on the mass balance within the model, the amount and percentage of induce recharge (percent of water obtained from the river) was made. Table 11 shows the amount and percentage of induced recharge in each sub-wellfield based on pumping data that occurred on October 22, 2014. Based on the model results, well D-1 had the highest percentage of induced recharge of 70 percent or

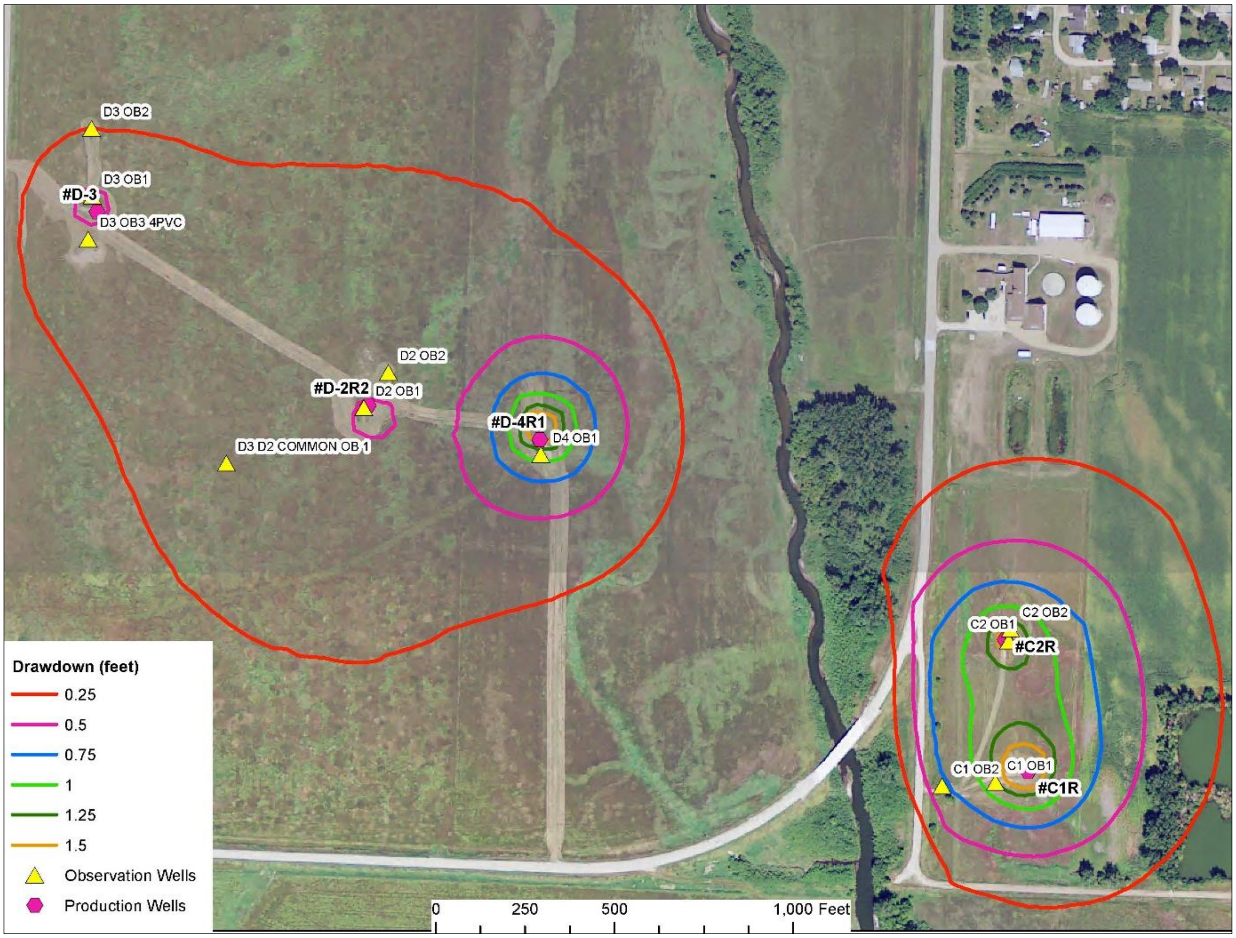

Figure 14. Simulated drawdown near the CD-Series wells used in model calibration in Table 10.

Sub-Wellfield	River Recharge (cfs)	River Recharge (gpd)	Pumping Rate (cfs)	Pumping Rate (gpd)	Percent Induced Recharge
D-1	0.56	361,938	0.8	517,054	70%
H-1, H-3, H-4	1.04	672,170	2.36	1,525,308	44%
C-2R, D-2R2, D-3R1	0.47	303,769	2.48	1,602,866	19%
R-1R, S-1, S-3	0.01	6,463	2.39	1,544,698	0.6%
Overall Wellfield	2.08	1,344,339	8.03	5,189,926	26%

Table 11. Simulated induced (river) recharge using the calibrated groundwater flow model.

362,000 gallons per day (gpd). This was followed by the H-Series sub-wellfield, which had 44 percent or 672,000,000 gpd. The CD-Series and the RS-Series sub-wellfields had relatively small percentages (19%, 304,000 gpd) and 0.6%, 6,500 gpd). Wells D-3 and the RS-Series wells are located between 1,200 and 4,800 feet from the Ocheyedan River. This greatly reduces the induced recharge that can occur in these sub-wellfields.

H-Series Sub-Wellfield

An evaluation of a proposed low-head dam near wells H-1, H-2, H-3, and H-4 was conducted using the calibrated groundwater flow model. Everything was kept constant in the drought model, with the exception of raising the river stage along a 2,600 foot reach of the Ocheyedan River as shown in Figure 16. The location of the proposed low-head dam is also shown in Figure 16, and was arbitrarily chosen to maximize

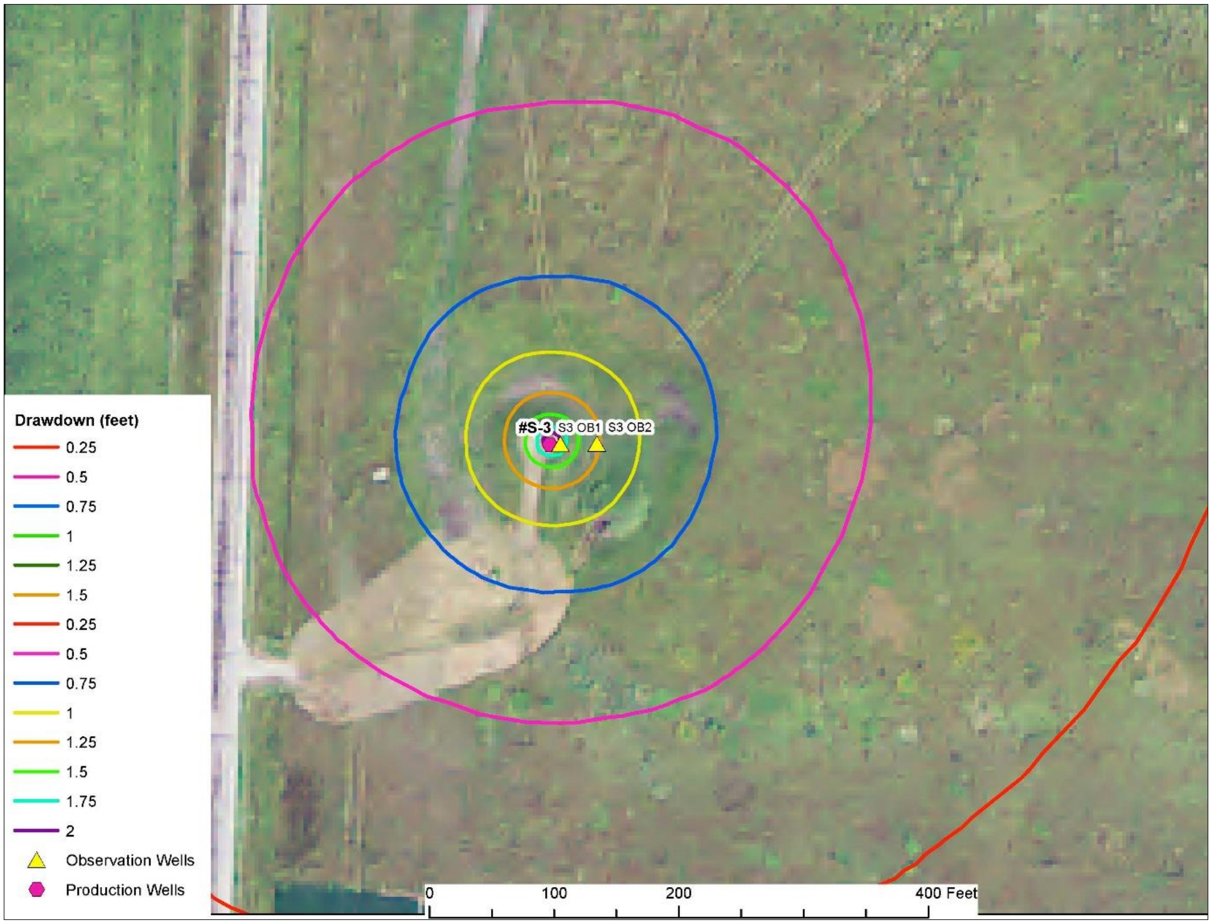

Figure 15. Simulated drawdown near RS-Series wells used in model calibration in Table 10.

groundwater upwelling in the H-Series wells. The actual location of the proposed low-head dam should be determined following discussions with the USACE, IDNR, and an engineering firm.

Figure 16 shows the simulated upwelling in the water table at the end of a 180 day period created by the installation of a proposed low-head dam. Based on model results, a proposed low-head dam would raise the river stage approximately 3 feet immediately behind the dam during low flow conditions. Increases in water table elevations range from over 2 feet in wells H-3 and H-4, to 1 to 1.5 feet in wells H-1 and H-2. The increase in groundwater storage would allow the H-Series wells to maintain water production even during a severe drought. Induced recharge would increase from 44% (without the low-head dam) to 67% with the low-head dam. Adding additional production wells in the H-Series sub-wellfield may also be possible. Adding new production wells will require additional hydrogeologic exploration to evaluate the hydrogeology.

The model does indicate a substantial benefit of using a proposed low-head dam in the H-Series sub-wellfield. If the low-head dam is constructed, water quality data should be collected in wells H-1, H-2, H-3, and H-4 to see whether the low-head dam has any significant impact on water quality.

CD-Series Sub-Wellfield

An evaluation of a proposed low-head dam near wells D-2R2, D-3, D-4R1, C-1R, and C-2R (CD-Series sub-wellfield) was conducted using the calibrated groundwater flow model. Everything was kept constant in the drought model, with the exception of raising the river stage along a 2,700

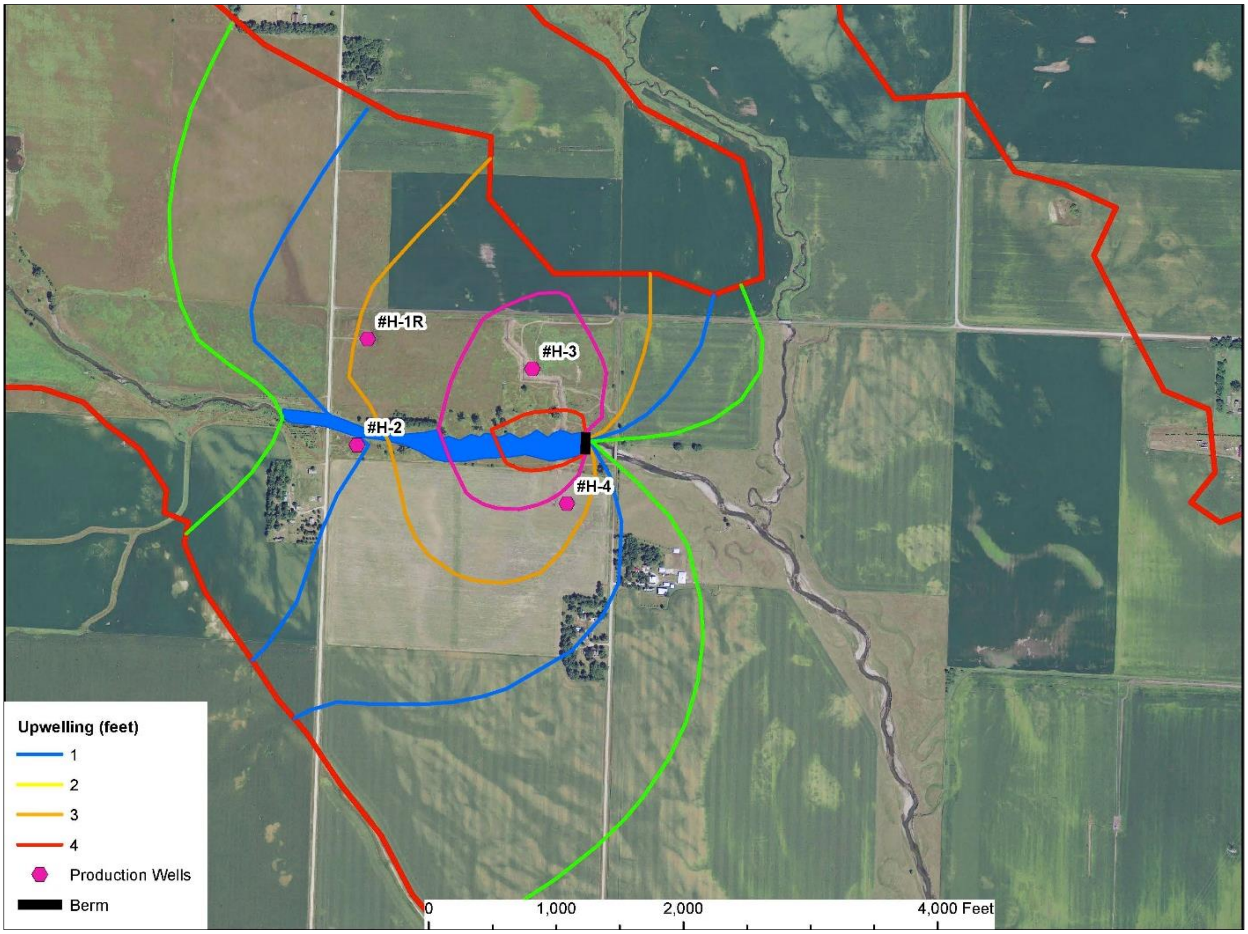

Figure 16. Proposed low head dam location and simulated upwelling (rise in water table) near the H-Series wells.

foot reach of the Ocheyedan River as shown in Figure 17. The location of the proposed low-head dam is also shown in Figure 17, and was arbitrarily chosen to maximize groundwater upwelling in the CD-Series wells. The actual location of the proposed low-head dam should be determined following discussions with the USACE, IDNR, and an engineering firm.

Figure 17 shows the simulated upwelling in the water table at the end of a 180 day period created by the installation of a proposed low-head dam. Based on model results, a proposed low-head dam would raise the river stage approximately 3 feet immediately behind the dam during low flow conditions. Based on the model simulation, increases in water table elevations range from 1 to 1.5 feet in wells C-1R and C-2R, to 0.5 to 1 foot in wells D-2R2 and D-4R1. Based on the model results, well D-3 would not benefit from the proposed low-head dam. The increase in groundwater storage created by a low-head dam would benefit the CD-Series sub-wellfield. Induced recharge would increase from 19% (no low-head dam) to 56% (with a proposed low-head dam), which is a 37% increase.

A second model simulation was done for the CD-Series sub-wellfield using the same proposed low-head dam example, but adding a possible cutoff channel as shown in Figure 18. The cutoff channel would reroute a segment of the Ocheyedan River so that the river is brought closer to wells D-2R2, D-3, and D-4R1. The proposed low-head dam and cutoff channel would increase the induced recharge available to the CD-Series wells from 19% (no low-head dam or cutoff channel) to 72% (low-head dam and

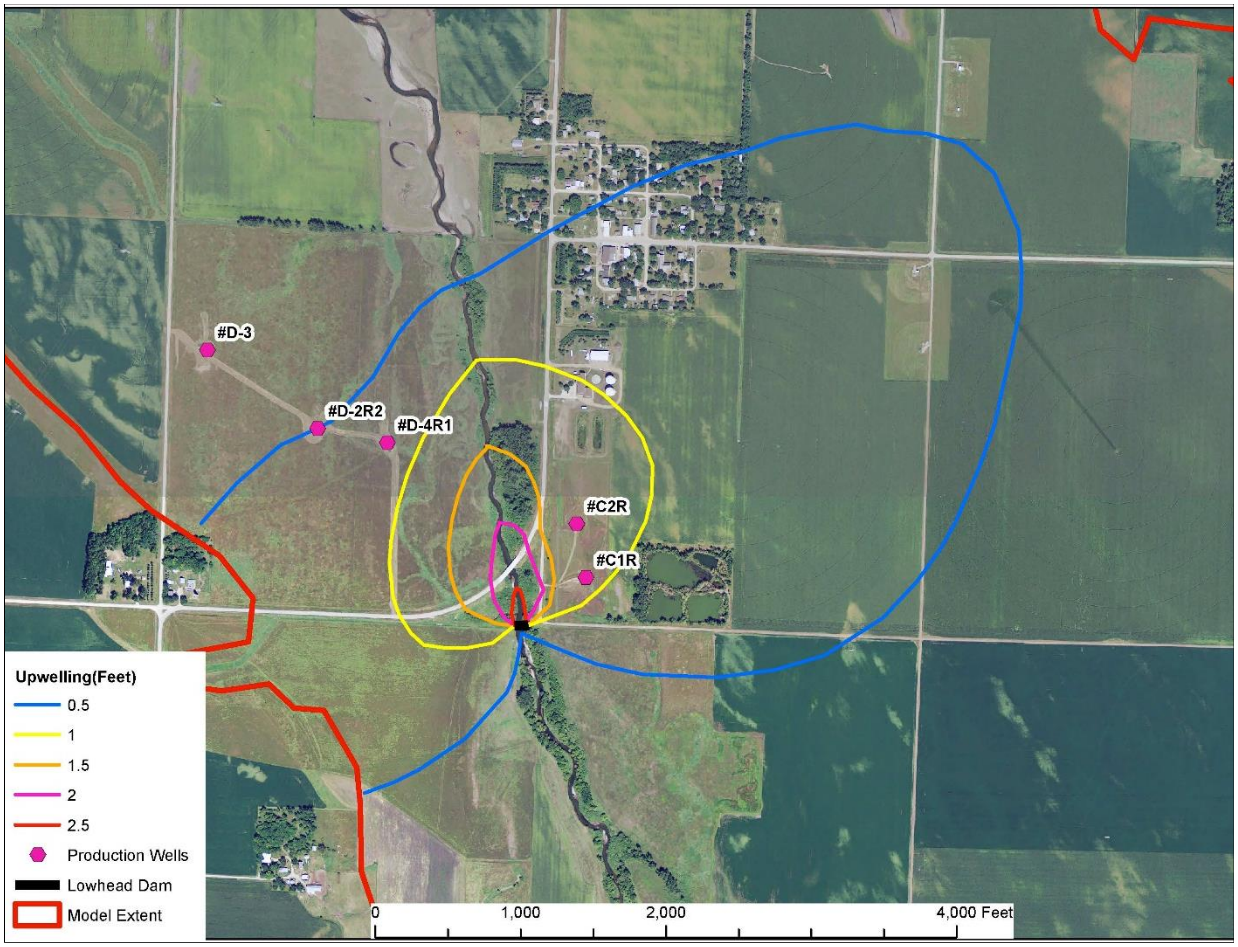

Figure 17. Proposed low head dam location and simulated upwelling (rise in water table) near the CD-Series wells.

cutoff channel), which is a 53% increase. Figure 18 also shows the simulated upwelling in the water table at the end of a 180 day period created by the installation of a proposed low-head dam and the proposed cutoff channel. Based on the model simulation, increases in water table elevations range from 1.5 to 2 feet in wells C-1R, C-2R, and D-4R1, 1 to 1.5 feet in wells D-2R2, and D-4R1, and between 0.5 and 1 foot in well D-3. The combination of a proposed low-head dam and cutoff channel not only increases the induced recharge, but is more effective at increasing overall groundwater storage compared to a low-head dam alone.

OCRWD Well D-1

An evaluation of a proposed earthen berm near well D-1 was conducted using the calibrated groundwater flow model. The proposed berm would not only capture spring runoff, but could also be used in combination with the pumping from one of the upgradient sand and gravel quarries. Everything was kept constant in the drought model, with the exception of adding a general head boundary approximately 5 feet higher than the adjacent groundwater elevation. The location of the proposed earthen berm is shown in Figure 19. The actual location of the proposed earthen berm should be determined following discussions with the USACE, IDNR, and your engineering firm. Any pumping from the upgradient sand and gravel quarries would require the permission from the quarry owners, and a temporary water-use permit from the IDNR.

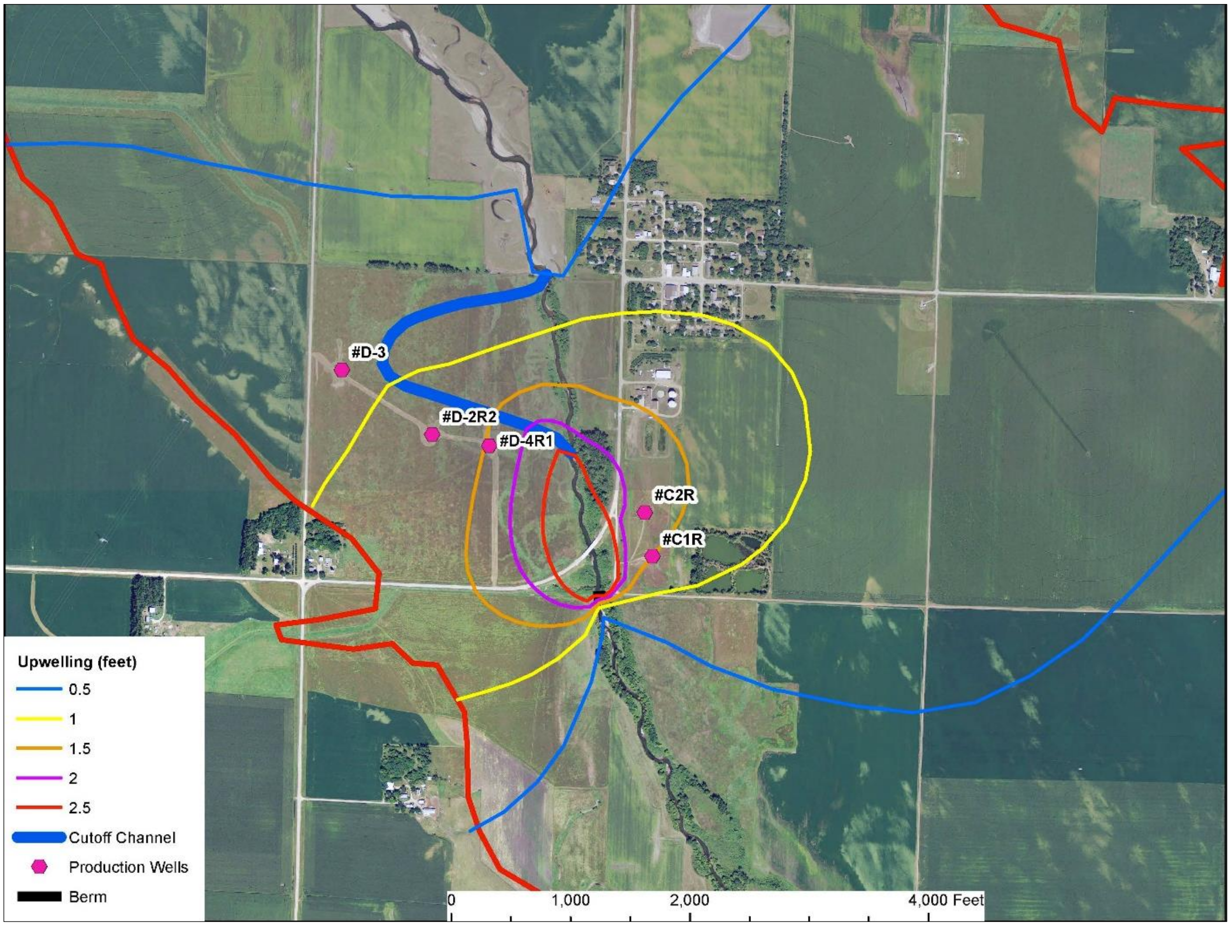

Figure 18. Proposed low head dam location and simulated upwelling (rise in water table) near the CD-Series wells with the addition of a proposed cutoff channel.

Figure 19 shows the simulated upwelling in the water table at the end of a 90 day period created by the installation of a proposed earthen berm. Based on the model results, the proposed berm would increase the water table elevation approximately 2 feet near well D-1. The increase in groundwater storage would allow well D-1 to maintain water production even during a severe drought.

R-Series and S-Series Sub-Wellfield

The R- and S-Series wells are located from 1,600 feet from the Ocheyedan River (Well S-3) to 4,800 feet from the Ocheyedan River (R-1R2). Based on our model simulations, the R and S-Series sub-wellfield receives less than 1 % induced recharge from the Ocheyedan River. Strategies to enhance induced recharge in the RS-Series wells were not considered because of the relatively large separation distances.

There is a small drainageway that runs through this sub-wellfield, but the potential runoff is unknown. Creating potential earthen berms in this drainageway may increase groundwater recharge and storage slightly. A more effective strategy might involve the possible decommissioning of one or more of the irrigation wells shown on Figure 20. This will obviously involve land purchase or some type of compensation to the landowner. Based on the IDNR Water-Use Database, Larry Ten Lkey pumps approximately 600,000 gallons per day (gpd) during the summer (2 wells), Karmen Schoelerman pumps approximately 400,000 gpd during the summer, and Rossman Farms, Inc. pumps approximately 200,000 gpd. Total daily

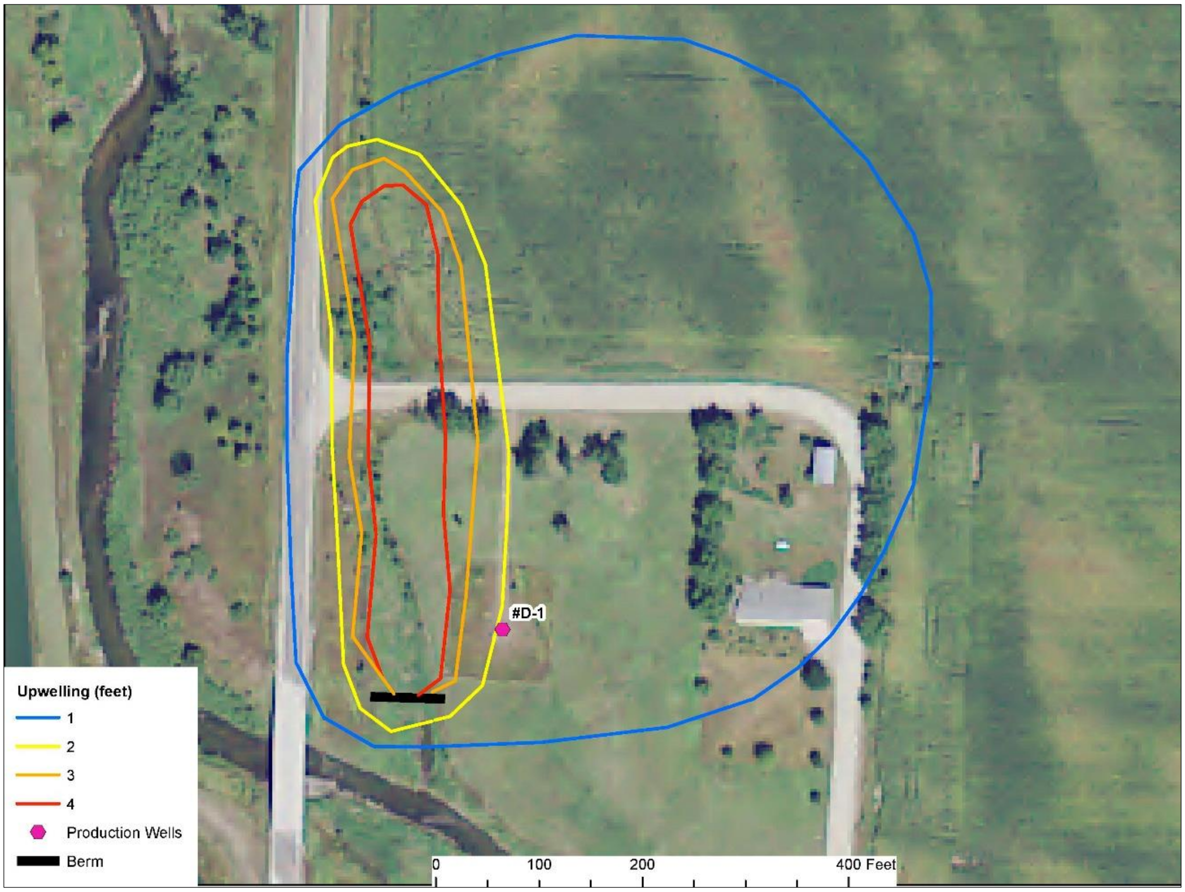

Figure 19. Proposed earthen berm location and simulated upwelling near Well D-1.

pumping from the four irrigation wells during the summer is approximately 1.2 million gallons per day. The simulated upwelling in the groundwater table if the irrigation wells are decommission is shown on Figure 20. Based on the calibrated groundwater flow model, approximately 0.25 and 0.5 feet of upwelling would occur in the R and S-Series wells if the irrigation wells were not used during the peak summer months. Most of this well interference is created by the pumping of Karmen Schoelerman's well.

DISCUSSION

Based on the results of the OCRWD drought assessment and groundwater flow model application, current and future groundwater availability was evaluated. OCRWD has limited additional groundwater and wellfield expansion potential under current conditions in the northern half of its wellfield. Well D-1 obtains a majority of its water production from induced recharge, and Wells H-1 through H-4 obtain almost half of their water production from induced recharge. Critical streamflow conditions occurred during the fall of 2014 in the vicinity of the H-Series wells. Adding additional wells near Well D-1 or the H-Series wells could result in a sharp increase in drawdowns and an overall decrease in water production during a moderate to severe drought.

Adding a low-head dam downstream of the H-Series wells could substantially increase the groundwater storage and overall groundwater availability in both Well D-1 and the H-Series wells. Storing both surface water and groundwater during periodic wet periods would

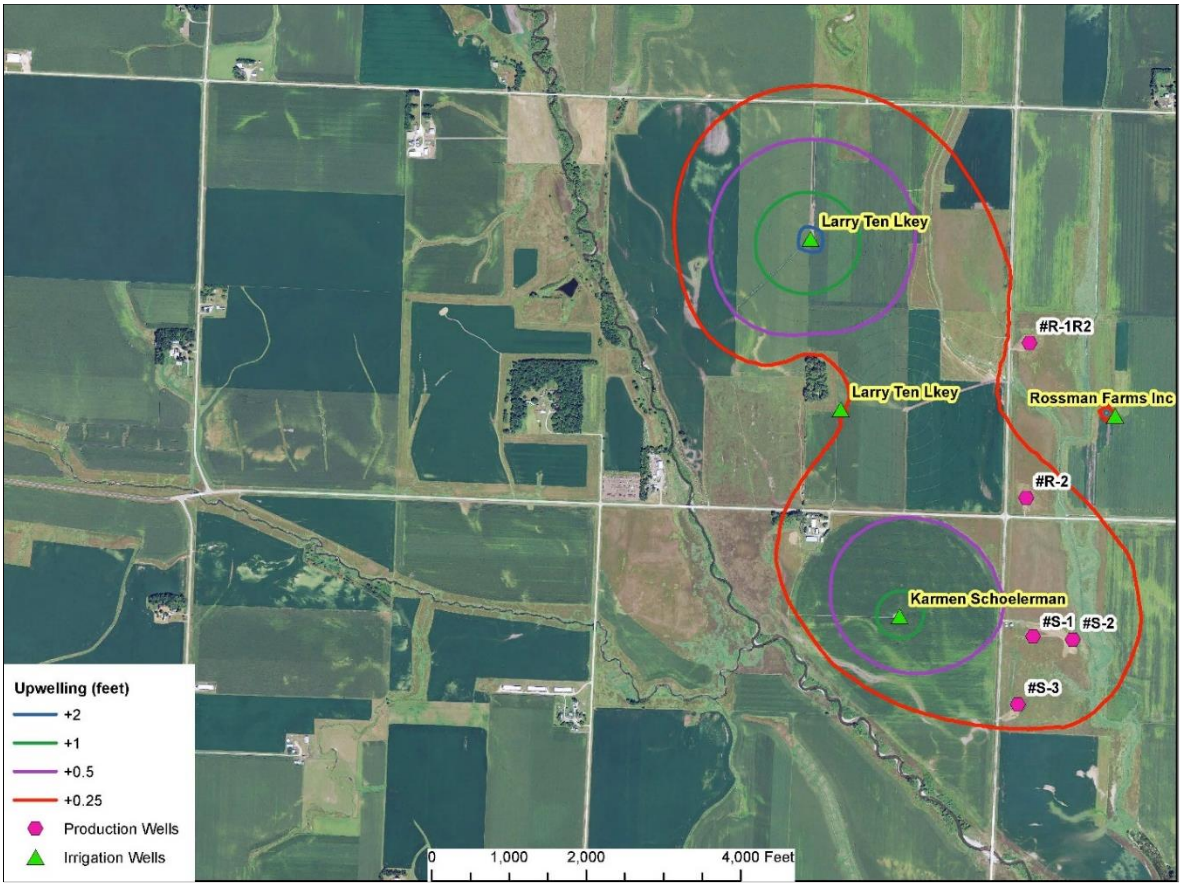

Figure 20. Simulated upwelling in the groundwater table if the irrigation wells are shutoff near the RS-Series wells.

increase the water availability during periodic dry periods. Limitation of this strategy may occur if the duration and severity of the drought intensifies. Long term monitoring of the wellfield would help evaluate the limitations of this drought strategy.

Adding a low-head dam or combination low-head dam and cutoff channel in the vicinity of the CD-Series wells would also substantially increase groundwater storage and water availability. A cost benefit analysis would need to be conducted to justify the additional cost of the cutoff channel. Additional production wells could also be installed in the vicinity of the CD-Series wells. A thorough evaluation of the hydrogeology would need to be made to determine the locations and exact number of potential production wells.

A long term strategy in the RS-Series wells would be to reduce the pumping stress and well interference effects of the nearby irrigation wells. Decommissioning one or more of the irrigation wells near the RS-Series wells would increase the available drawdown in the OCRWD wells, and may allow for future wellfield expansion in this area.

CONCLUSIONS

The IGS completed a drought assessment to evaluate current and future groundwater availability for the OCRWD wellfield near May City, Iowa. In addition, a calibrated groundwater flow model was constructed to provide OCRWD with various strategies to enhance and increase both aquifer storage and induced recharge. The current users include OCRWD North Wellfield and approximately 23 irrigation wells.

OCRWD has limited additional groundwater and wellfield expansion potential under current conditions in the northern half of its wellfield.

Well D-1 obtains a majority of its water production from induced recharge, and Wells H-1 through H-4 obtain almost half of their water production from induced recharge. Critical streamflow conditions occurred during the fall of 2014 in the vicinity of the H-Series wells. Adding additional wells near Well D-1 or the H-Series wells could result in a sharp increase in drawdowns and an overall decrease in water production during a moderate to severe drought.

Based on the model results, well D-1 had the highest percentage of induced recharge at 70 percent or 362,000 gallons per day (gpd). This was followed by the H-Series sub-wellfield, which had 44 percent or 672,000,000 gpd. The CD-Series and the RS-Series sub-wellfields had relatively small percentages (19%, 304,000 gpd) and 0.6%, 6,500 gpd). Wells D-3 and the RS-Series wells are located between 1,200 and 4,800 feet from the Ocheyedan River. This greatly reduces the induced recharge that can occur in these sub-wellfields.

On October 22, 2014, the critical streamflow flow (minimum streamflow to maintain water production) appears to have been reached along the Ocheyedan River in the vicinity of the H-Series sub-wellfield. Adding any additional wells near current wells H-1 through H-4 would likely exceed the critical streamflow necessary to maintain water production during a moderate to severe drought.

Based on model results, a proposed low-head dam downgradient of the H-Series production wells would raise the river stage approximately 3 feet immediately behind the dam during low flow conditions. Increases in water table elevations range from over 2 feet in wells H-3 and H-4, to 1 to 1.5 feet in wells H-1 and H-2. The increase in groundwater storage would allow the H-Series wells to maintain water production even during a severe drought. Induced recharge would increase from 44% (without the low-head dam) to 67% with the low-head dam. Adding additional production wells in the H-Series sub-wellfield may also be possible.

Based on model results, a proposed low-head dam downstream of the CD-Series wells would raise the river stage approximately 3 feet immediately behind the dam during low flow conditions. Based on the model simulation, increases in water table elevations range from 1 to 1.5 feet in wells C-1R and C-2R, to 0.5 to 1 foot in wells D-2R2 and D-4R1. Based on the model results, well D-3 would not benefit from the proposed low-head dam. The increase in groundwater storage created by a low-head dam would benefit the CD-Series sub-wellfield. Induced recharge would increase from 19% (no low-head dam) to 56% (with a proposed low-head dam).

Based on model results, a proposed low-head dam and cutoff channel would increase the induced recharge available to the CD-Series wells from 19% (no low-head dam or cutoff channel) to 72% (low-head dam and cutoff channel). Based on model results, increases in water table elevations range from 1.5 to 2 feet in wells C-1R, C-2R, and D-4R1, to 1 to 1.5 feet in wells D-2R2, and D-4R1, and between 0.5 and 1 foot in well D-3. The combination of a proposed low-head dam and cutoff channel not only increases the induced recharge, but is more effective at increasing overall groundwater storage compared to a low-head dam alone.

Based on model results, a proposed earthen berm near Well D-1 would increase the water table elevation approximately 2 feet. The potential increase in groundwater storage would allow well D-1 to maintain water production even during a severe drought.

A possible strategy for the RS-Series wells might involve the possible decommissioning of one or more of the nearby irrigation wells. Based on model results, approximately 0.25 and 0.5 feet of upwelling would occur in the R and S-series wells if the irrigation wells were not used during the peak summer months. Most of this well interference is created by the pumping of Karmen Schoelerman’s well.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the contributions of the many individuals who assisted in the production of this report. The funding for this project was provided by the Iowa Department of Natural Resources. Dr. Art Bettis and Phillip Kerr conducted the grain size analyses. Dr. Colby Swan provided access to his material laboratory for permeability testing. Rick Langel assisted with streamflow measurements. DRG, Engineers (Rock Rapids, Iowa) did all of the on-site surveying. The report layout and editing was done by Megan Hauswirth.

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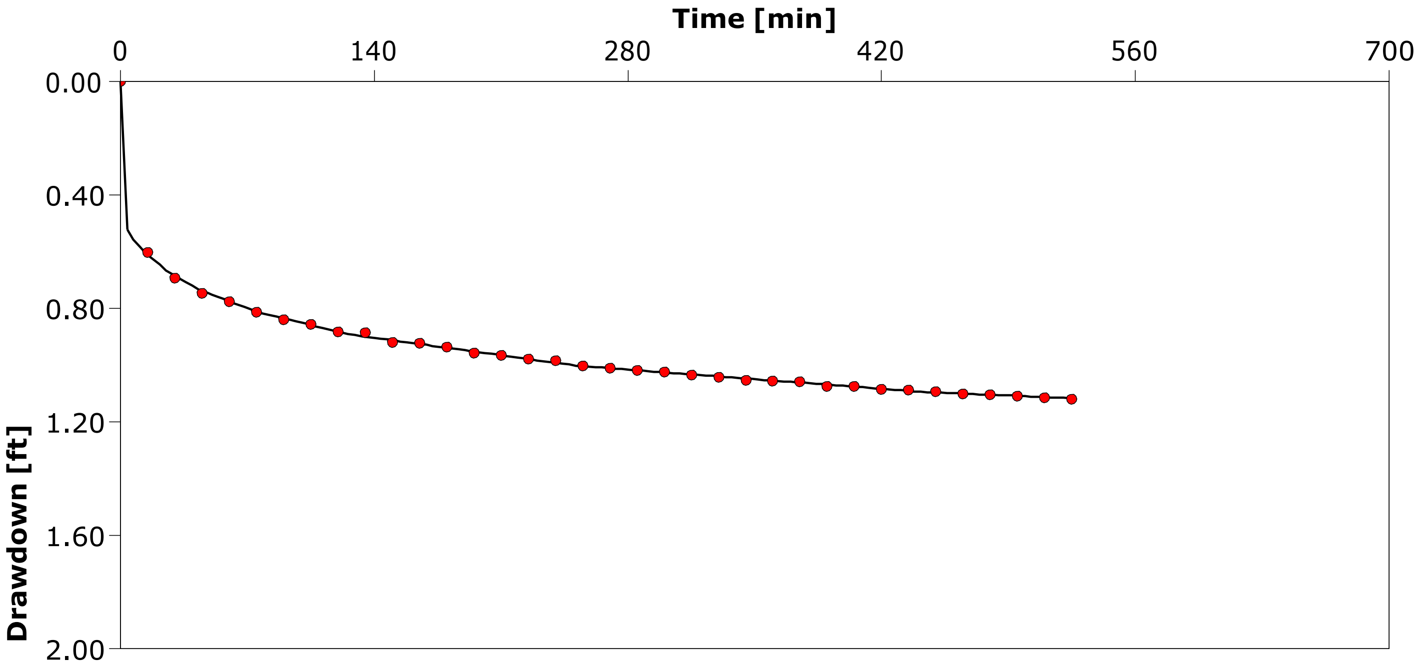
Appendix A

	Pumping Test Analysis Report
IOWA GEOLOGICAL SURVEY	Project: OCRWD
	Number:
	Client:

Location: May City, Iowa	Pumping Test: C-1 Observation Well 1	Pumping Well: C-1
Test Conducted by: IGS		Test Date: 10/8/2014
Analysis Performed by:	New analysis 1	Analysis Date: 10/14/2014
Aquifer Thickness: 40.00 ft	Discharge Rate: 220 [U.S. gal/min]	

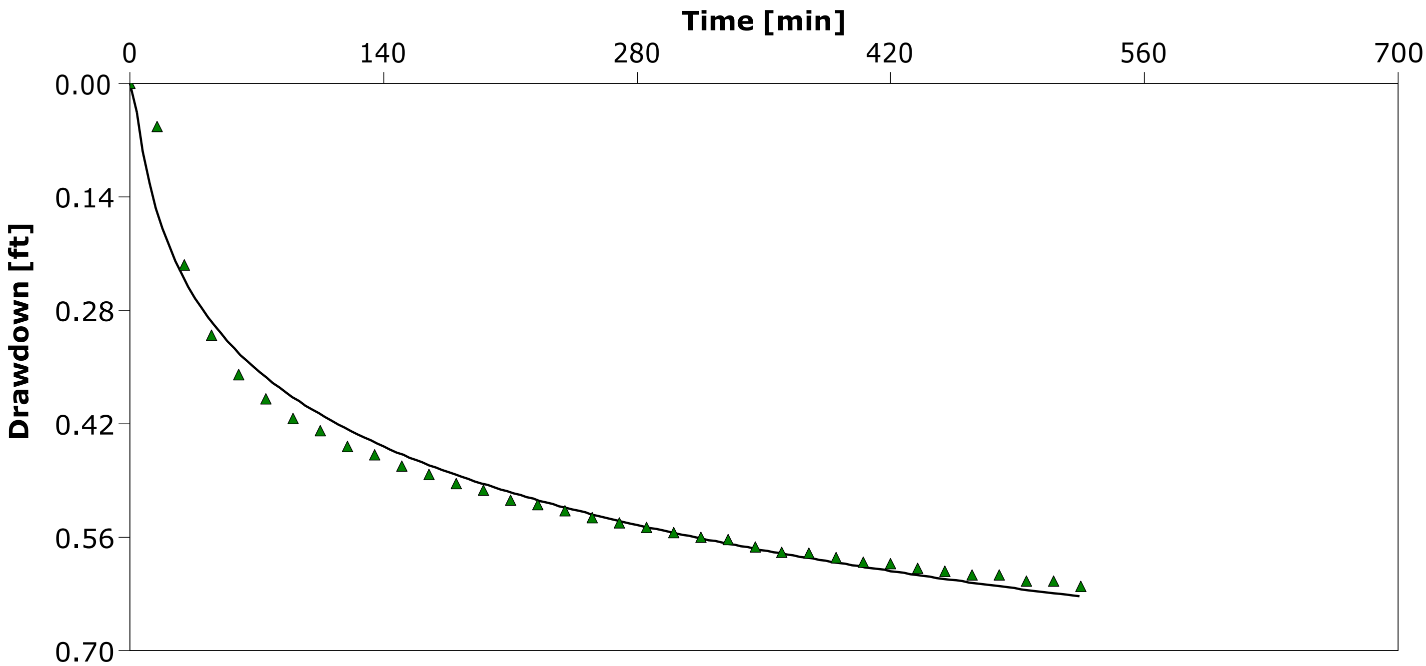


Calculation using Neuman

Observation Well	Transmissivity [ft²/d]	Hydraulic Conductivity	Specific Yield	Ratio K(v)/K(h)	Ratio Sy/S	Radial Distance to PW [ft]
OB1	2.06×10^{4}	5.14×10^{2}	1.95×10^{-3}	3.52×10^{-3}	7.29×10^{1}	96.0

IOWA GEOLOGICAL SURVEY	Pumping Test Analysis Report
	Project: OCRWD
	Number:
	Client:

Location: May City, Iowa	Pumping Test: C-1 Observation Well 1	Pumping Well: C-1
Test Conducted by: IGS		Test Date: 10/8/2014
Analysis Performed by:	New analysis 2	Analysis Date: 10/14/2014
Aquifer Thickness: 40.00 ft	Discharge Rate: 220 [U.S. gal/min]	

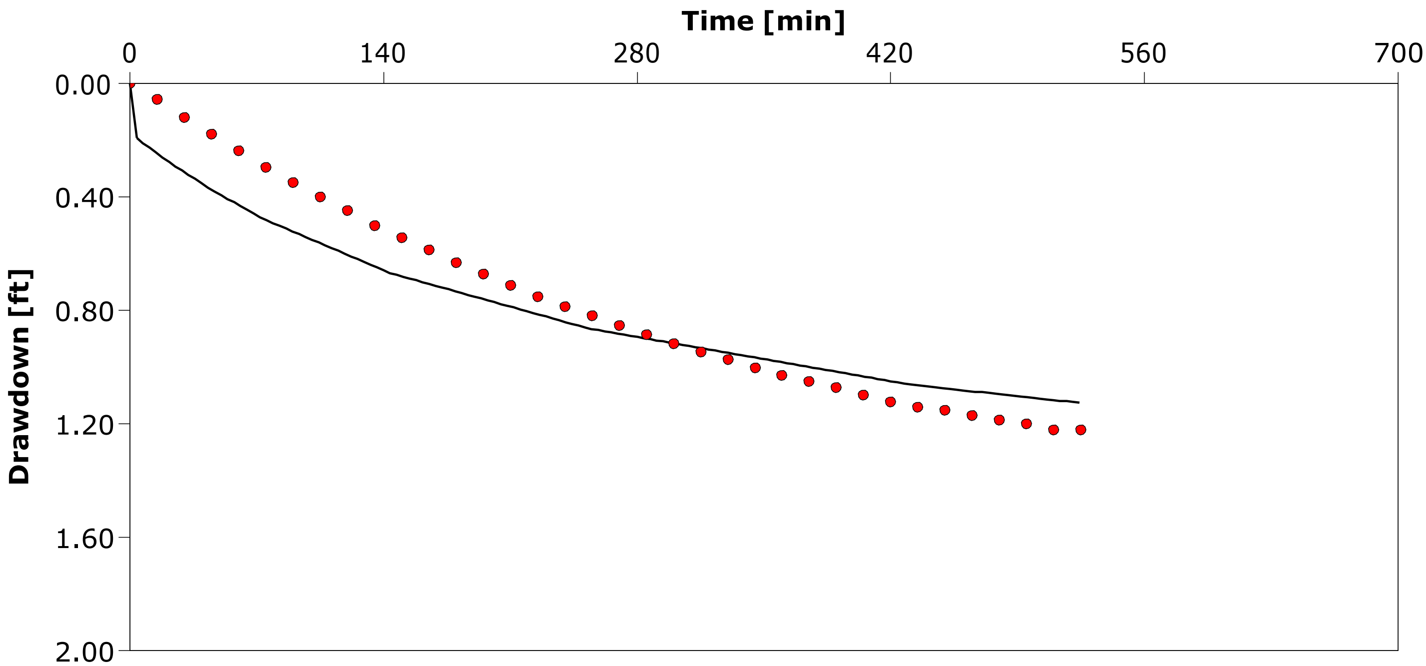


Calculation using Neuman

Observation Well	Transmissivity [ft²/d]	Hydraulic Conductivity [ft/d]	Specific Yield	Ratio K(v)/K(h)	Ratio Sy/S	Radial Distance to PW [ft]
OB-2	2.37×10^{4}	5.94×10^{2}	3.79×10^{-3}	1.00×10^{0}	6.64×10^{4}	244.0

IOWA GEOLOGICAL SURVEY	**Pumping Test Analysis Report**
	Project: OCRWD Pump Test C-2
	Number:
	Client:

Location: May City, Iowa	Pumping Test: C-2	Pumping Well: C-2
Test Conducted by: Mike Gannon		Test Date: 9/24/2014
Analysis Performed by:	New analysis 1	Analysis Date: 10/15/2014
Aquifer Thickness: 40.00 ft	Discharge Rate: 600 [U.S. gal/min]	

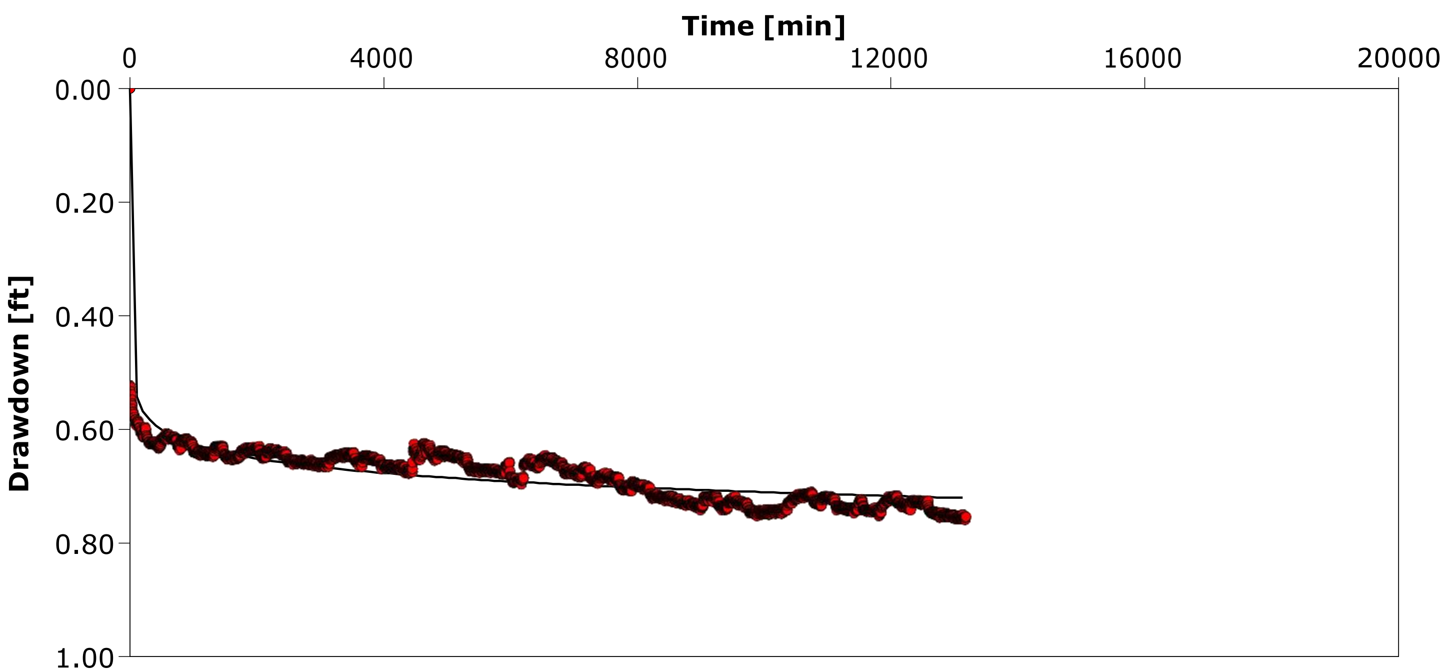


Calculation using Neuman

Observation Well	Transmissivity [ft²/d]	Hydraulic Conductivity [ft/d]	Specific Yield	Ratio K(v)/K(h)	Ratio Sy/S	Radial Distance to PW [ft]
Well 2	2.29×10^{4}	5.72×10^{2}	9.90×10^{-1}	1.00×10^{0}	5.93×10^{5}	34.0

IOWA GEOLOGICAL SURVEY	**Pumping Test Analysis Report**
	Project: OCRWD Pump Test D-1
	Number:
	Client:

Location: May City, Iowa	Pumping Test: D-1	Pumping Well: D-1
Test Conducted by: Mike Gannon		Test Date: 9/3/2014
Analysis Performed by:	New analysis 1	Analysis Date: 10/15/2014
Aquifer Thickness: 31.00 ft	Discharge Rate: 320 [U.S. gal/min]	

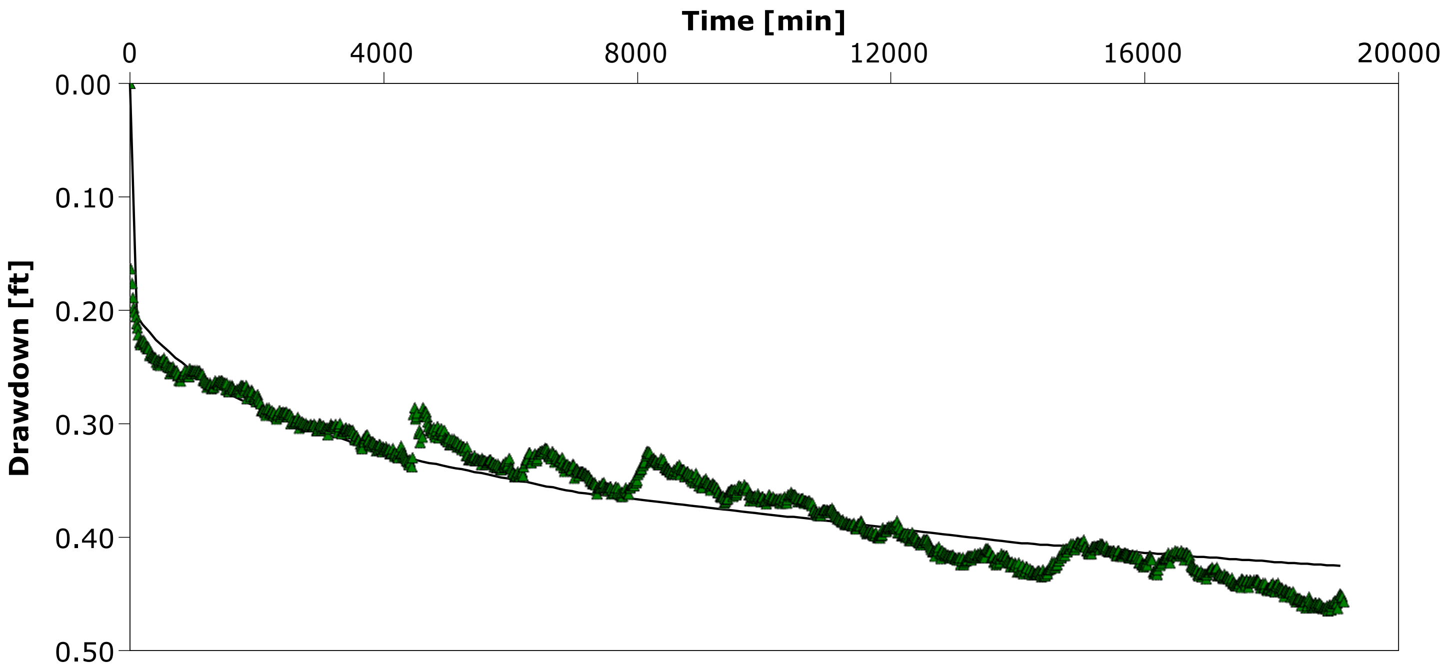


Calculation using Neuman

Observation Well	Transmissivity [ft²/d]	Hydraulic Conductivity [ft/d]	Specific Yield	Ratio K(v)/K(h)	Ratio Sy/S	Radial Distance to PW [ft]
OB-1	1.33×10^{5}	4.30×10^{3}	2.65×10^{-6}	1.16×10^{-1}	6.71×10^{2}	56.0

IOWA GEOLOGICAL SURVEY	**Pumping Test Analysis Report**
	Project: OCRWD Pump Test D-1
	Number:
	Client:

Location: May City, Iowa	Pumping Test: D-1	Pumping Well: D-1
Test Conducted by: Mike Gannon		Test Date: 9/3/2014
Analysis Performed by:	New analysis 3	Analysis Date: 10/15/2014
Aquifer Thickness: 31.00 ft	Discharge Rate: 320 [U.S. gal/min]	

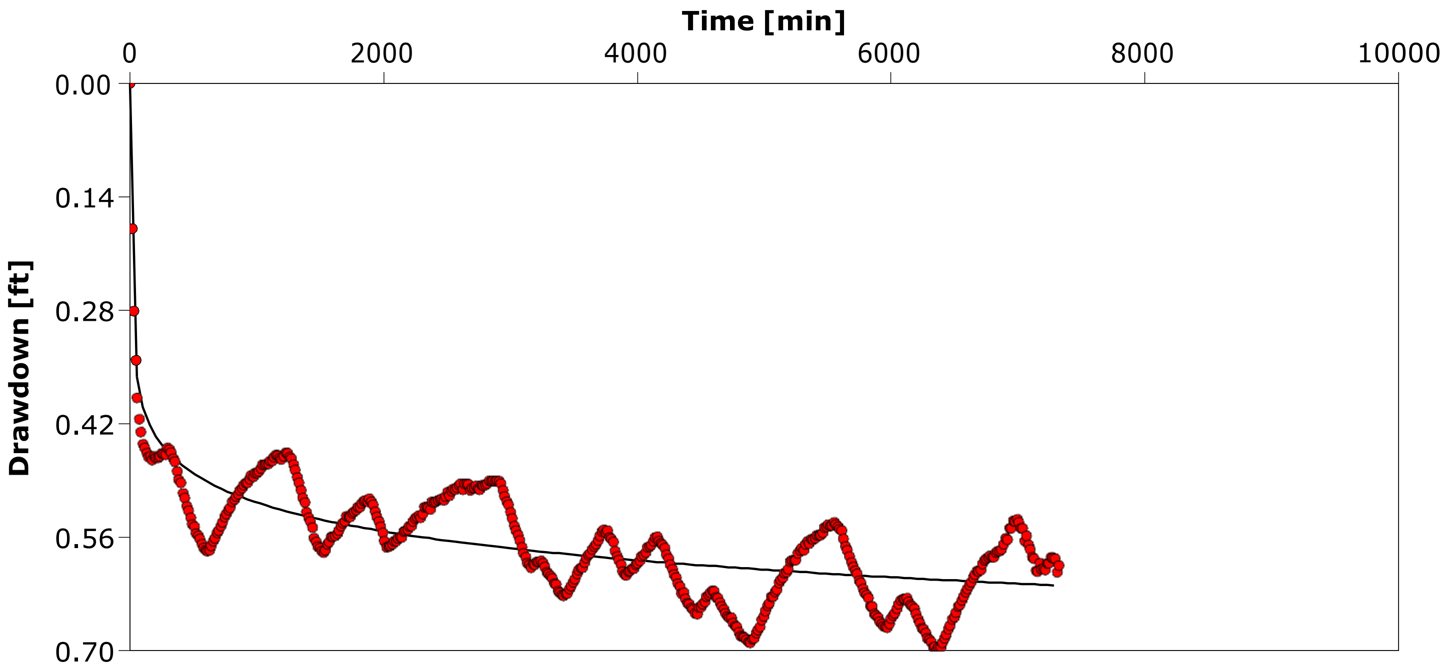


Calculation using Neuman

Observation Well	Transmissivity [ft²/d]	Hydraulic Conductivity [ft/d]	Specific Yield	Ratio K(v)/K(h)	Ratio Sy/S	Radial Distance to PW [ft]
OB-2	7.38×10^{4}	2.38×10^{3}	1.03×10^{-1}	5.48×10^{-4}	3.59×10^{4}	188.0

IOWA GEOLOGICAL SURVEY	**Pumping Test Analysis Report**
	Project: OCRWD Pump Test D-2
	Number:
	Client:

Location: May City, Iowa	Pumping Test: D-2	Pumping Well: D-2
Test Conducted by: Mike Gannon		Test Date: 10/15/2014
Analysis Performed by:	New analysis 1	Analysis Date: 10/15/2014
Aquifer Thickness: 40.00 ft	Discharge Rate: 400 [U.S. gal/min]	

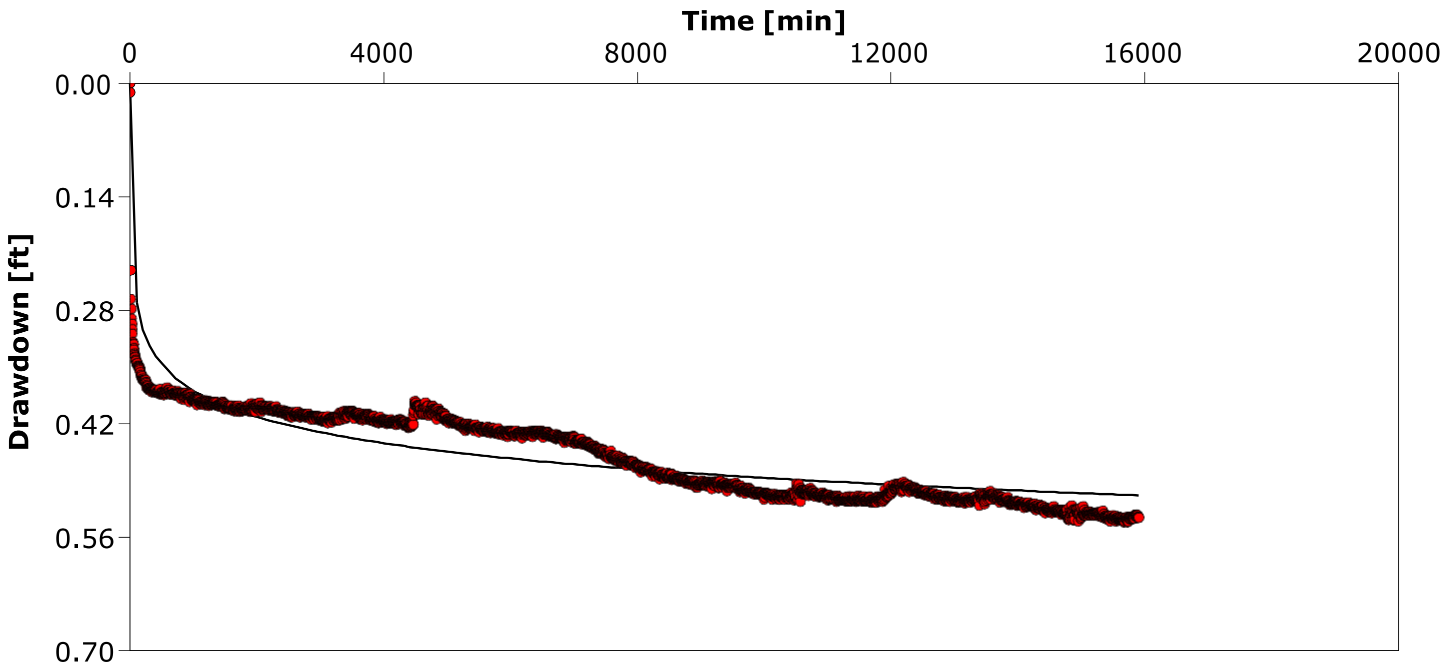


Calculation using Neuman

Observation Well	Transmissivity [ft²/d]	Hydraulic Conductivity [ft/d]	Specific Yield	Ratio K(v)/K(h)	Ratio Sy/S	Radial Distance to PW [ft]
OB2	1.19×10^{5}	2.97×10^{3}	6.96×10^{-4}	9.60×10^{-1}	1.38×10^{4}	108.0

IOWA GEOLOGICAL SURVEY	**Pumping Test Analysis Report**
	Project: OCRWD Pump Test D-3
	Number:
	Client:

Location: May City, Iowa	Pumping Test: D-3	Pumping Well: D-3
Test Conducted by: Mike Gannon		Test Date: 9/3/2014
Analysis Performed by:	New analysis 1	Analysis Date: 10/15/2014
Aquifer Thickness: 43.00 ft	Discharge Rate: 400 [U.S. gal/min]	

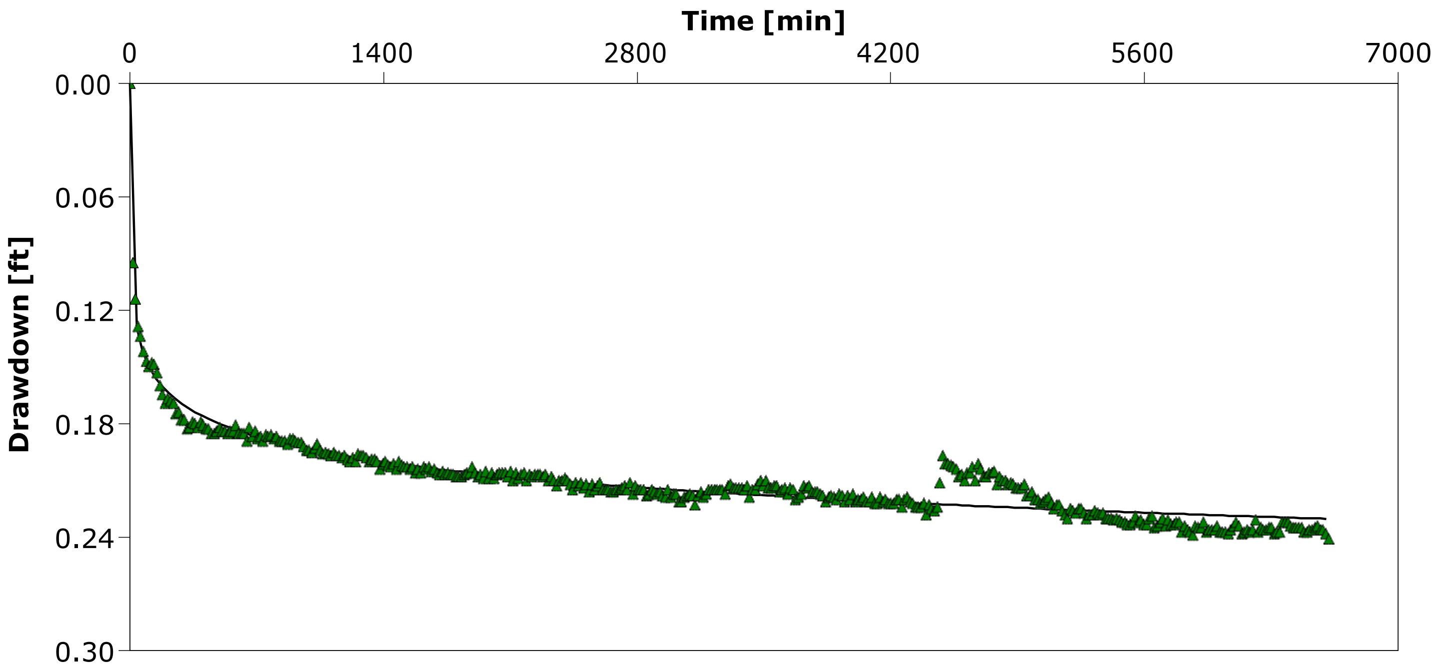


Calculation using Neuman

Observation Well	Transmissivity [ft²/d]	Hydraulic Conductivity [ft/d]	Specific Yield	Ratio K(v)/K(h)	Ratio Sy/S	Radial Distance to PW [ft]
OB-2	1.31×10^{5}	3.05×10^{3}	9.49×10^{-3}	7.95×10^{-2}	2.47×10^{4}	80.0

IOWA GEOLOGICAL SURVEY	**Pumping Test Analysis Report**
	Project: OCRWD Pump Test D-3
	Number:
	Client:

Location: May City, Iowa	Pumping Test: D-3	Pumping Well: D-3
Test Conducted by: Mike Gannon		Test Date: 9/3/2014
Analysis Performed by:	New analysis 2	Analysis Date: 10/15/2014
Aquifer Thickness: 43.00 ft	Discharge Rate: 400 [U.S. gal/min]	

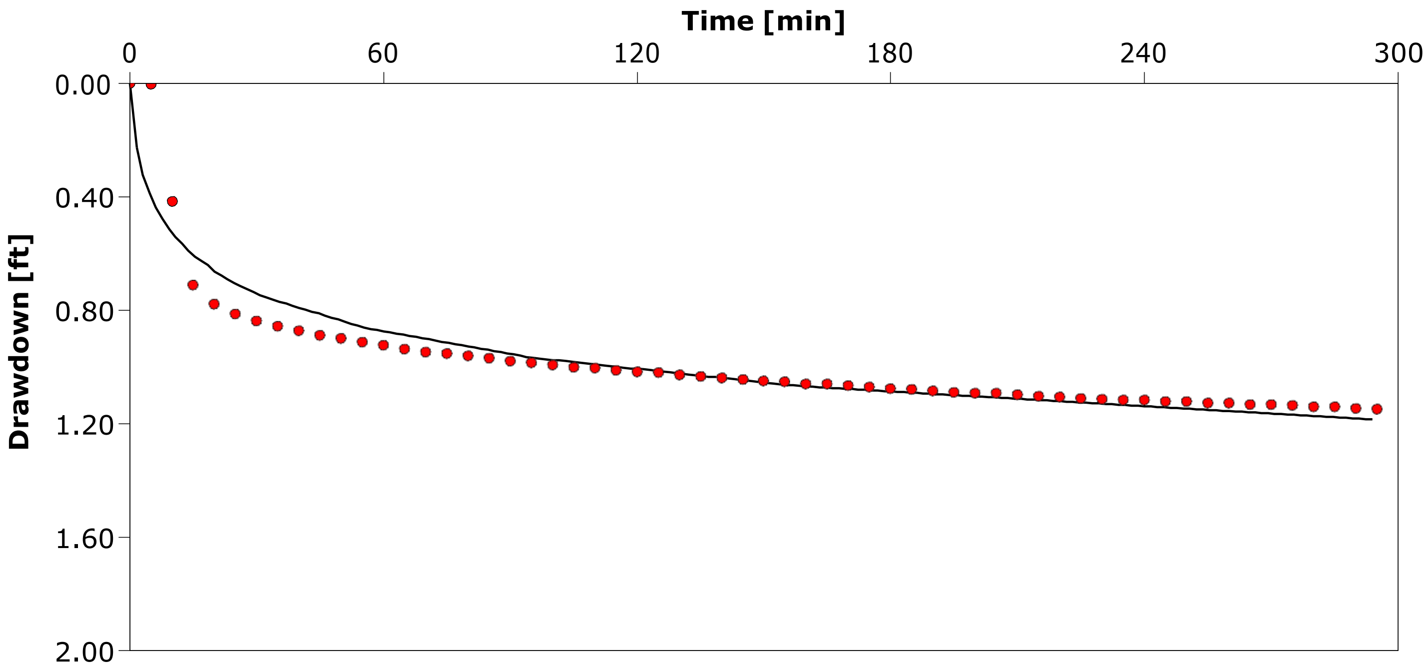


Calculation using Neuman

Observation Well	Transmissivity [ft²/d]	Hydraulic Conductivity [ft/d]	Specific Yield	Ratio K(v)/K(h)	Ratio Sy/S	Radial Distance to PW [ft]
OB-3	3.16×10^{5}	7.36×10^{3}	4.06×10^{-4}	2.07×10^{-1}	2.49×10^{2}	235.0

	Pumping Test Analysis Report
IOWA GEOLOGICAL SURVEY	Project: OCRWD Pump Test D-4
	Number:
	Client:

Location: May City, Iowa	Pumping Test: D-4	Pumping Well: D-4
Test Conducted by:		Test Date: 9/3/2014
Analysis Performed by:	New analysis 1	Analysis Date: 10/15/2014
Aquifer Thickness: 48.00 ft	Discharge Rate: 400 [U.S. gal/min]	

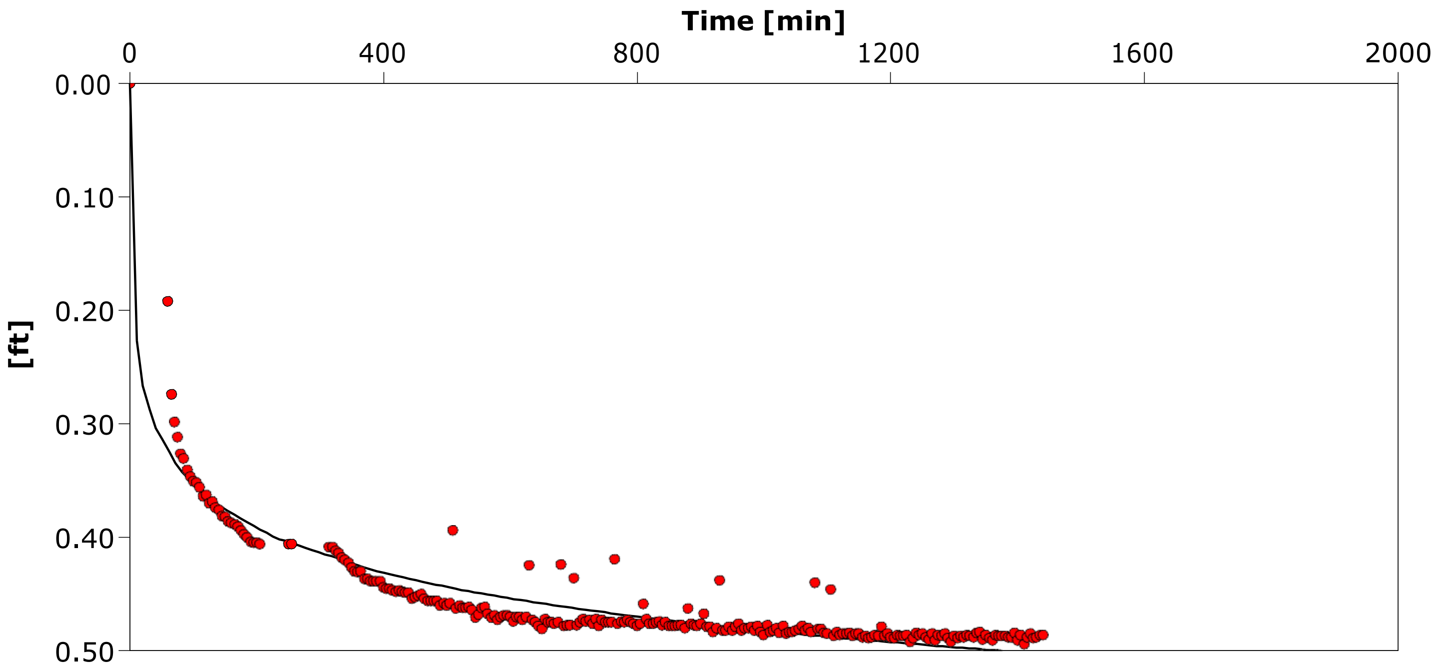


Calculation using Neuman

Observation Well	Transmissivity [ft²/d]	Hydraulic Conductivity [ft/d]	Specific Yield	Ratio K(v)/K(h)	Ratio Sy/S	Radial Distance to PW [ft]
OB-1	3.11×10^{4}	6.48×10^{2}	1.93×10^{-2}	1.00×10^{0}	6.34×10^{5}	42.0

	Pumping Test Analysis Report
IOWA GEOLOGICAL SURVEY	Project: OCRWD H-1 Pump Test
	Number:
	Client:

Location: Osceola County	Pumping Test: H-1	Pumping Well: H-1
Test Conducted by:		Test Date: 9/3/2014
Analysis Performed by:	New analysis 2	Analysis Date: 9/22/2014
Aquifer Thickness: 39.00 ft	Discharge Rate: 333 [U.S. gal/min]	

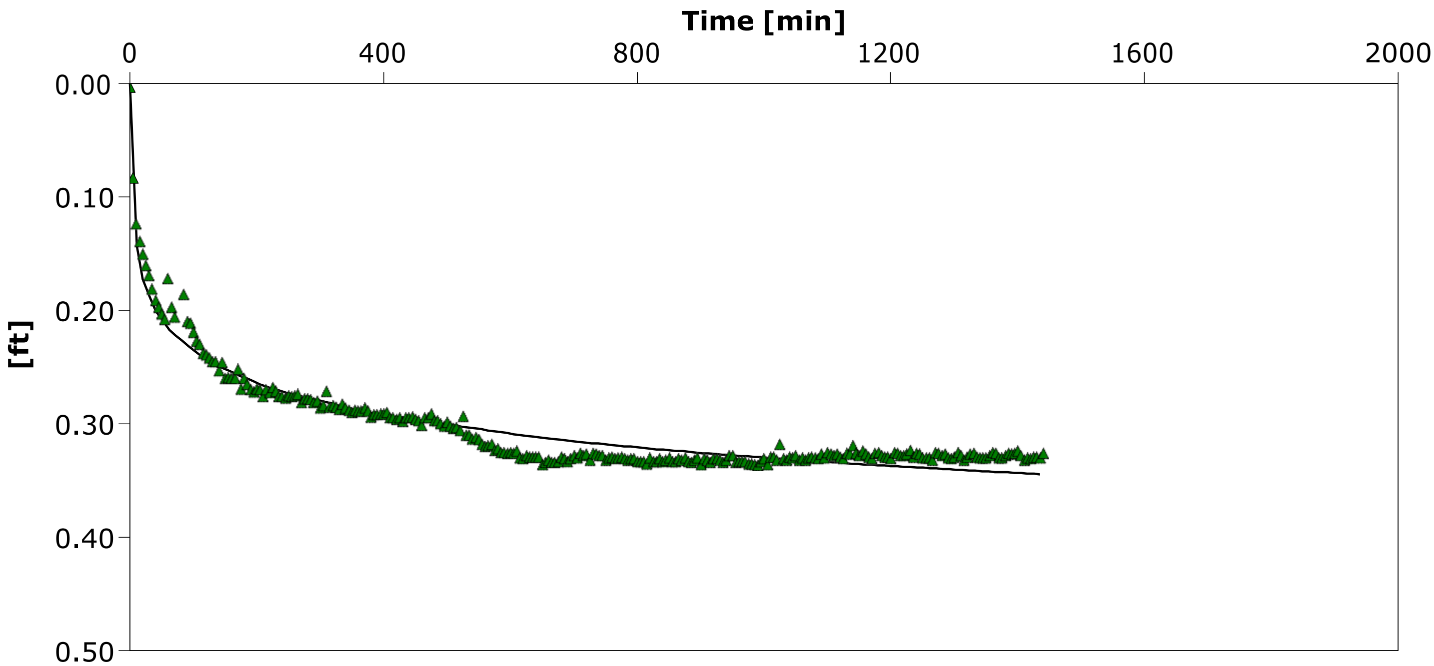


Calculation using Neuman

Observation Well	Transmissivity [ft²/d]	Hydraulic Conductivity [ft/d]	Specific Yield	Ratio K(v)/K(h)	Ratio Sy/S	Radial Distance to PW [ft]
ob1	9.18×10^{4}	2.36×10^{3}	2.63×10^{-3}	9.94×10^{-1}	2.05×10^{5}	96.0

IOWA GEOLOGICAL SURVEY	**Pumping Test Analysis Report**
	Project: OCRWD H-1 Pump Test
	Number:
	Client:

Location: Osceola County	Pumping Test: H-1	Pumping Well: H-1
Test Conducted by:		Test Date: 9/3/2014
Analysis Performed by:	New analysis 2	Analysis Date: 9/22/2014
Aquifer Thickness: 39.00 ft	Discharge Rate: 333 [U.S. gal/min]	

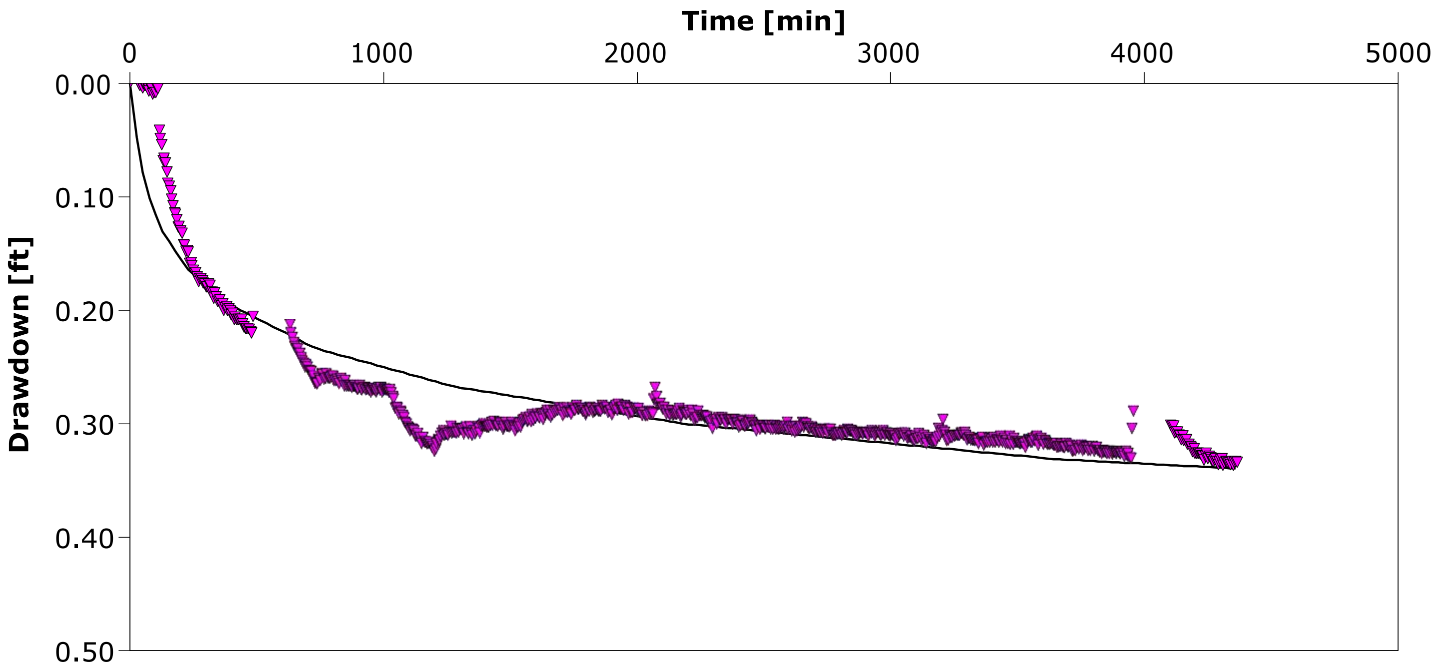


Calculation using Neuman

Observation Well	Transmissivity [ft²/d]	Hydraulic Conductivity [ft/d]	Specific Yield	Ratio K(v)/K(h)	Ratio Sy/S	Radial Distance to PW [ft]
ob2	1.26×10^{5}	3.24×10^{3}	9.11×10^{-4}	1.75×10^{-1}	4.71×10^{3}	247.0

IOWA GEOLOGICAL SURVEY	**Pumping Test Analysis Report**
	Project: OCRWD H-1 Pump Test
	Number:
	Client:

Location: Osceola County	Pumping Test: H-1	Pumping Well: H-1
Test Conducted by:		Test Date: 9/3/2014
Analysis Performed by:	New analysis 3	Analysis Date: 9/22/2014
Aquifer Thickness: 39.00 ft	Discharge Rate: 333 [U.S. gal/min]	

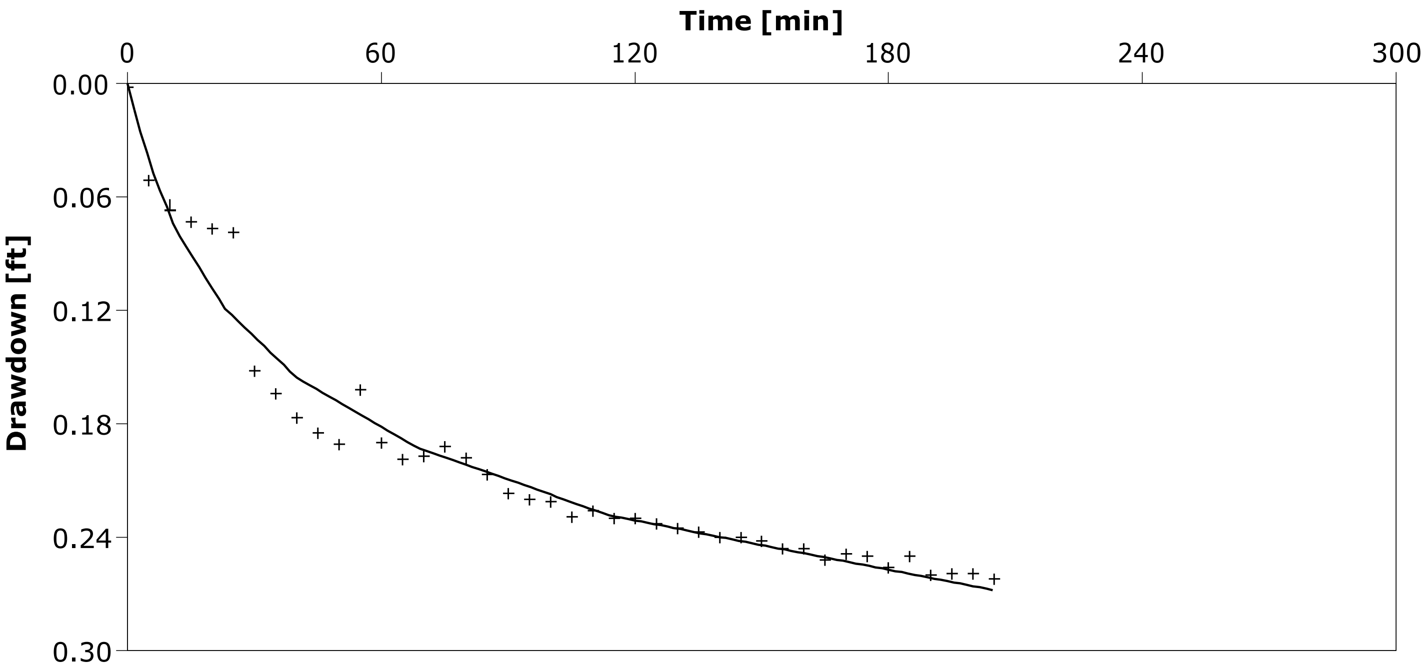


Calculation using Neuman

Observation Well	Transmissivity [ft²/d]	Hydraulic Conductivity [ft/d]	Specific Yield	Ratio K(v)/K(h)	Ratio Sy/S	Radial Distance to PW [ft]
WN1	8.34×10^{4}	2.14×10^{3}	1.55×10^{-2}	7.78×10^{-2}	1.84×10^{2}	370.0

IOWA GEOLOGICAL SURVEY	**Pumping Test Analysis Report**
	Project: OCRWD H-1 Pump Test
	Number:
	Client:

Location: Osceola County	Pumping Test: H-1	Pumping Well: H-1
Test Conducted by:		Test Date: 9/3/2014
Analysis Performed by:	New analysis 4	Analysis Date: 9/22/2014
Aquifer Thickness: 39.00 ft	Discharge Rate: 333 [U.S. gal/min]	

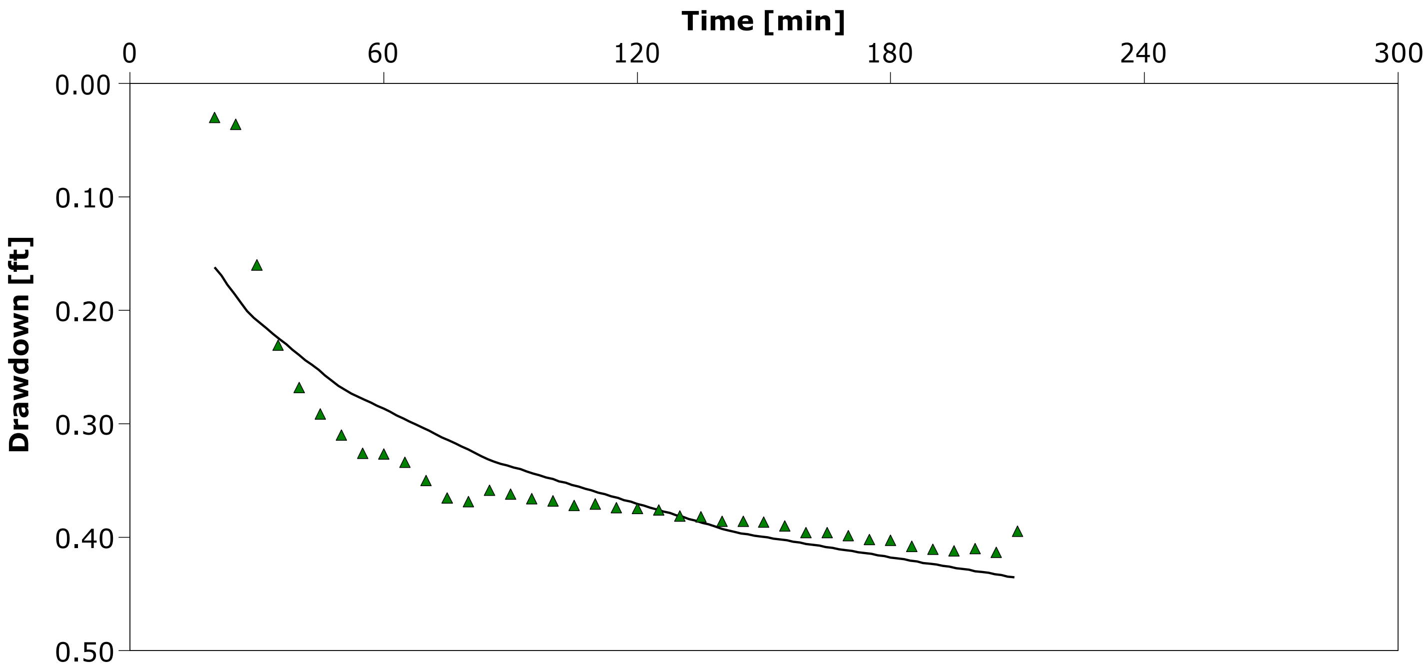


Calculation using Neuman

Observation Well	Transmissivity [ft²/d]	Hydraulic Conductivity [ft/d]	Specific Yield	Ratio K(v)/K(h)	Ratio Sy/S	Radial Distance to PW [ft]
WN2	7.00×10^{4}	1.79×10^{3}	1.19×10^{-3}	1.31×10^{-2}	6.87×10^{3}	682.0

IOWA GEOLOGICAL SURVEY	**Pumping Test Analysis Report**
	Project: OCRWD H-2
	Number:
	Client:

Location:	Pumping Test: H-2	Pumping Well: H-2
Test Conducted by:		Test Date: 9/3/2014
Analysis Performed by:	New analysis 2	Analysis Date: 9/22/2014
Aquifer Thickness: 26.00 ft	Discharge Rate: 150 [U.S. gal/min]	

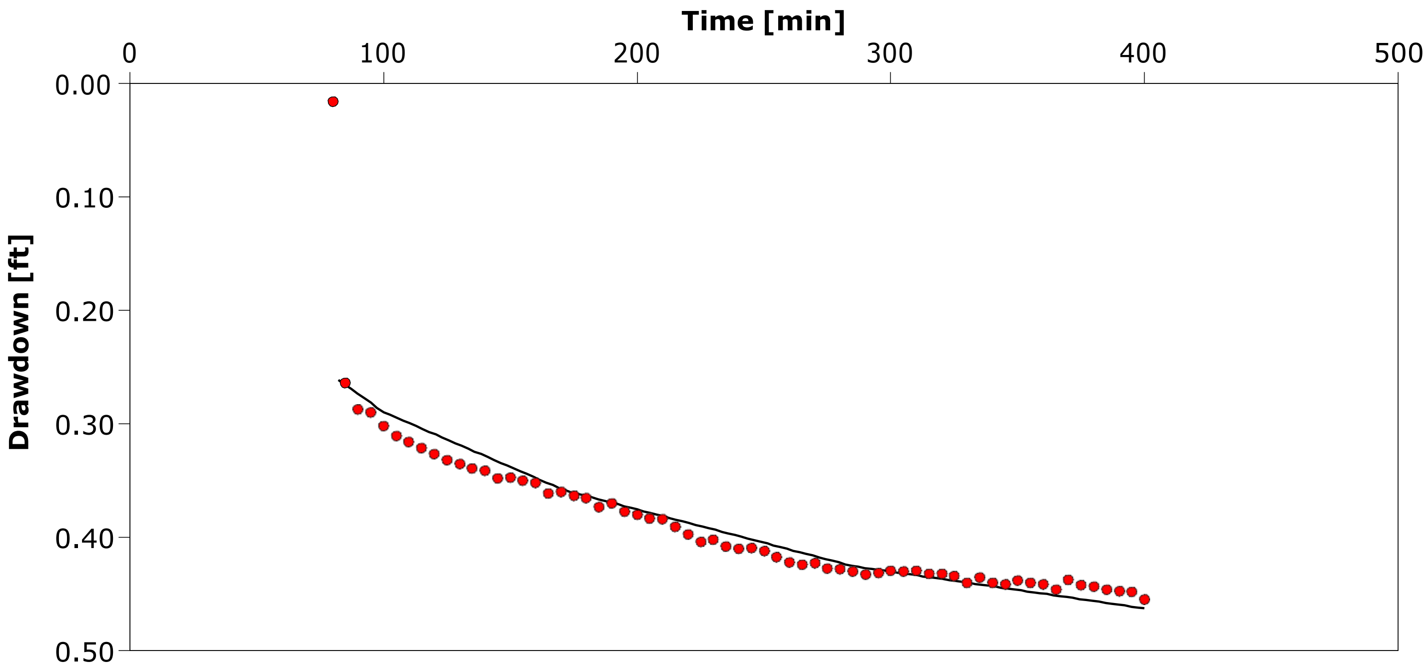


Calculation using Neuman

Observation Well	Transmissivity [ft²/d]	Hydraulic Conductivity [ft/d]	Specific Yield	Ratio K(v)/K(h)	Ratio Sy/S	Radial Distance to PW [ft]
WN3	1.82×10^{4}	7.01×10^{2}	4.28×10^{-2}	1.00×10^{0}	2.29×10^{3}	65.0

IOWA GEOLOGICAL SURVEY	**Pumping Test Analysis Report**
	Project: OCRWD H-2
	Number:
	Client:

Location:	Pumping Test: H-2	Pumping Well: H-2
Test Conducted by:		Test Date: 9/3/2014
Analysis Performed by:	New analysis 1	Analysis Date: 9/22/2014
Aquifer Thickness: 26.00 ft	Discharge Rate: 150 [U.S. gal/min]	

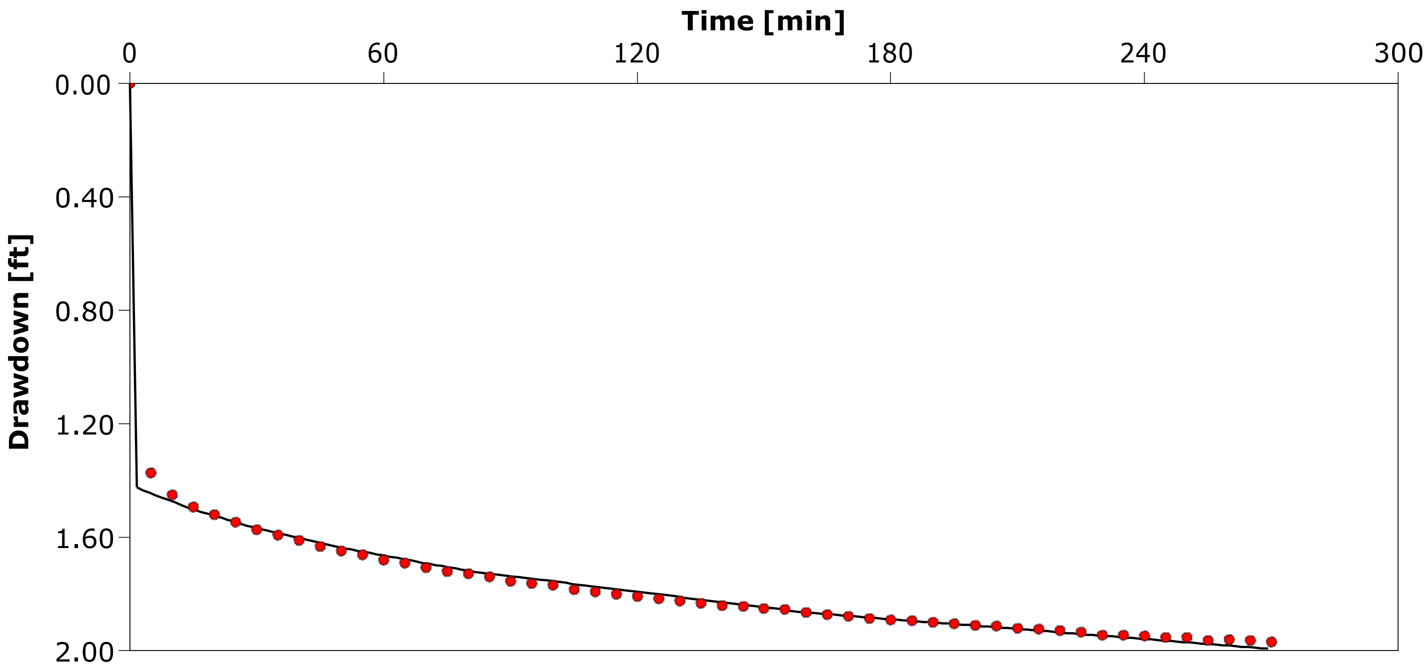


Calculation using Neuman

Observation Well	Transmissivity [ft²/d]	Hydraulic Conductivity [ft/d]	Specific Yield	Ratio K(v)/K(h)	Ratio Sy/S	Radial Distance to PW [ft]
OB1	1.69×10^{4}	6.52×10^{2}	1.52×10^{-1}	1.00×10^{0}	2.34×10^{4}	47.0

	Pumping Test Analysis Report		
IOWA GEOLOGICAL SURVEY	Project: OCRWD Pump Test S-3		
	Number:		
	Client:		

Location: May City, Iowa	Pumping Test: S-3	Pumping Well: S-3
Test Conducted by: Mike Gannon		Test Date: 8/19/2014
Analysis Performed by:	New analysis 1	Analysis Date: 10/15/2014
Aquifer Thickness: 32.00 ft	Discharge Rate: 400 [U.S. gal/min]	



Calculation using Neuman

Observation Well	Transmissivity [ft²/d]	Hydraulic Conductivity [ft/d]	Specific Yield	Ratio K(v)/K(h)	Ratio Sy/S	Radial Distance to PW [ft]
OB 1	2.06×10^{4}	6.44×10^{2}	5.10×10^{-2}	1.35×10^{-2}	9.47×10^{3}	15.0

Appendix B

SAMPLE STATISTICS

SAMPLE IDENTITY: **CC**

ANALYST & DATE: ,

SAMPLE TYPE: Unimodal, Poorly Sorted

TEXTURAL GROUP: Sandy Gravel

SEDIMENT NAME: Sandy Very Fine Gravel

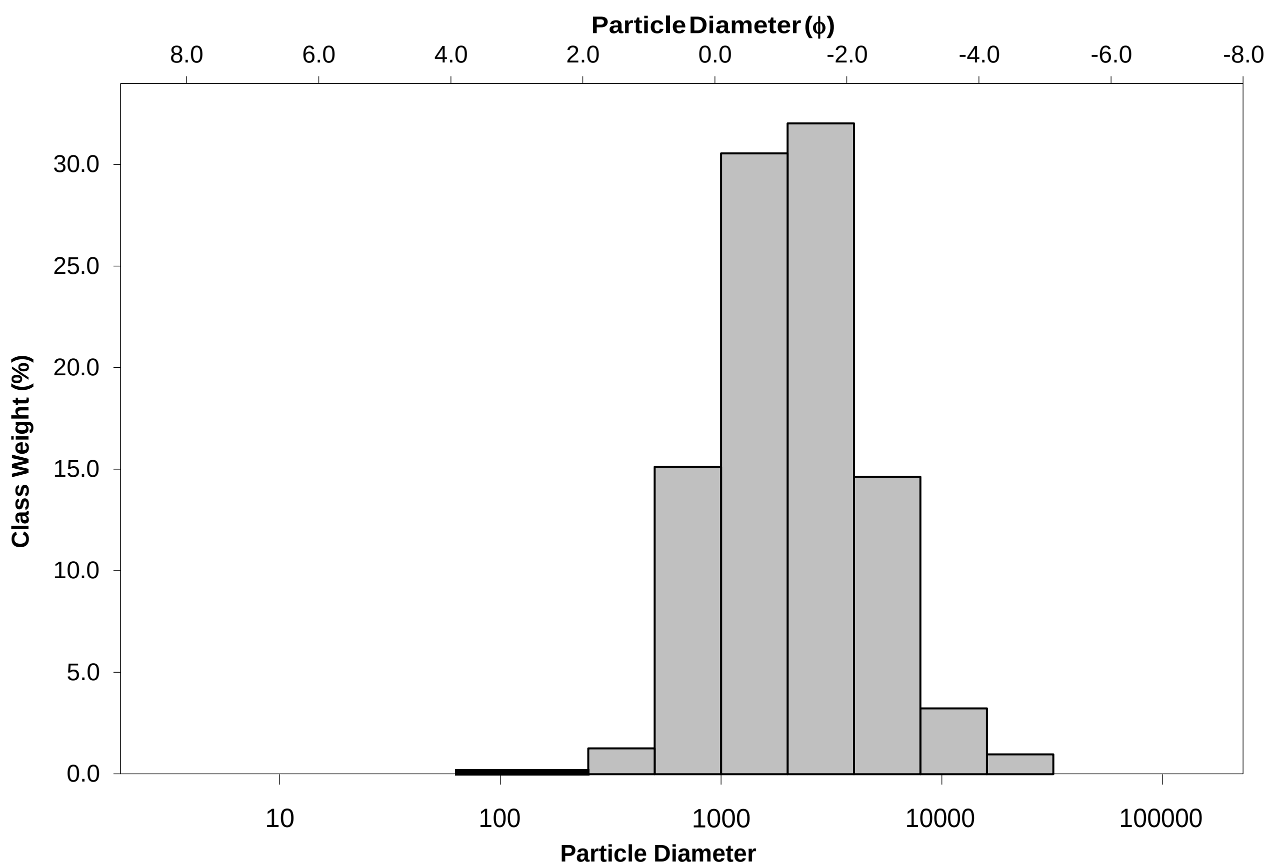
	μm	φ
MODE 1:	3000.0	-1.500
MODE 2:		
MODE 3:		
D_{10}:	726.5	-2.617
MEDIAN or D_{50}:	2078.0	-1.055
D_{90}:	6136.6	0.461
(D_{90} / D_{10}):	8.447	-0.176
(D_{90} - D_{10}):	5410.2	3.078
(D_{75} / D_{25}):	2.965	0.139
(D_{75} - D_{25}):	2343.4	1.568

GRAIN SIZE DISTRIBUTION

GRAVEL:	51.8%	COARSE SAND:	15.4%
SAND:	48.2%	MEDIUM SAND:	1.3%
MUD:	0.0%	FINE SAND:	0.2%
		V FINE SAND:	0.2%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	0.0%
COARSE GRAVEL:	1.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	3.3%	MEDIUM SILT:	0.0%
FINE GRAVEL:	14.9%	FINE SILT:	0.0%
V FINE GRAVEL:	32.6%	V FINE SILT:	0.0%
V COARSE SAND:	31.1%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic φ	Geometric μm	Logarithmic φ	Description
MEAN ($\bar{x}$):	3095.4	2098.0	-1.069	2093.9	-1.066	Very Fine Gravel
SORTING	3164.9	2.212	1.145	2.201	1.138	Poorly Sorted
SKEWNESS (Sk):	3.618	0.125	-0.125	0.015	-0.015	Symmetrical
KURTOSIS (K):	21.28	3.431	3.431	0.977	0.977	Mesokurtic

GRAIN SIZE DISTRIBUTION



SAMPLE STATISTICS

SAMPLE IDENTITY: **C-H** ANALYST & DATE: ,

SAMPLE TYPE: Bimodal, Very Poorly Sorted TEXTURAL GROUP: Sandy Gravel

SEDIMENT NAME: Sandy Very Coarse Gravel

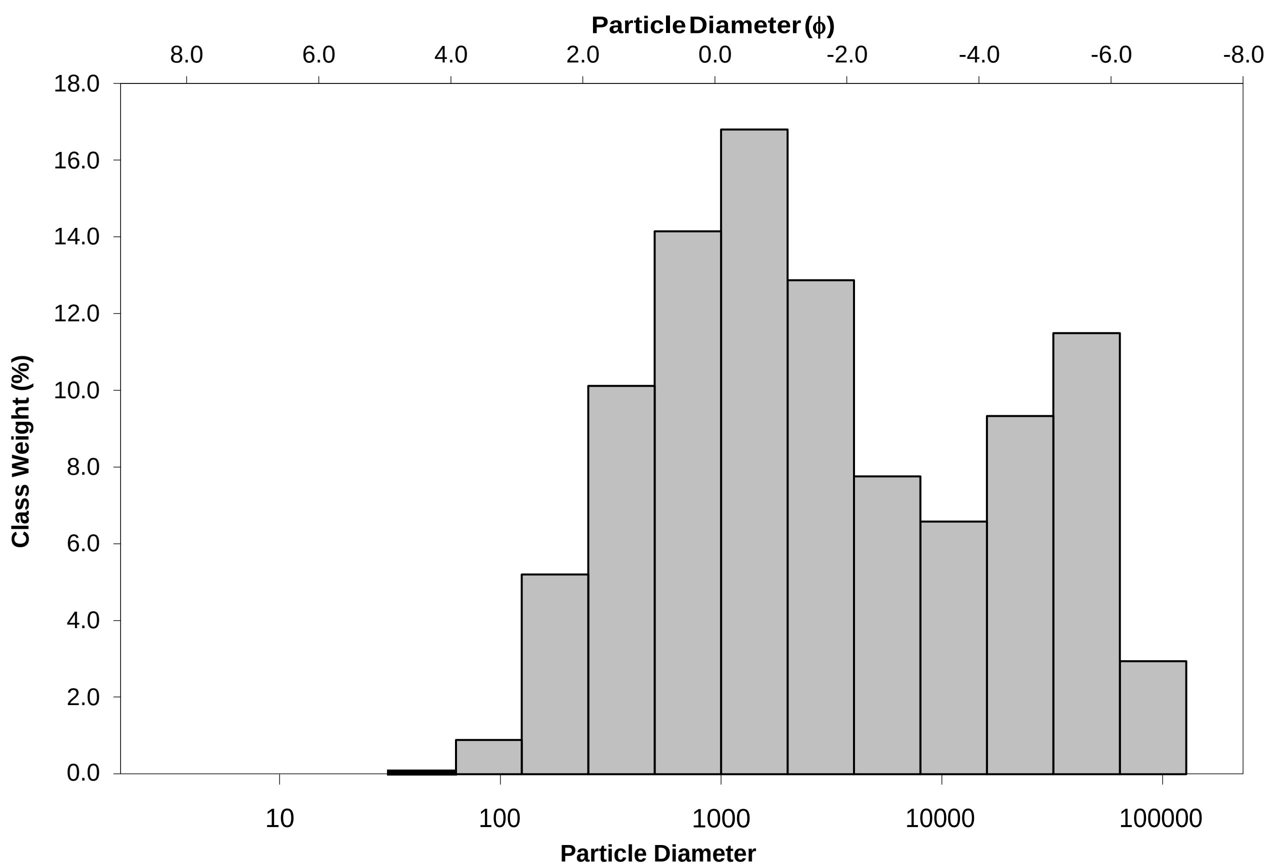
	μm	φ
MODE 1:	1500.0	-0.500
MODE 2:	48000.0	-5.500
MODE 3:		
D_{10}:	320.7	-5.402
MEDIAN or D_{50}:	2211.5	-1.145
D_{90}:	42274.3	1.641
(D_{90} / D_{10}):	131.8	-0.304
$(D_{90} - D_{10})$:	41953.6	7.042
(D_{75} / D_{25}):	19.66	-0.107
$(D_{75} - D_{25})$:	13979.9	4.297

GRAIN SIZE DISTRIBUTION

GRAVEL:	51.9%	COARSE SAND:	14.4%
SAND:	48.0%	MEDIUM SAND:	10.3%
MUD:	0.1%	FINE SAND:	5.3%
		V FINE SAND:	0.9%
V COARSE GRAVEL:	14.7%	V COARSE SILT:	0.1%
COARSE GRAVEL:	9.5%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	6.7%	MEDIUM SILT:	0.0%
FINE GRAVEL:	7.9%	FINE SILT:	0.0%
V FINE GRAVEL:	13.1%	V FINE SILT:	0.0%
V COARSE SAND:	17.1%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic φ	Geometric μm	Logarithmic φ	Description
MEAN ($\bar{x}$):	12861.0	3000.2	-1.585	3138.3	-1.650	Very Fine Gravel
SORTING	21201.8	5.934	2.569	6.515	2.704	Very Poorly Sorted
SKEWNESS (Sk):	2.252	0.230	-0.230	0.208	-0.208	Coarse Skewed
KURTOSIS (K):	8.040	2.003	2.003	0.770	0.770	Platykurtic

GRAIN SIZE DISTRIBUTION



SAMPLE STATISTICS

SAMPLE IDENTITY: **CS**

ANALYST & DATE: ,

SAMPLE TYPE: Bimodal, Very Poorly Sorted

TEXTURAL GROUP: Sandy Gravel

SEDIMENT NAME: Sandy Coarse Gravel

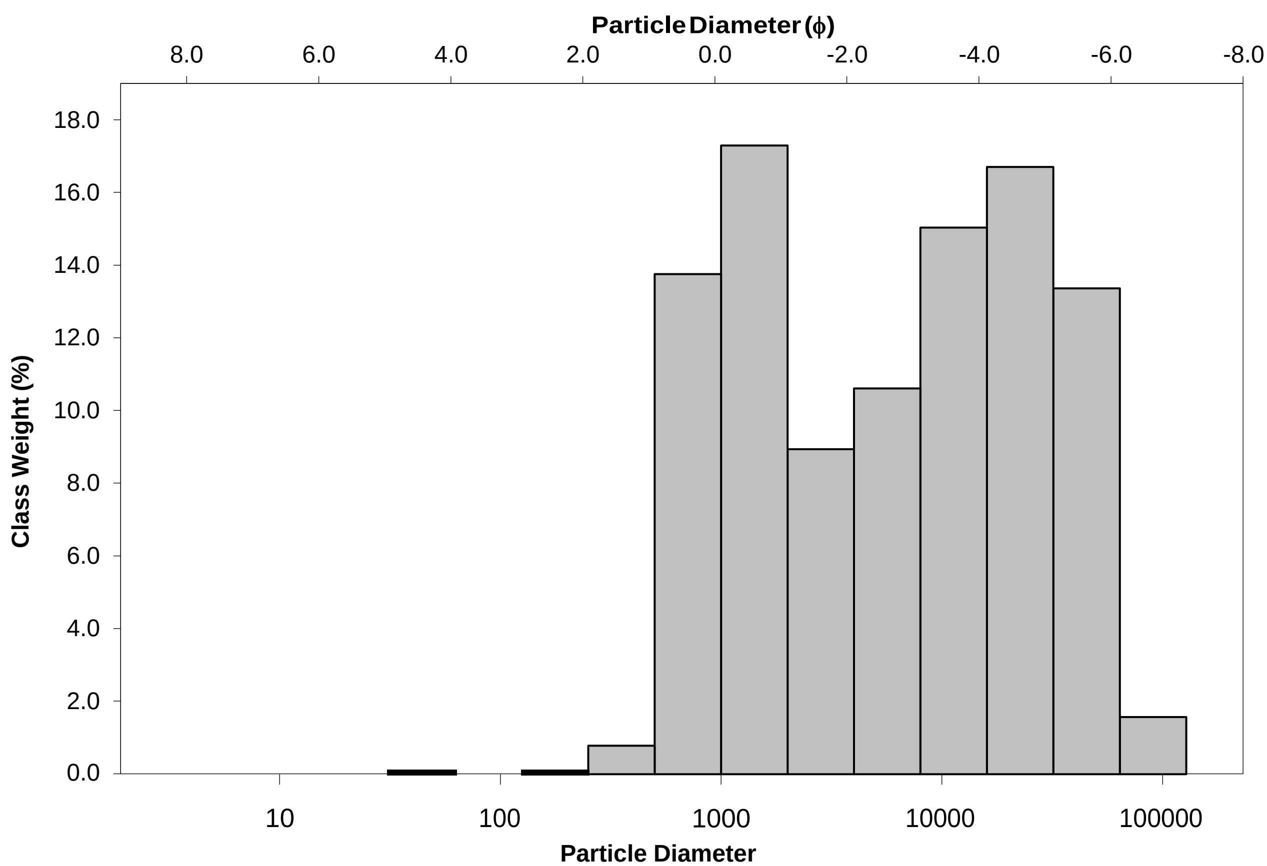
	μm	φ
MODE 1:	1500.0	-0.500
MODE 2:	24000.0	-4.500
MODE 3:		
D_{10}:	780.7	-5.382
MEDIAN or D_{50}:	6814.1	-2.769
D_{90}:	41710.9	0.357
(D_{90} / D_{10}):	53.43	-0.066
$(D_{90} - D_{10})$:	40930.2	5.739
(D_{75} / D_{25}):	14.47	0.128
$(D_{75} - D_{25})$:	19976.6	3.855

GRAIN SIZE DISTRIBUTION

GRAVEL:	67.4%	COARSE SAND:	14.0%
SAND:	32.5%	MEDIUM SAND:	0.8%
MUD:	0.1%	FINE SAND:	0.1%
		V FINE SAND:	0.0%
V COARSE GRAVEL:	15.2%	V COARSE SILT:	0.1%
COARSE GRAVEL:	17.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	15.3%	MEDIUM SILT:	0.0%
FINE GRAVEL:	10.8%	FINE SILT:	0.0%
V FINE GRAVEL:	9.1%	V FINE SILT:	0.0%
V COARSE SAND:	17.6%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic φ	Geometric μm	Logarithmic φ	Description
MEAN ($\bar{x}$):	15273.2	5888.9	-2.558	6032.5	-2.593	Fine Gravel
SORTING	18779.3	4.398	2.137	4.606	2.203	Very Poorly Sorted
SKEWNESS (Sk):	1.829	-0.087	0.087	-0.093	0.093	Symmetrical
KURTOSIS (K):	6.854	1.794	1.794	0.687	0.687	Platykurtic

GRAIN SIZE DISTRIBUTION



SAMPLE STATISTICS

SAMPLE IDENTITY: **DN**

ANALYST & DATE: ,

SAMPLE TYPE: Unimodal, Moderately Sorted

TEXTURAL GROUP: Gravelly Sand

SEDIMENT NAME: Very Fine Gravelly Very Coarse Sand

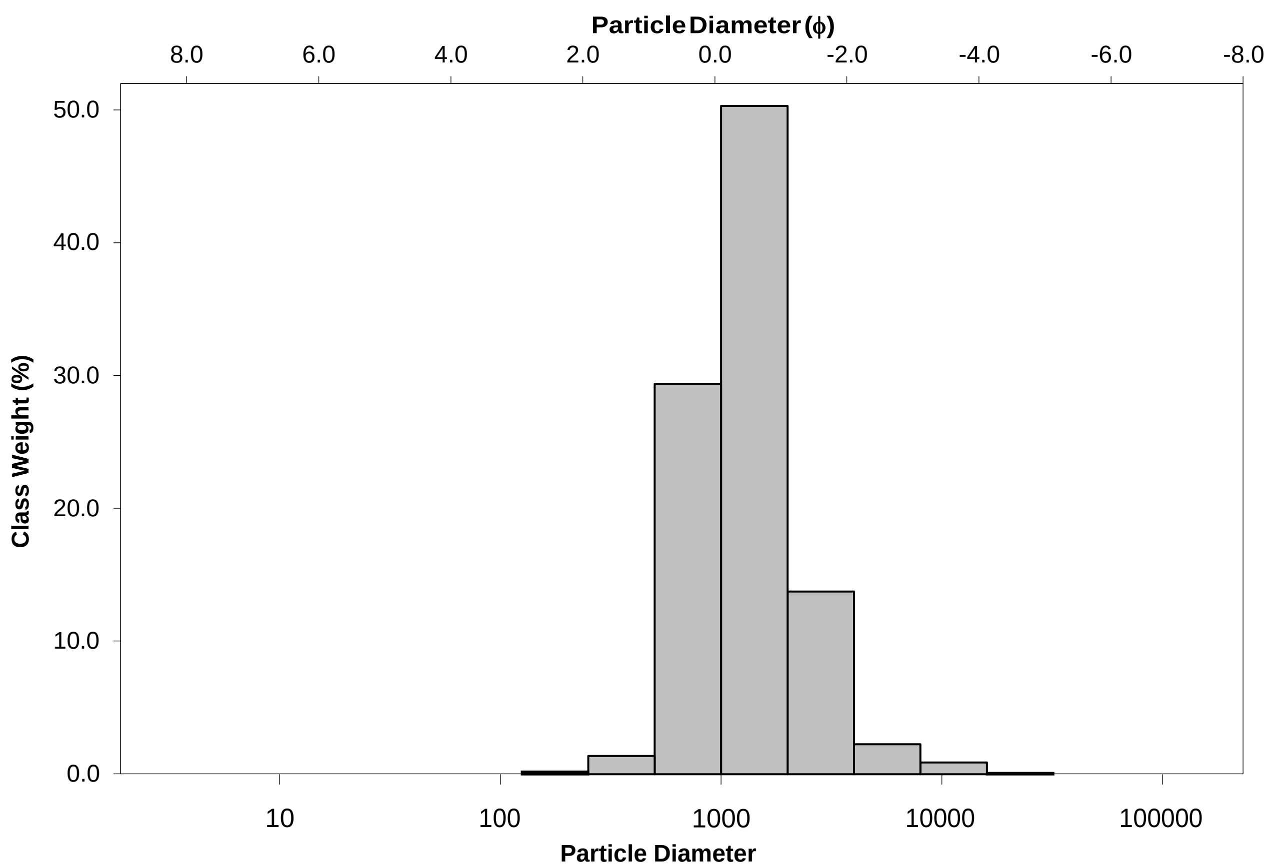
	μm	φ
MODE 1:	1500.0	-0.500
MODE 2:		
MODE 3:		
D_{10}:	607.5	-1.521
MEDIAN or D_{50}:	1284.6	-0.361
D_{90}:	2870.8	0.719
(D_{90} / D_{10}):	4.726	-0.473
$(D_{90} - D_{10})$:	2263.3	2.240
(D_{75} / D_{25}):	2.095	-0.256
$(D_{75} - D_{25})$:	941.9	1.067

GRAIN SIZE DISTRIBUTION

GRAVEL:	17.3%	COARSE SAND:	29.9%
SAND:	82.7%	MEDIUM SAND:	1.4%
MUD:	0.0%	FINE SAND:	0.2%
		V FINE SAND:	0.0%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	0.0%
COARSE GRAVEL:	0.1%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.9%	MEDIUM SILT:	0.0%
FINE GRAVEL:	2.3%	FINE SILT:	0.0%
V FINE GRAVEL:	14.0%	V FINE SILT:	0.0%
V COARSE SAND:	51.2%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic φ	Geometric μm	Logarithmic φ	Description
MEAN ($\bar{x}$):	1687.9	1305.0	-0.384	1241.4	-0.312	Very Coarse Sand
SORTING	1559.9	1.777	0.830	1.768	0.822	Moderately Sorted
SKEWNESS (Sk):	6.020	0.713	-0.713	0.003	-0.003	Symmetrical
KURTOSIS (K):	60.51	4.875	4.875	1.062	1.062	Mesokurtic

GRAIN SIZE DISTRIBUTION



SAMPLE STATISTICS

SAMPLE IDENTITY: **DC** ANALYST & DATE: ,

SAMPLE TYPE: Bimodal, Very Poorly Sorted TEXTURAL GROUP: Sandy Gravel

SEDIMENT NAME: Sandy Very Coarse Gravel

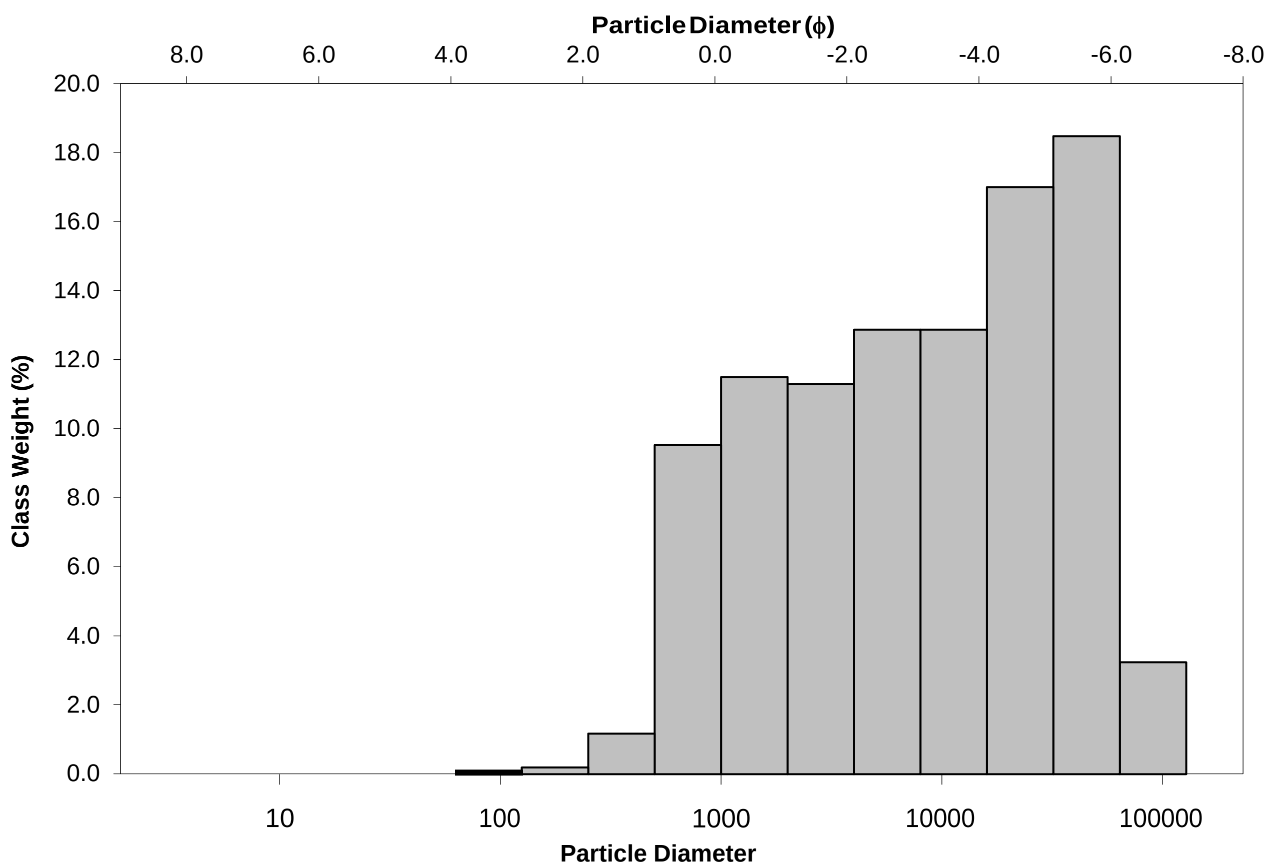
	μm	φ
MODE 1:	48000.0	-5.500
MODE 2:	1500.0	-0.500
MODE 3:		
D_{10}:	917.8	-5.644
MEDIAN or D_{50}:	9131.4	-3.191
D_{90}:	49991.7	0.124
(D_{90} / D_{10}):	54.47	-0.022
(D_{90} - D_{10}):	49073.9	5.767
(D_{75} / D_{25}):	12.55	0.245
(D_{75} - D_{25}):	26219.9	3.650

GRAIN SIZE DISTRIBUTION

GRAVEL:	77.1%	COARSE SAND:	9.7%
SAND:	22.9%	MEDIUM SAND:	1.2%
MUD:	0.0%	FINE SAND:	0.2%
		V FINE SAND:	0.1%
V COARSE GRAVEL:	22.1%	V COARSE SILT:	0.0%
COARSE GRAVEL:	17.3%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	13.1%	MEDIUM SILT:	0.0%
FINE GRAVEL:	13.1%	FINE SILT:	0.0%
V FINE GRAVEL:	11.5%	V FINE SILT:	0.0%
V COARSE SAND:	11.7%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic φ	Geometric μm	Logarithmic φ	Description
MEAN ($\bar{x}$):	19300.2	7830.0	-2.969	7863.6	-2.975	Fine Gravel
SORTING	22121.6	4.391	2.135	4.661	2.221	Very Poorly Sorted
SKEWNESS (Sk):	1.581	-0.279	0.279	-0.151	0.151	Fine Skewed
KURTOSIS (K):	5.460	1.977	1.977	0.735	0.735	Platykurtic

GRAIN SIZE DISTRIBUTION



SAMPLE STATISTICS

SAMPLE IDENTITY: **DS**

ANALYST & DATE: ,

SAMPLE TYPE: Unimodal, Poorly Sorted

TEXTURAL GROUP: Sandy Gravel

SEDIMENT NAME: Sandy Medium Gravel

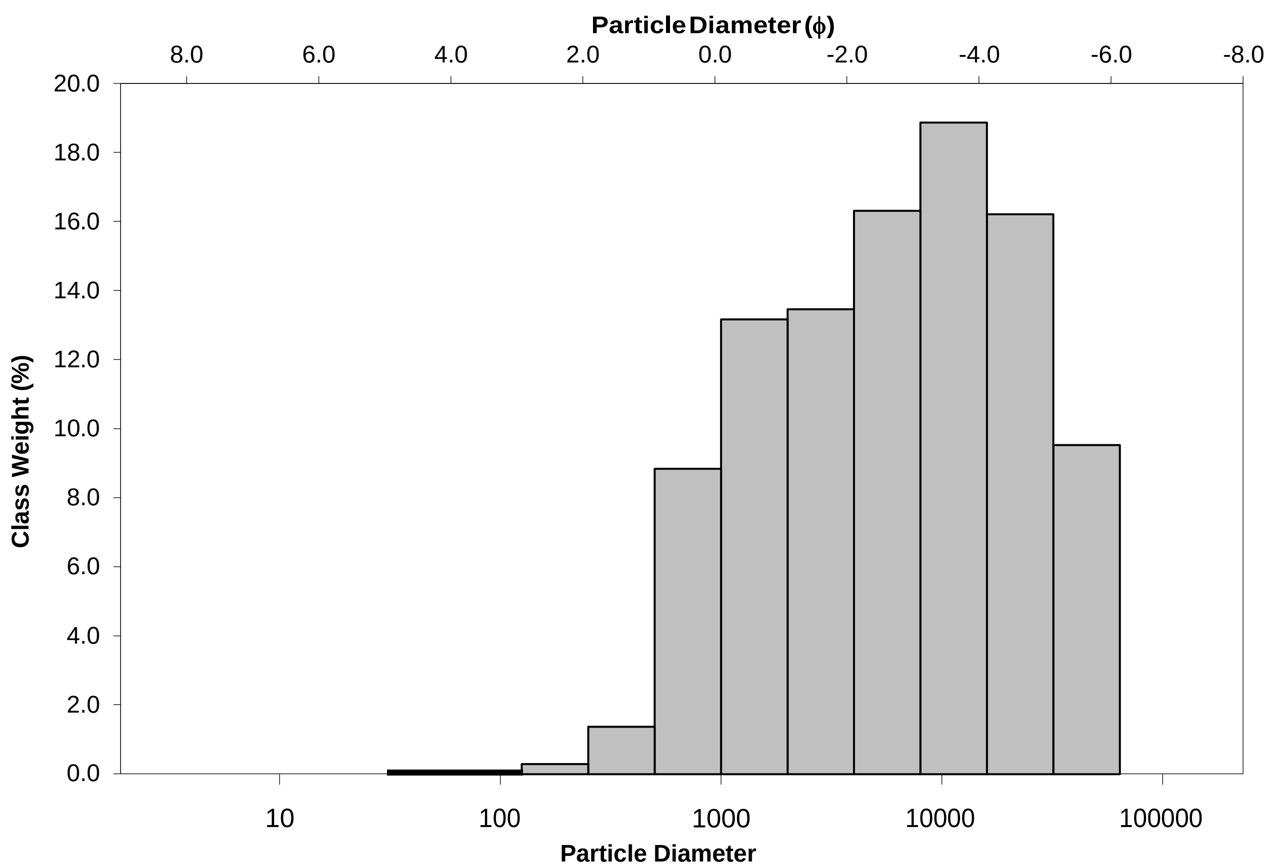
	μm	φ
MODE 1:	12000.0	-3.500
MODE 2:		
MODE 3:		
D_{10}:	933.0	-4.982
MEDIAN or D_{50}:	6601.9	-2.723
D_{90}:	31599.2	0.100
(D_{90} / D_{10}):	33.87	-0.020
$(D_{90} - D_{10})$:	30666.2	5.082
(D_{75} / D_{25}):	8.121	0.258
$(D_{75} - D_{25})$:	14755.1	3.022

GRAIN SIZE DISTRIBUTION

GRAVEL:	75.7%	COARSE SAND:	9.0%
SAND:	24.2%	MEDIUM SAND:	1.4%
MUD:	0.1%	FINE SAND:	0.3%
		V FINE SAND:	0.1%
V COARSE GRAVEL:	9.7%	V COARSE SILT:	0.1%
COARSE GRAVEL:	16.5%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	19.2%	MEDIUM SILT:	0.0%
FINE GRAVEL:	16.6%	FINE SILT:	0.0%
V FINE GRAVEL:	13.7%	V FINE SILT:	0.0%
V COARSE SAND:	13.4%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic φ	Geometric μm	Logarithmic φ	Description
MEAN ($\bar{x}$):	12601.5	5872.6	-2.554	5954.1	-2.574	Fine Gravel
SORTING	13962.2	3.718	1.894	3.972	1.990	Poorly Sorted
SKEWNESS (Sk):	1.473	-0.282	0.282	-0.103	0.103	Fine Skewed
KURTOSIS (K):	4.232	2.311	2.311	0.833	0.833	Platykurtic

GRAIN SIZE DISTRIBUTION



SAMPLE STATISTICS

SAMPLE IDENTITY: **HC-CENTER** ANALYST & DATE: ,

SAMPLE TYPE: Trimodal, Very Poorly Sorted TEXTURAL GROUP: Gravel

SEDIMENT NAME: Very Coarse Gravel

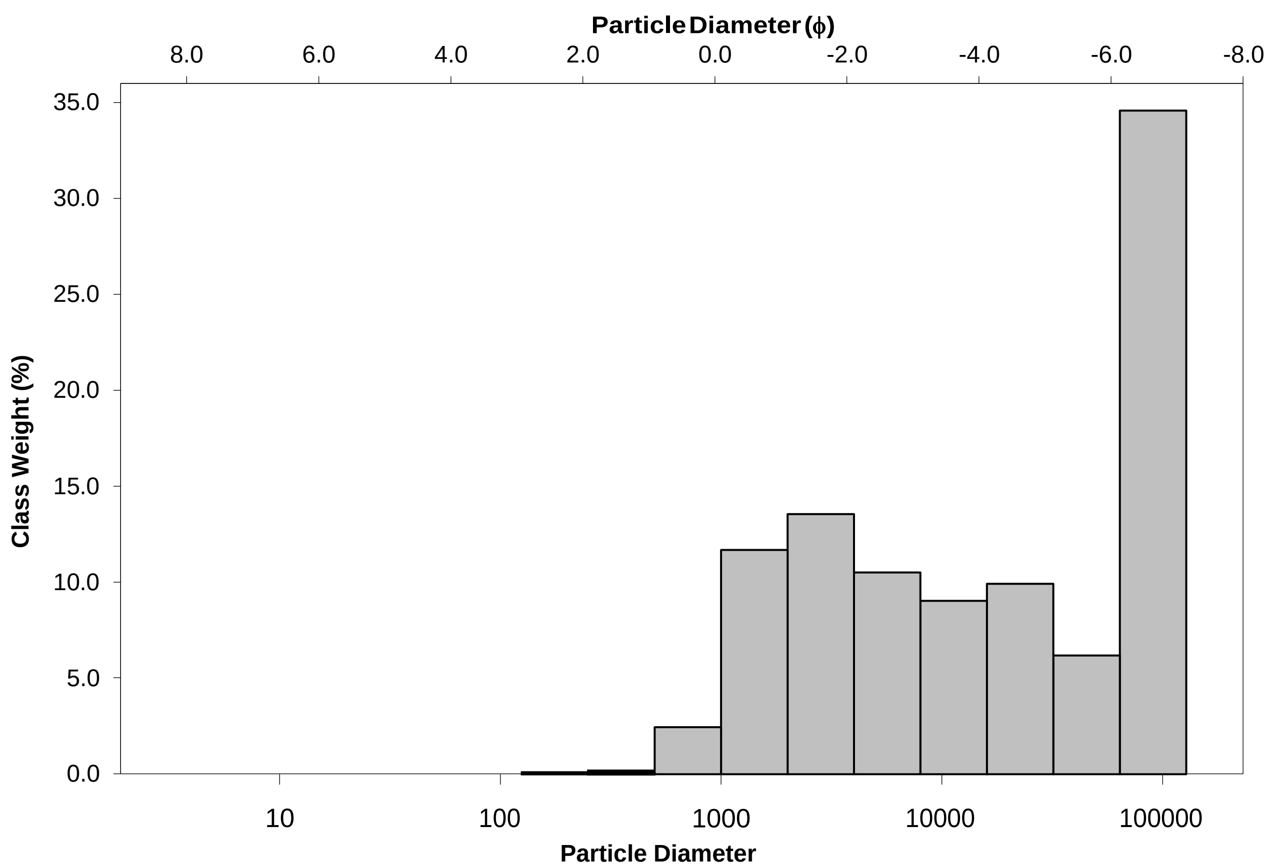
	μm	φ
MODE 1:	96000.0	-6.500
MODE 2:	3000.0	-1.500
MODE 3:	24000.0	-4.500
D_{10}:	1521.0	-6.716
MEDIAN or D_{50}:	17857.0	-4.158
D_{90}:	105121.1	-0.605
(D_{90} / D_{10}):	69.11	0.090
(D_{90} - D_{10}):	103600.1	6.111
(D_{75} / D_{25}):	23.32	0.278
(D_{75} - D_{25}):	74881.5	4.543

GRAIN SIZE DISTRIBUTION

GRAVEL:	85.3%	COARSE SAND:	2.5%
SAND:	14.7%	MEDIUM SAND:	0.2%
MUD:	0.0%	FINE SAND:	0.1%
		V FINE SAND:	0.0%
V COARSE GRAVEL:	41.5%	V COARSE SILT:	0.0%
COARSE GRAVEL:	10.1%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	9.2%	MEDIUM SILT:	0.0%
FINE GRAVEL:	10.7%	FINE SILT:	0.0%
V FINE GRAVEL:	13.8%	V FINE SILT:	0.0%
V COARSE SAND:	11.9%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic φ	Geometric μm	Logarithmic φ	Description
MEAN ($\bar{x}$):	41598.2	15210.5	-3.927	15270.7	-3.933	Medium Gravel
SORTING	41660.2	5.122	2.357	5.183	2.374	Very Poorly Sorted
SKEWNESS (Sk):	0.434	-0.273	0.273	-0.158	0.158	Fine Skewed
KURTOSIS (K):	1.337	1.637	1.637	0.602	0.602	Very Platykurtic

GRAIN SIZE DISTRIBUTION



SAMPLE STATISTICS

SAMPLE IDENTITY: **HC EAST** ANALYST & DATE: ,

SAMPLE TYPE: Unimodal, Poorly Sorted TEXTURAL GROUP: Gravelly Sand

SEDIMENT NAME: Very Fine Gravelly Coarse Sand

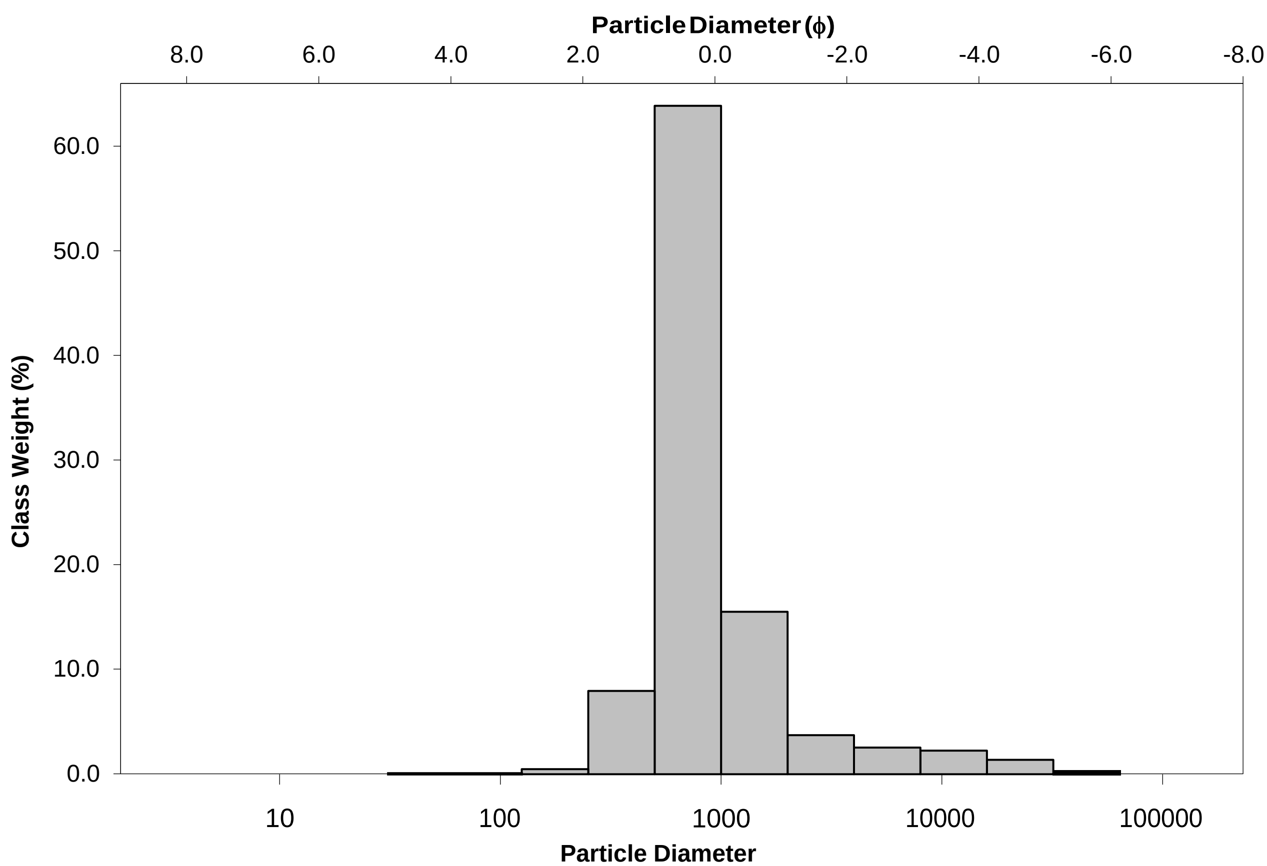
	μm	φ
MODE 1:	750.0	0.500
MODE 2:		
MODE 3:		
D_{10}:	506.4	-1.105
MEDIAN or D_{50}:	775.8	0.366
D_{90}:	2151.4	0.982
(D_{90} / D_{10}):	4.248	-0.888
(D_{90} - D_{10}):	1644.9	2.087
(D_{75} / D_{25}):	1.774	-9.885
(D_{75} - D_{25}):	459.8	0.827

GRAIN SIZE DISTRIBUTION

GRAVEL:	10.4%	COARSE SAND:	65.0%
SAND:	89.5%	MEDIUM SAND:	8.1%
MUD:	0.1%	FINE SAND:	0.5%
		V FINE SAND:	0.1%
V COARSE GRAVEL:	0.3%	V COARSE SILT:	0.1%
COARSE GRAVEL:	1.4%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	2.3%	MEDIUM SILT:	0.0%
FINE GRAVEL:	2.6%	FINE SILT:	0.0%
V FINE GRAVEL:	3.8%	V FINE SILT:	0.0%
V COARSE SAND:	15.8%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic φ	Geometric μm	Logarithmic φ	Description
MEAN ($\bar{x}$):	1782.0	929.2	0.106	868.6	0.203	Coarse Sand
SORTING	4138.0	2.231	1.158	2.004	1.003	Poorly Sorted
SKEWNESS (Sk):	6.708	2.046	-2.046	0.389	-0.389	Very Coarse Skewed
KURTOSIS (K):	59.21	8.688	8.688	2.025	2.025	Very Leptokurtic

GRAIN SIZE DISTRIBUTION



SAMPLE STATISTICS

SAMPLE IDENTITY: **HC NORTH**

ANALYST & DATE: ,

SAMPLE TYPE: Bimodal, Very Poorly Sorted

TEXTURAL GROUP: Sandy Gravel

SEDIMENT NAME: Sandy Very Coarse Gravel

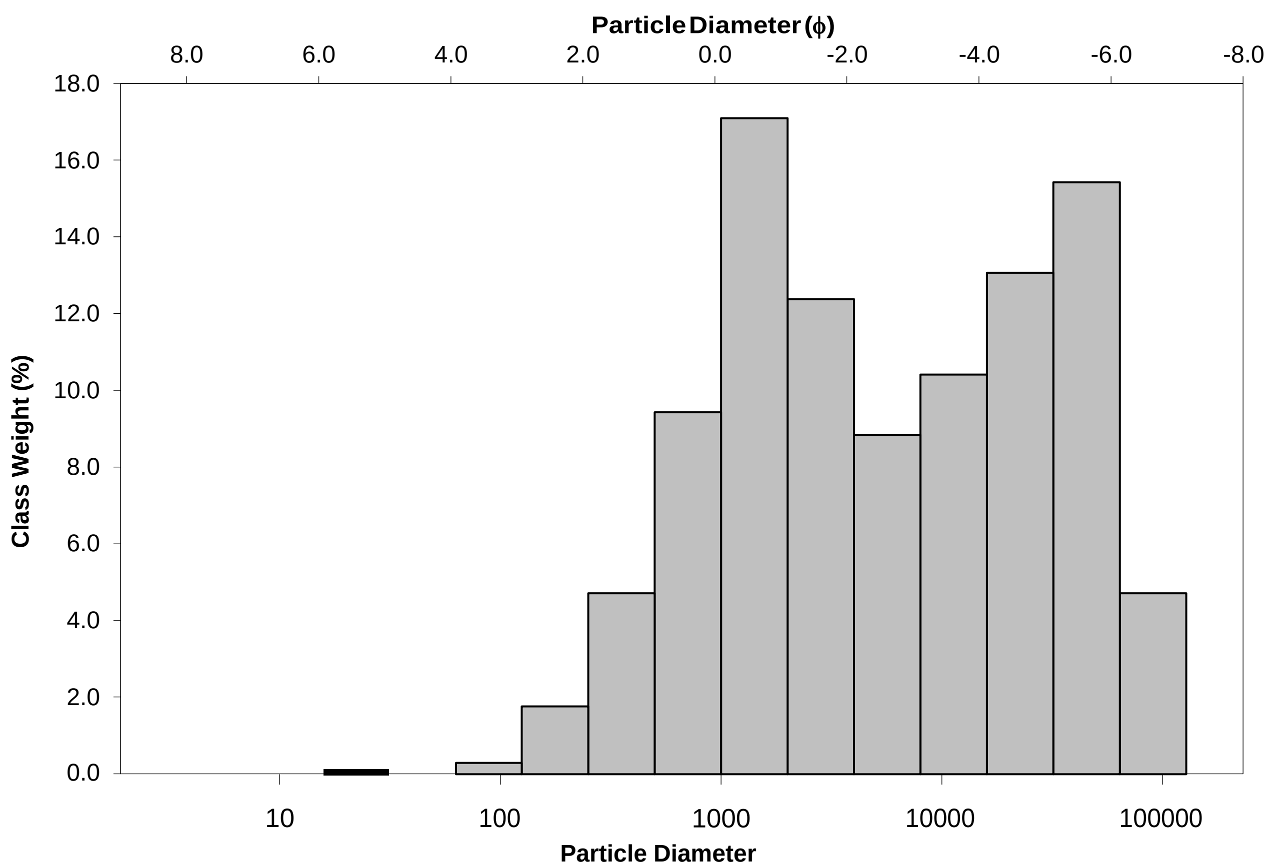
	μm	φ
MODE 1:	1500.0	-0.500
MODE 2:	48000.0	-5.500
MODE 3:		
D_{10}:	620.9	-5.669
MEDIAN or D_{50}:	5197.4	-2.378
D_{90}:	50871.6	0.688
(D_{90} / D_{10}):	81.93	-0.121
$(D_{90} - D_{10})$:	50250.7	6.356
(D_{75} / D_{25}):	18.11	0.104
$(D_{75} - D_{25})$:	23912.9	4.179

GRAIN SIZE DISTRIBUTION

GRAVEL:	66.0%	COARSE SAND:	9.6%
SAND:	33.9%	MEDIUM SAND:	4.8%
MUD:	0.1%	FINE SAND:	1.8%
		V FINE SAND:	0.3%
V COARSE GRAVEL:	20.5%	V COARSE SILT:	0.0%
COARSE GRAVEL:	13.3%	COARSE SILT:	0.1%
MEDIUM GRAVEL:	10.6%	MEDIUM SILT:	0.0%
FINE GRAVEL:	9.0%	FINE SILT:	0.0%
V FINE GRAVEL:	12.6%	V FINE SILT:	0.0%
V COARSE SAND:	17.4%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic φ	Geometric μm	Logarithmic φ	Description
MEAN ($\bar{x}$):	17880.7	5521.4	-2.465	5791.6	-2.534	Fine Gravel
SORTING	24105.5	5.380	2.428	5.499	2.459	Very Poorly Sorted
SKEWNESS (Sk):	1.784	-0.104	0.104	0.031	-0.031	Symmetrical
KURTOSIS (K):	5.783	1.991	1.991	0.726	0.726	Platykurtic

GRAIN SIZE DISTRIBUTION



SAMPLE STATISTICS

SAMPLE IDENTITY: **HC SOUTH** ANALYST & DATE: ,

SAMPLE TYPE: Bimodal, Very Poorly Sorted TEXTURAL GROUP: Sandy Gravel

SEDIMENT NAME: Sandy Very Fine Gravel

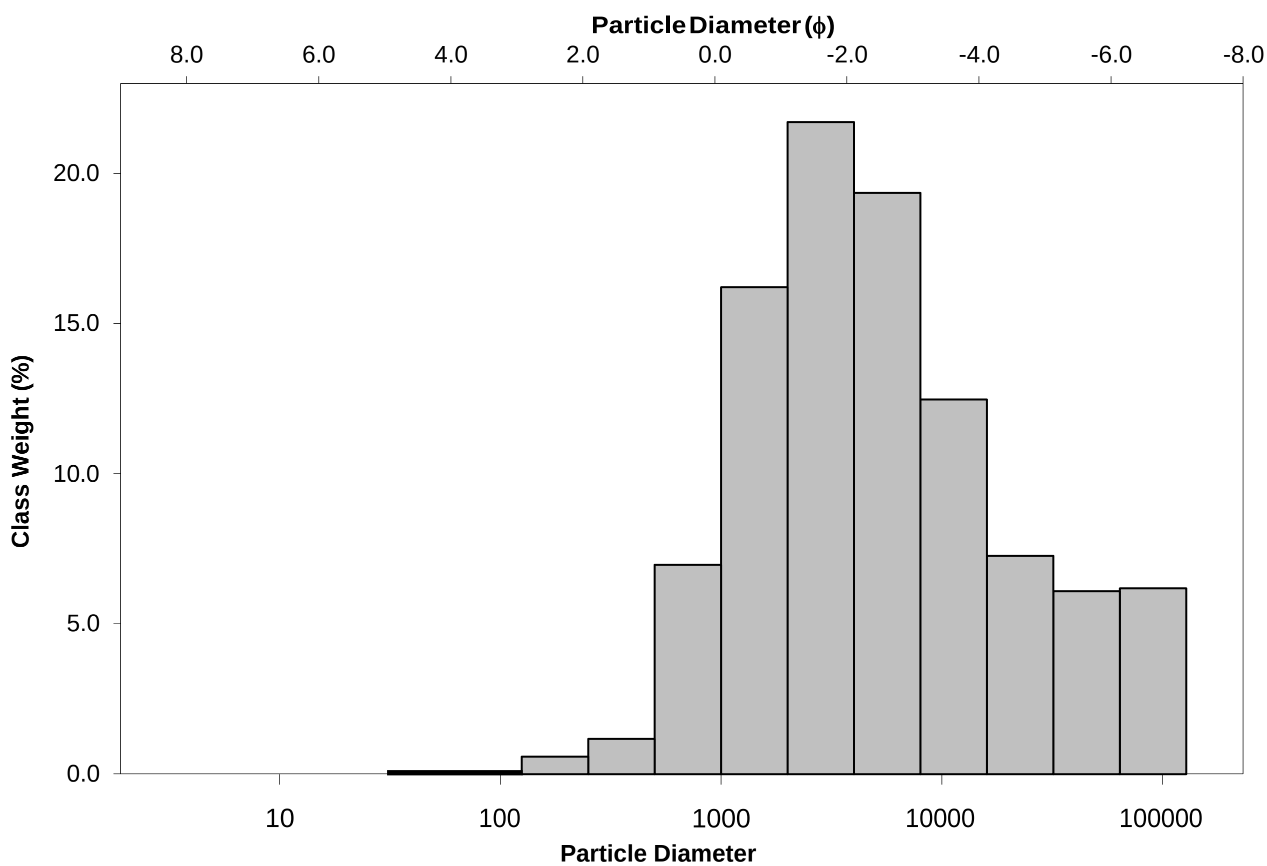
	μm	φ
MODE 1:	3000.0	-1.500
MODE 2:	96000.0	-6.500
MODE 3:		
D_{10}:	1038.5	-5.403
MEDIAN or D_{50}:	4337.2	-2.117
D_{90}:	42318.8	-0.055
(D_{90} / D_{10}):	40.75	0.010
$(D_{90} - D_{10})$:	41280.2	5.349
(D_{75} / D_{25}):	6.211	0.268
$(D_{75} - D_{25})$:	10162.3	2.635

GRAIN SIZE DISTRIBUTION

GRAVEL:	74.4%	COARSE SAND:	7.1%
SAND:	25.5%	MEDIUM SAND:	1.2%
MUD:	0.1%	FINE SAND:	0.6%
		V FINE SAND:	0.1%
V COARSE GRAVEL:	12.5%	V COARSE SILT:	0.1%
COARSE GRAVEL:	7.4%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	12.7%	MEDIUM SILT:	0.0%
FINE GRAVEL:	19.7%	FINE SILT:	0.0%
V FINE GRAVEL:	22.1%	V FINE SILT:	0.0%
V COARSE SAND:	16.5%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic φ	Geometric μm	Logarithmic φ	Description
MEAN ($\bar{x}$):	14475.5	5126.6	-2.358	5112.4	-2.354	Fine Gravel
SORTING	24172.7	3.942	1.979	4.156	2.055	Very Poorly Sorted
SKEWNESS (Sk):	2.512	0.331	-0.331	0.189	-0.189	Coarse Skewed
KURTOSIS (K):	8.419	2.776	2.776	1.055	1.055	Mesokurtic

GRAIN SIZE DISTRIBUTION



SAMPLE STATISTICS

SAMPLE IDENTITY: **HC WEST** ANALYST & DATE: ,

SAMPLE TYPE: Bimodal, Very Poorly Sorted TEXTURAL GROUP: Sandy Gravel
SEDIMENT NAME: Sandy Very Fine Gravel

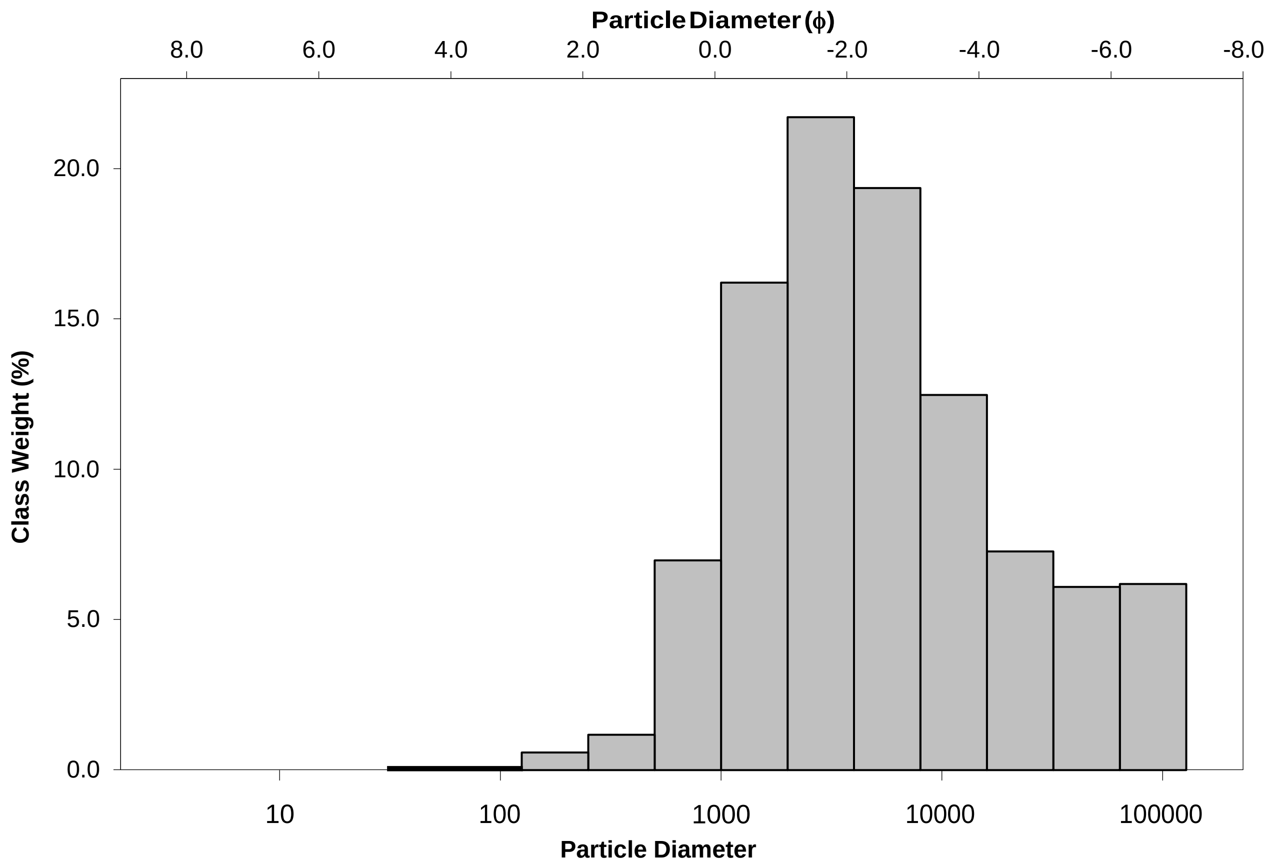
	μm	φ
MODE 1:	3000.0	-1.500
MODE 2:	96000.0	-6.500
MODE 3:		
D_{10}:	1038.5	-5.403
MEDIAN or D_{50}:	4337.2	-2.117
D_{90}:	42318.8	-0.055
(D_{90} / D_{10}):	40.75	0.010
(D_{90} - D_{10}):	41280.2	5.349
(D_{75} / D_{25}):	6.211	0.268
(D_{75} - D_{25}):	10162.3	2.635

GRAIN SIZE DISTRIBUTION

GRAVEL:	74.4%	COARSE SAND:	7.1%
SAND:	25.5%	MEDIUM SAND:	1.2%
MUD:	0.1%	FINE SAND:	0.6%
		V FINE SAND:	0.1%
V COARSE GRAVEL:	12.5%	V COARSE SILT:	0.1%
COARSE GRAVEL:	7.4%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	12.7%	MEDIUM SILT:	0.0%
FINE GRAVEL:	19.7%	FINE SILT:	0.0%
V FINE GRAVEL:	22.1%	V FINE SILT:	0.0%
V COARSE SAND:	16.5%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic φ	Geometric μm	Logarithmic φ	Description
MEAN ($\bar{x}$):	14475.5	5126.6	-2.358	5112.4	-2.354	Fine Gravel
SORTING	24172.7	3.942	1.979	4.156	2.055	Very Poorly Sorted
SKEWNESS (Sk):	2.512	0.331	-0.331	0.189	-0.189	Coarse Skewed
KURTOSIS (K):	8.419	2.776	2.776	1.055	1.055	Mesokurtic

GRAIN SIZE DISTRIBUTION



SAMPLE STATISTICS

SAMPLE IDENTITY: **SC** ANALYST & DATE: ,

SAMPLE TYPE: Bimodal, Very Poorly Sorted TEXTURAL GROUP: Sandy Gravel

SEDIMENT NAME: Sandy Coarse Gravel

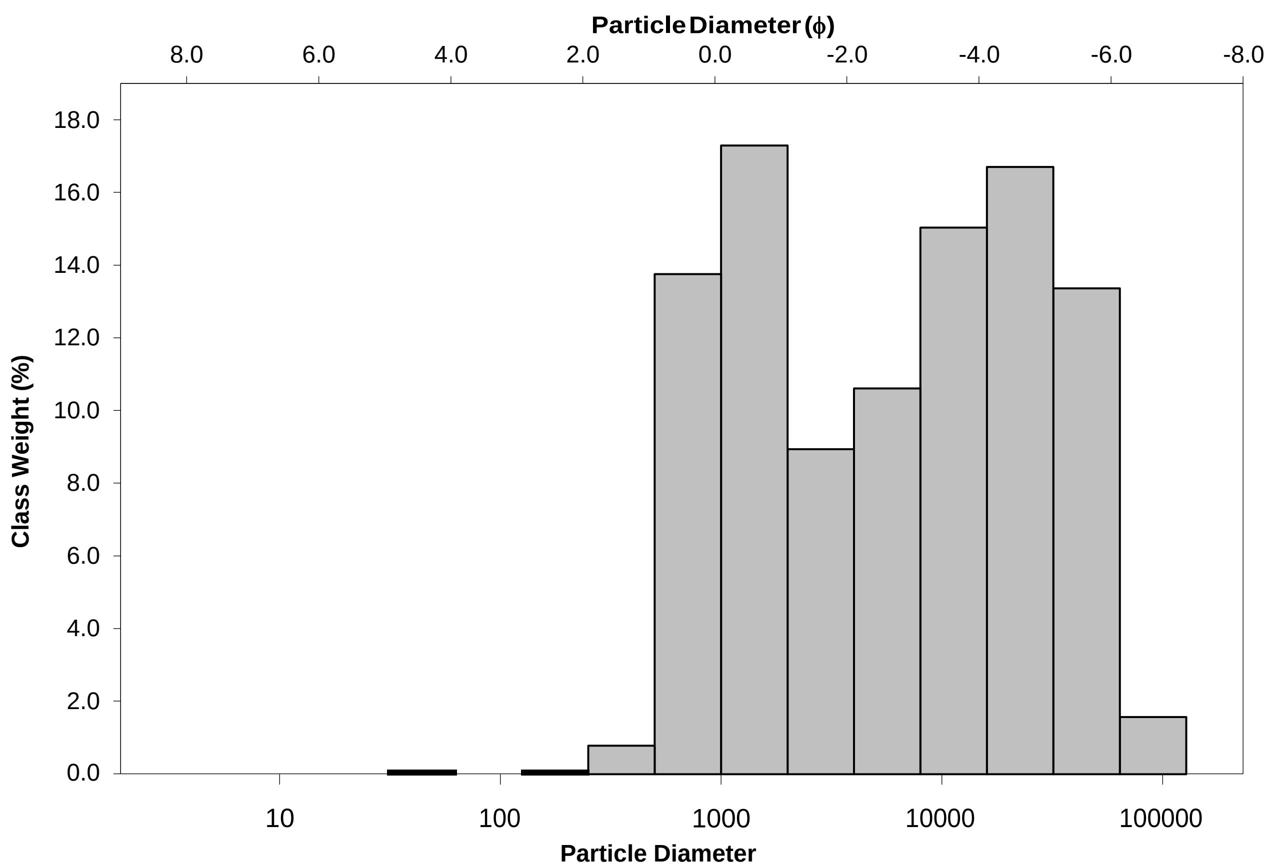
	μm	φ
MODE 1:	1500.0	-0.500
MODE 2:	24000.0	-4.500
MODE 3:		
D_{10}:	780.7	-5.382
MEDIAN or D_{50}:	6814.1	-2.769
D_{90}:	41710.9	0.357
(D_{90} / D_{10}):	53.43	-0.066
$(D_{90} - D_{10})$:	40930.2	5.739
(D_{75} / D_{25}):	14.47	0.128
$(D_{75} - D_{25})$:	19976.6	3.855

GRAIN SIZE DISTRIBUTION

GRAVEL:	67.4%	COARSE SAND:	14.0%
SAND:	32.5%	MEDIUM SAND:	0.8%
MUD:	0.1%	FINE SAND:	0.1%
		V FINE SAND:	0.0%
V COARSE GRAVEL:	15.2%	V COARSE SILT:	0.1%
COARSE GRAVEL:	17.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	15.3%	MEDIUM SILT:	0.0%
FINE GRAVEL:	10.8%	FINE SILT:	0.0%
V FINE GRAVEL:	9.1%	V FINE SILT:	0.0%
V COARSE SAND:	17.6%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic φ	Geometric μm	Logarithmic φ	Description
MEAN ($\bar{x}$):	15273.2	5888.9	-2.558	6032.5	-2.593	Fine Gravel
SORTING	18779.3	4.398	2.137	4.606	2.203	Very Poorly Sorted
SKEWNESS (Sk):	1.829	-0.087	0.087	-0.093	0.093	Symmetrical
KURTOSIS (K):	6.854	1.794	1.794	0.687	0.687	Platykurtic

GRAIN SIZE DISTRIBUTION



SAMPLE STATISTICS

SAMPLE IDENTITY: **SN** — ANALYST & DATE: ,

SAMPLE TYPE: Unimodal, Poorly Sorted — TEXTURAL GROUP: Gravel

SEDIMENT NAME: Coarse Gravel

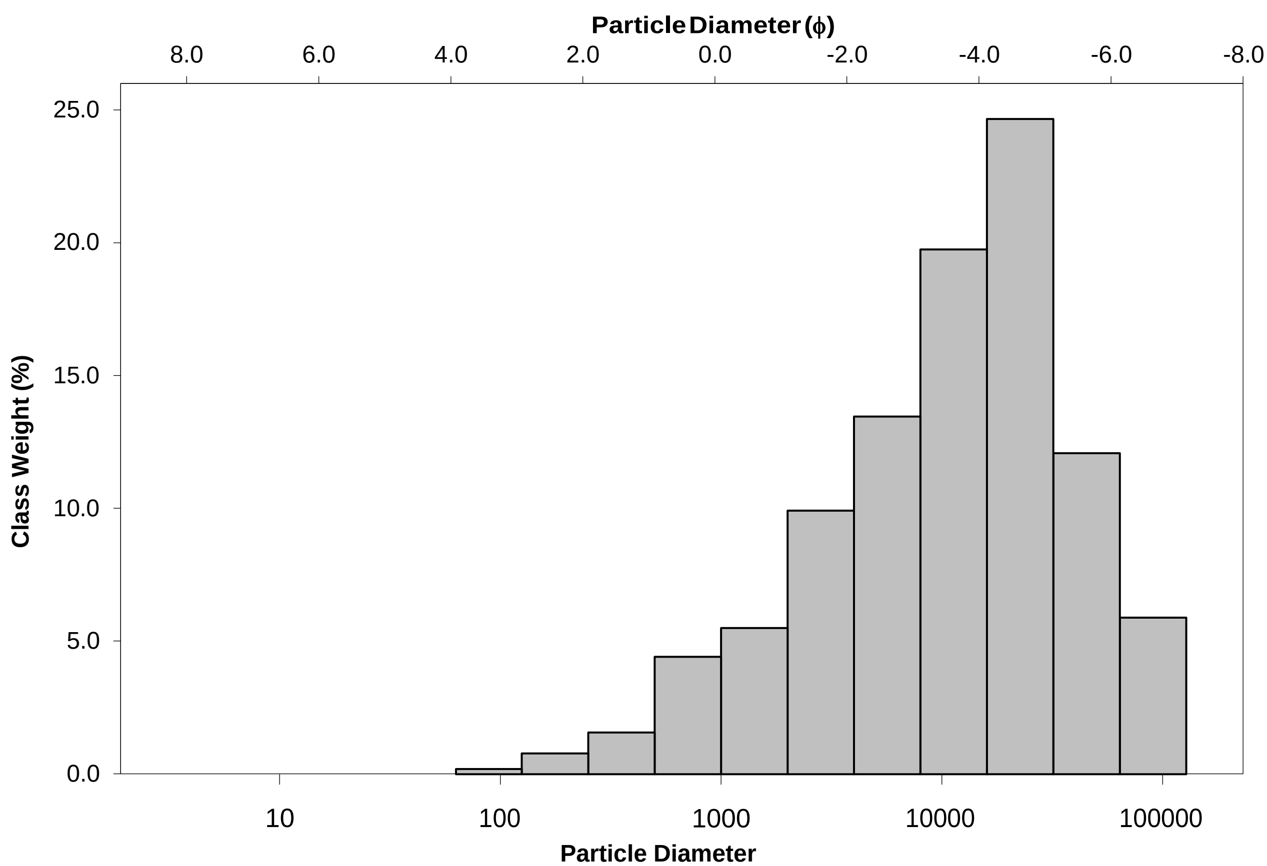
	μm	φ
MODE 1:	24000.0	-4.500
MODE 2:		
MODE 3:		
D_{10}:	1431.8	-5.675
MEDIAN or D_{50}:	12743.1	-3.672
D_{90}:	51083.9	-0.518
(D_{90} / D_{10}):	35.68	0.091
(D_{90} - D_{10}):	49652.1	5.157
(D_{75} / D_{25}):	5.948	0.456
(D_{75} - D_{25}):	22123.8	2.572

GRAIN SIZE DISTRIBUTION

GRAVEL:	87.3%	COARSE SAND:	4.5%
SAND:	12.7%	MEDIUM SAND:	1.6%
MUD:	0.0%	FINE SAND:	0.8%
		V FINE SAND:	0.2%
V COARSE GRAVEL:	18.3%	V COARSE SILT:	0.0%
COARSE GRAVEL:	25.1%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	20.1%	MEDIUM SILT:	0.0%
FINE GRAVEL:	13.7%	FINE SILT:	0.0%
V FINE GRAVEL:	10.1%	V FINE SILT:	0.0%
V COARSE SAND:	5.6%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic φ	Geometric μm	Logarithmic φ	Description
MEAN ($\bar{x}$):	21350.4	10182.4	-3.348	10520.4	-3.395	Medium Gravel
SORTING	23664.9	3.869	1.952	3.918	1.970	Poorly Sorted
SKEWNESS (Sk):	1.881	-0.693	0.693	-0.231	0.231	Fine Skewed
KURTOSIS (K):	6.274	3.194	3.194	1.057	1.057	Mesokurtic

GRAIN SIZE DISTRIBUTION



SAMPLE STATISTICS

SAMPLE IDENTITY: **S-S** ANALYST & DATE: ,

SAMPLE TYPE: Bimodal, Poorly Sorted TEXTURAL GROUP: Sandy Gravel

SEDIMENT NAME: Sandy Fine Gravel

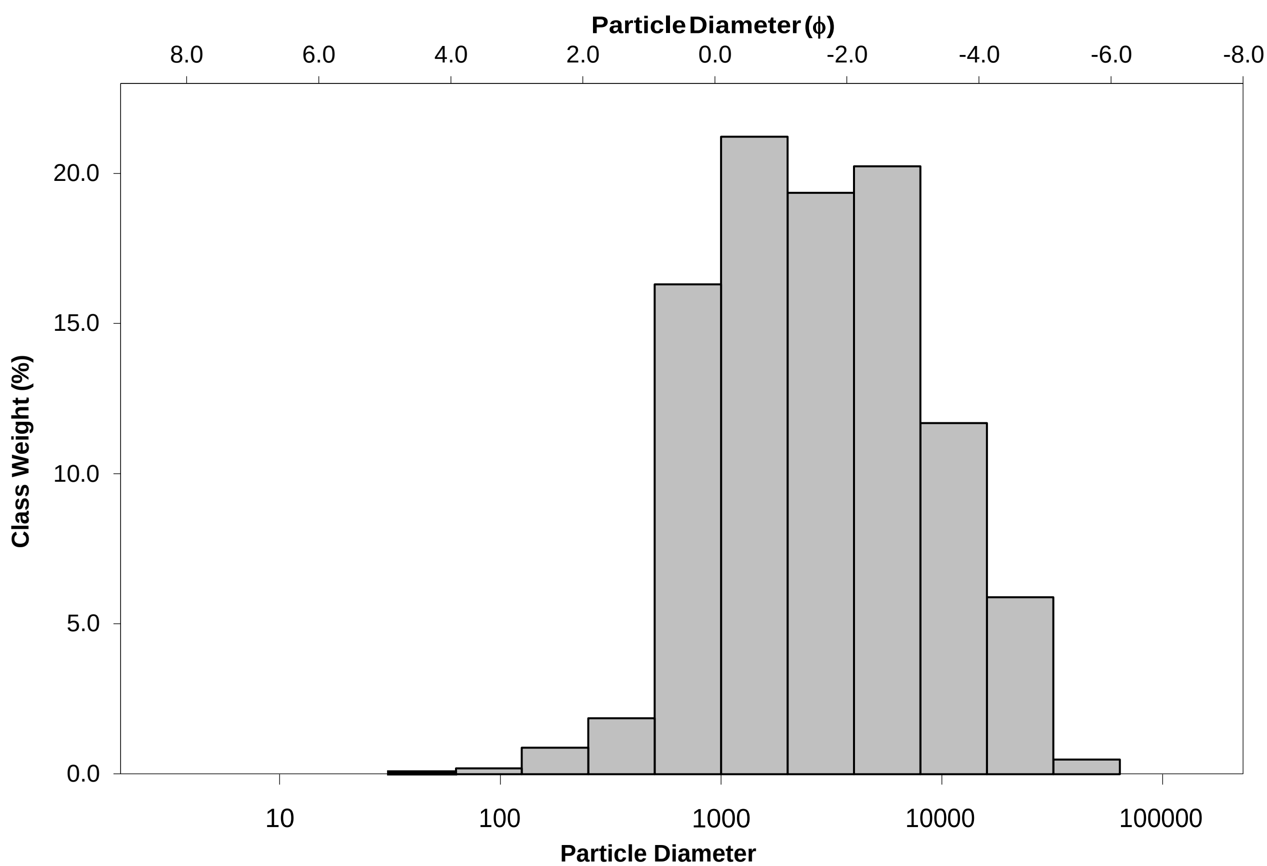
	μm	φ
MODE 1:	1500.0	-0.500
MODE 2:	6000.0	-2.500
MODE 3:		
D_{10}:	667.0	-3.706
MEDIAN or D_{50}:	2716.3	-1.442
D_{90}:	13049.1	0.584
(D_{90} / D_{10}):	19.57	-0.158
$(D_{90} - D_{10})$:	12382.2	4.290
(D_{75} / D_{25}):	5.405	0.092
$(D_{75} - D_{25})$:	5221.4	2.434

GRAIN SIZE DISTRIBUTION

GRAVEL:	58.7%	COARSE SAND:	16.6%
SAND:	41.2%	MEDIUM SAND:	1.9%
MUD:	0.1%	FINE SAND:	0.9%
		V FINE SAND:	0.2%
V COARSE GRAVEL:	0.5%	V COARSE SILT:	0.1%
COARSE GRAVEL:	6.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	11.9%	MEDIUM SILT:	0.0%
FINE GRAVEL:	20.6%	FINE SILT:	0.0%
V FINE GRAVEL:	19.7%	V FINE SILT:	0.0%
V COARSE SAND:	21.6%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic φ	Geometric μm	Logarithmic φ	Description
MEAN ($\bar{x}$):	5392.5	2803.1	-1.487	2776.9	-1.473	Very Fine Gravel
SORTING	6626.3	3.046	1.607	3.104	1.634	Poorly Sorted
SKEWNESS (Sk):	2.652	0.024	-0.024	0.061	-0.061	Symmetrical
KURTOSIS (K):	12.48	2.625	2.625	0.865	0.865	Platykurtic

GRAIN SIZE DISTRIBUTION



Appendix C

DISCHARGE CALCULATION

Station No.: Msmt No.:
Station Name: D-1
Meter/No.: Remarks:
GHT: Date: ,06 Time:
Width: 17 Area: 4.90 Vel.: 0.289 Q: 1.42 Est Q:
Section: 17 Rating %: #####

Angle	Pt.	Wdth	Dpth	Rev.	Sec.	Pt. Vel.	Adj Vel.	Area	Q.
	0.00	1.00	0.00			0.000	0.000	0.00	0.000
	2.00	1.50	0.10			0.000	0.000	0.15	0.000
	3.00	1.00	0.15			0.100	0.100	0.15	0.015
	4.00	1.00	0.25			0.130	0.130	0.25	0.033
	5.00	1.00	0.30			0.270	0.270	0.30	0.081
	6.00	1.00	0.40			0.320	0.320	0.40	0.128
	7.00	1.00	0.40			0.250	0.250	0.40	0.100
	8.00	1.00	0.45			0.330	0.330	0.45	0.149
	9.00	1.00	0.50			0.370	0.370	0.50	0.185
	10.00	1.00	0.50			0.370	0.370	0.50	0.185
	11.00	1.00	0.40			0.350	0.350	0.40	0.140
	12.00	1.00	0.40			0.370	0.370	0.40	0.148
	13.00	1.00	0.30			0.340	0.340	0.30	0.102
	14.00	1.00	0.30			0.340	0.340	0.30	0.102
	15.00	1.00	0.20			0.200	0.200	0.20	0.040
	16.00	1.00	0.20			0.050	0.050	0.20	0.010
	17.00	0.50	0.00			0.000	0.000	0.00	0.000

DISCHARGE CALCULATION

Station No.: Msmt No.:

Station Name: H-1

Meter/No.: Remarks:

GHT: Date: ,06 Time:

Width: 9 Area: 2.96 Vel.: 0.394 Q: 1.17 Est Q:

Section: 16 Rating %: #####

Angle	Pt.	Wdth	Dpth	Rev.	Sec.	Pt. Vel.	Adj Vel.	Area	Q.
	0.00	0.50	0.00			0.000	0.000	0.00	0.000
	1.00	0.75	0.10			0.000	0.000	0.08	0.000
	1.50	0.50	0.30			0.190	0.190	0.15	0.029
	2.00	0.50	0.45			0.270	0.270	0.23	0.061
	2.50	0.50	0.50			0.520	0.520	0.25	0.130
	3.00	0.50	0.60			0.520	0.520	0.30	0.156
	3.50	0.50	0.65			0.490	0.490	0.33	0.159
	4.00	0.50	0.60			0.480	0.480	0.30	0.144
	4.50	0.50	0.50			0.480	0.480	0.25	0.120
	5.00	0.50	0.50			0.490	0.490	0.25	0.123
	5.50	0.50	0.40			0.410	0.410	0.20	0.082
	6.00	0.50	0.40			0.400	0.400	0.20	0.080
	6.50	0.50	0.30			0.300	0.300	0.15	0.045
	7.00	0.75	0.25			0.210	0.210	0.19	0.039
	8.00	1.00	0.10			0.000	0.000	0.10	0.000
	9.00	0.50	0.00			0.000	0.000	0.00	0.000

DISCHARGE CALCULATION

Station No.: Msmt No.:
Station Name: H-2
Meter/No.: Remarks:
GHT: Date: ,06 Time:
Width: 3.5 Area: 0.45 Vel.: 0.217 Q: 0.10 Est Q:
Section: 8 Rating %: #####

Angle	Pt.	Wdth	Dpth	Rev.	Sec.	Pt. Vel.	Adj Vel.	Area	Q.
	0.00	0.25	0.00			0.000	0.000	0.00	0.000
	0.50	0.50	0.10			0.120	0.120	0.05	0.006
	1.00	0.50	0.20			0.280	0.280	0.10	0.028
	1.50	0.50	0.20			0.350	0.350	0.10	0.035
	2.00	0.50	0.20			0.240	0.240	0.10	0.024
	2.50	0.50	0.10			0.090	0.090	0.05	0.005
	3.00	0.50	0.10			0.000	0.000	0.05	0.000
	3.50	0.25	0.00			0.000	0.000	0.00	0.000

DISCHARGE CALCULATION

Station No.: ______ Msmt No.: ______

Station Name: S-1

Meter/No.: ______ Remarks: ______

GHT: ______ Date: ,06 Time: ______

Width: 35 Area: 15.65 Vel.: 0.805 Q: 12.59 Est Q: ______

Section: 20 Rating %: #####

Angle	Pt.	Wdth	Dpth	Rev.	Sec.	Pt. Vel.	Adj Vel.	Area	Q.
	0.00	1.00	0.00			0.000	0.000	0.00	0.000
	2.00	2.00	0.30			0.210	0.210	0.60	0.126
	4.00	1.50	0.30			0.350	0.350	0.45	0.158
	5.00	1.00	0.60			0.780	0.780	0.60	0.468
	6.00	1.50	0.60			0.940	0.940	0.90	0.846
	8.00	2.00	0.40			0.620	0.620	0.80	0.496
	10.00	2.00	0.30			0.620	0.620	0.60	0.372
	12.00	2.00	0.40			0.810	0.810	0.80	0.648
	14.00	2.00	0.50			1.220	1.220	1.00	1.220
	16.00	2.00	0.50			1.140	1.140	1.00	1.140
	18.00	2.00	0.40			1.080	1.080	0.80	0.864
	20.00	2.00	0.30			0.970	0.970	0.60	0.582
	22.00	2.00	0.30			0.700	0.700	0.60	0.420
	24.00	2.00	0.20			0.660	0.660	0.40	0.264
	26.00	2.00	0.20			0.260	0.260	0.40	0.104
	28.00	2.00	0.20			0.270	0.270	0.40	0.108
	30.00	2.00	0.30			0.450	0.450	0.60	0.270
	32.00	2.00	0.30			0.690	0.690	0.60	0.414
	34.00	1.50	3.00			0.910	0.910	4.50	4.095
	35.00	0.50	0.00			0.000	0.000	0.00	0.000

DISCHARGE CALCULATION

Station No.: Msmt No.:
Station Name: LOC
Meter/No.: Remarks:
GHT: Date: ,06 Time:
Width: 19.5 Area: 18.89 Vel.: 0.290 Q: 5.48 Est Q:
Section: 21 Rating %: #####

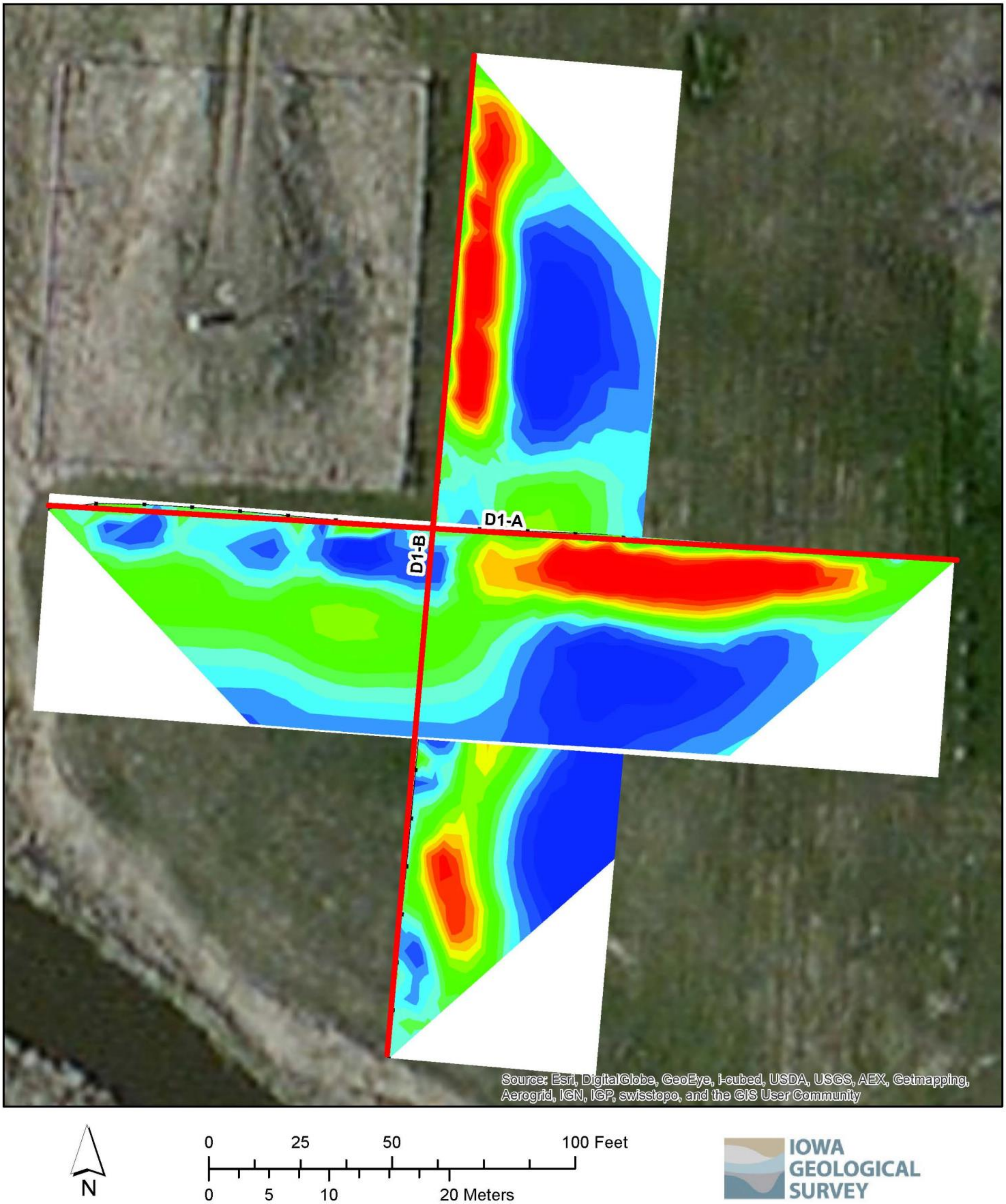
Angle	Pt.	Wdth	Dpth	Rev.	Sec.	Pt. Vel.	Adj Vel.	Area	Q.
	0.00	0.50	0.00			0.000	0.000	0.00	0.000
	1.00	1.00	0.70			0.020	0.020	0.70	0.014
	2.00	1.00	1.00			0.080	0.080	1.00	0.080
	3.00	1.00	1.20			0.240	0.240	1.20	0.288
	4.00	1.00	1.10			0.380	0.380	1.10	0.418
	5.00	1.00	1.10			0.380	0.380	1.10	0.418
	6.00	1.00	0.95			0.400	0.400	0.95	0.380
	7.00	1.00	0.90			0.440	0.440	0.90	0.396
	8.00	1.00	0.90			0.510	0.510	0.90	0.459
	9.00	1.00	0.80			0.500	0.500	0.80	0.400
	10.00	1.00	0.80			0.510	0.510	0.80	0.408
	11.00	1.00	0.70			0.480	0.480	0.70	0.336
	12.00	1.00	0.70			0.470	0.470	0.70	0.329
	13.00	1.00	0.60			0.450	0.450	0.60	0.270
	14.00	1.00	0.60			0.440	0.440	0.60	0.264
	15.00	1.00	0.60			0.410	0.410	0.60	0.246
	16.00	1.00	0.60			0.370	0.370	0.60	0.222
	17.00	1.00	0.60			0.300	0.300	0.60	0.180
	18.00	0.90	0.60			0.180	0.180	0.54	0.097
	18.80	0.75	6.00			0.060	0.060	4.50	0.270
	19.50	0.35	0.00			0.000	0.000	0.00	0.000

Appendix D

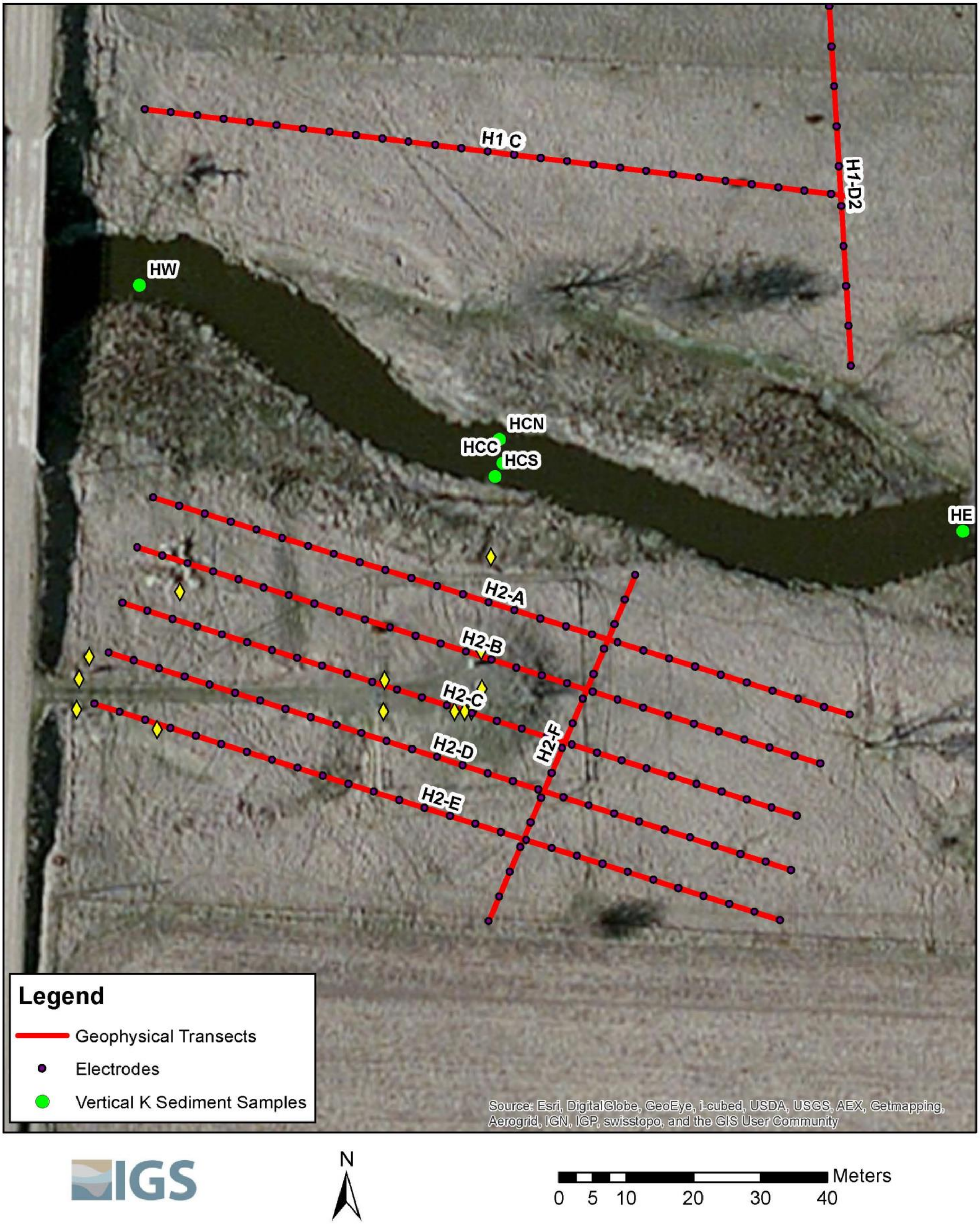

Osceola Rural Water - Site D1
D1-A
D1-B
DN
DC
DS
Legend
Geophysical Transects
Electrodes
Vertical K Sediment Samples
Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community
IGS
N
Meters
0 10 20 40 60 80

IGS Geophysical Survey Results - D1

Osceola County, Iowa

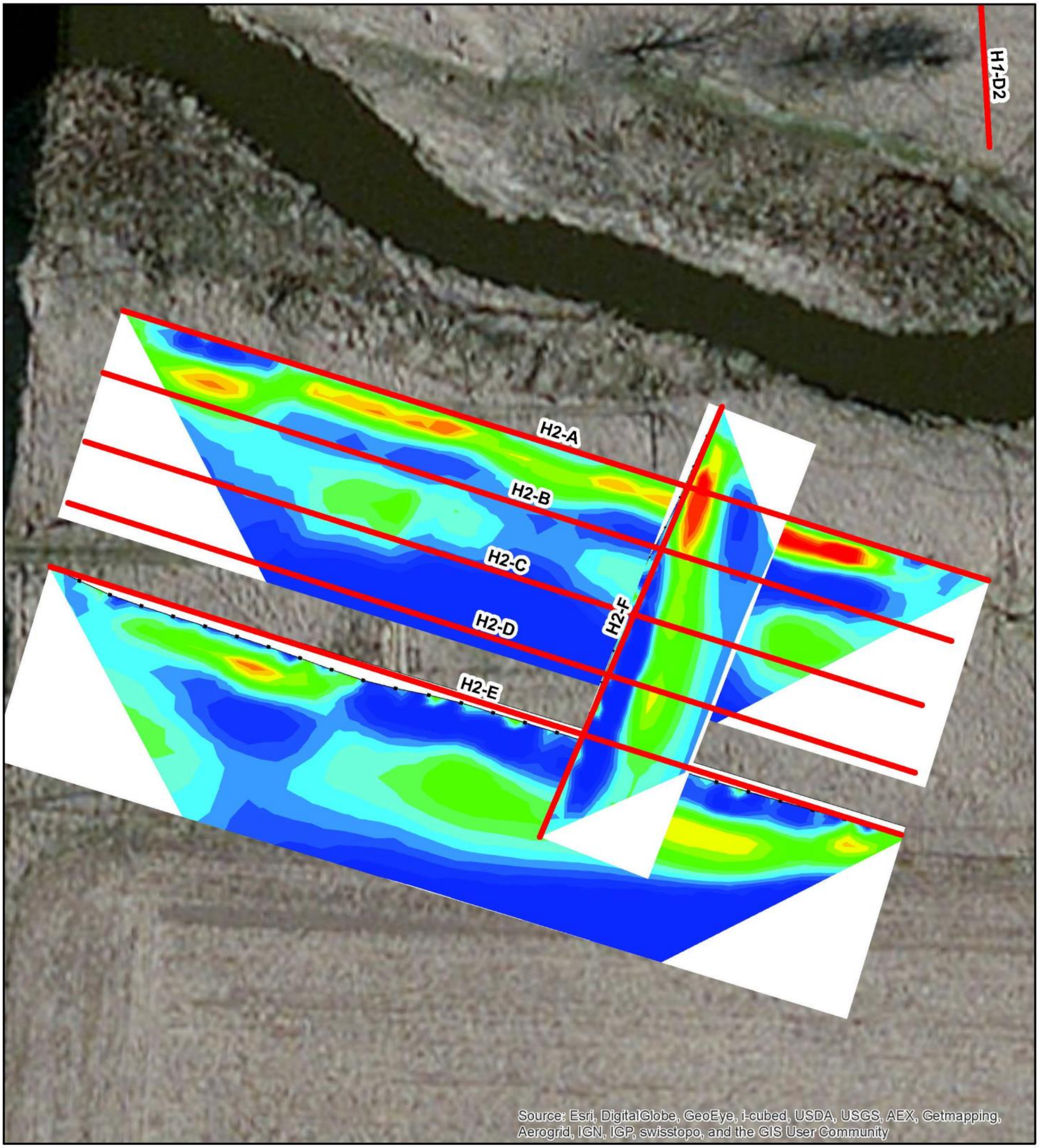


Osceola Rural Water - Site H2



IGS Geophysical Survey Results - H2

Osceola County, Iowa



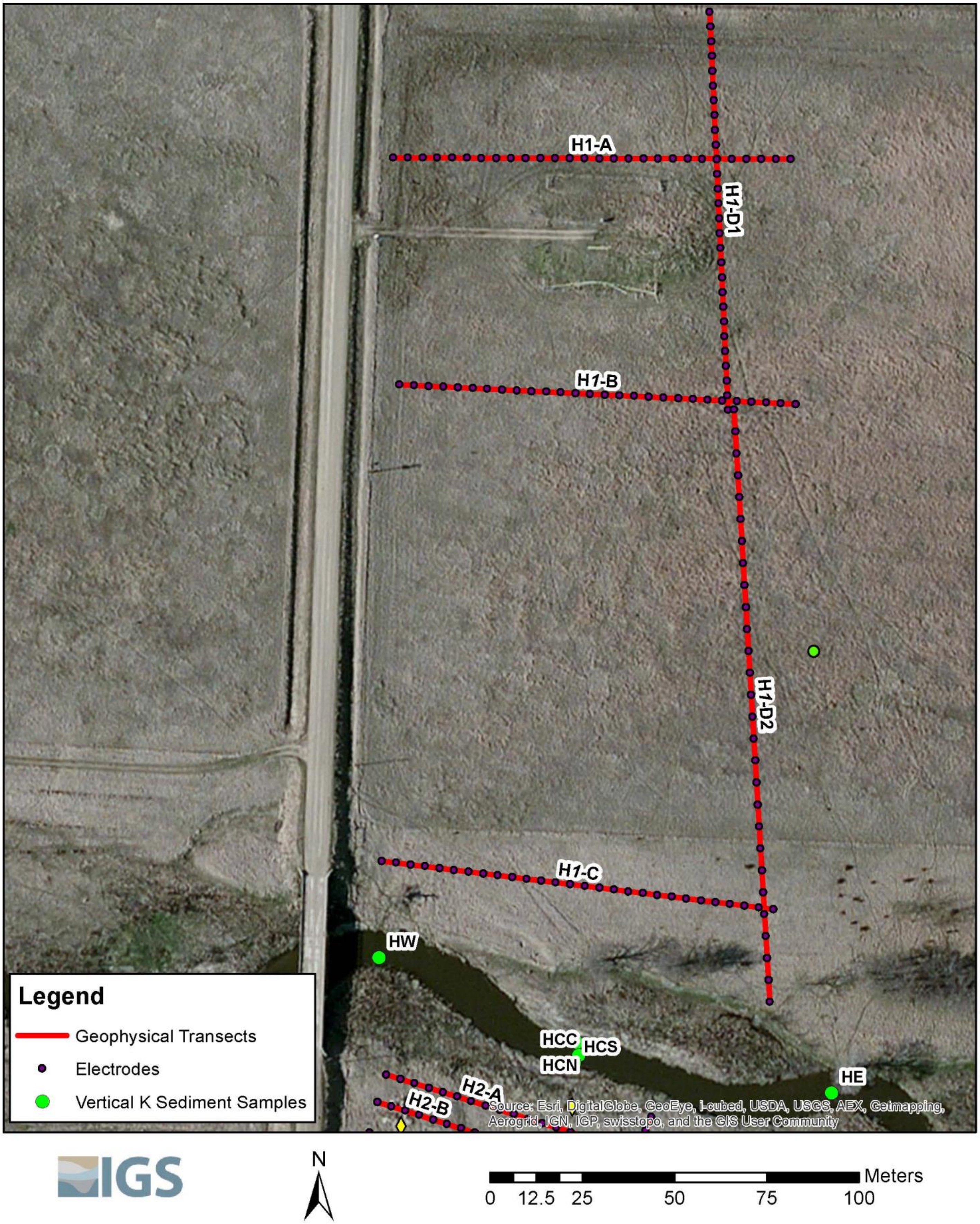
N

0 37.5 75 150 Feet

0 12.5 25 50 Meters

IOWA GEOLOGICAL SURVEY

Osceola Rural Water - Site H1



IGS Geophysical Survey Results - H1

Osceola County, Iowa