Surface-groundwater interactions in a test well field and Spring Creek, Fort Collins, CO

Christina J. Spence
Carleton College, Northfield, MN 55057
March 9, 2007

Submitted in partial fulfillment of the requirements for a Bachelor of Arts degree from Carleton College, Northfield, Minnesota.

TABLE OF CONTENTS

Abstract

Introduction…… 1

GetWET Observatory Background…… 2

Geologic Background…… 5

Hydrogeologic Background…… 6

Methods…….. 6

Results……..... 8

Discussion……..18

Conclusions……23

References……..24

Acknowledgements……25

Appendix……26

Surface-groundwater interactions in a test well field and Spring Creek, Fort Collins, CO

Christina J. Spence
Senior Integrative Exercise
March 9, 2007

Advisors:
Dr. Mary Savina, Carleton College
Dr. Sara Rathburn, Colorado State University

Abstract

The GetWET Observatory on Colorado State University (CSU) property consists of an educational groundwater well field that was constructed in spring 2006. Characterization of the groundwater well field was conducted in order to gain a better understanding of the subsurface material along with groundwater/surface water interactions. Cores were collected from the six wells during drilling. Water table elevations of each well were measured in relation to Spring Creek to create two maps of the water table and calculate hydraulic properties. The average hydraulic gradient in June was very low at about 1.25%, and was low again in November at 1.15%. Based on the direction of these gradients, I conclude that Spring Creek is an influent or losing stream. The thickness of the saturated subsurface aquifer ranges among the six wells from 0.83 m in GW3 to 2.30 m in GW4. This layer consists of mostly medium to coarse sand with some gravel. Groundwater discharge calculation yielded an average value of 2.26×10^{-7} m^3/s per one meter length of stream for June and 1.87×10^{-7} m^3/s per one meter length of stream for November. These data are useful for an initial understanding of groundwater flow patterns and the interaction with Spring Creek. CSU students will continue to evaluate aquifer properties of the site in the coming semesters.

Keywords: Colorado, Groundwater, Aquifer, Alluvium, Pierre Shale, Hydrogeology

INTRODUCTION

Groundwater movement has the potential to affect our very existence. Although many places get their water supply from surface water sources such as rivers and lakes, there is more and more focus being given to obtaining our water from groundwater sources. Therefore, it is important to understand how groundwater moves with respect to adjacent streams and other surface water supplies, among other things, so that we can have a better understanding of what we can and cannot feasibly do and still have a good source for clean water. For example, if a certain amount of some pollutant were to run off into a stream, or an adjacent lawn or field, it would be important to know where the water table was and how quickly the groundwater moved through that area in order to assess the possible threat to wildlife or humans.

Much of the time spent on this project was devoted to analyzing well drilling core with respect to characteristics such as soil color, grain size and shape, weathering, and moisture content. Observations from this portion of the project allowed for correlation of a few layers across the six wells in my study area. Among these layers was the saturated coarse sand layer that constitutes the aquifer. Upon observation of the aquifer's thickness I was able to begin calculations.

Hydraulic gradient, hydraulic conductivity, discharge, and specific discharge are all important values that I calculated in my study of the **G**round **W**ater **E**ducation and **T**eaching (GetWET) Observatory at Colorado State University (CSU) in Fort Collins, Colorado. They are all fundamental to my understanding of groundwater movement in the observatory.

GetWET OBSERVATORY BACKGROUND

The **G**round **W**ater **E**ducation and **T**eaching (GetWET) Observatory (Figure 1a and b, Figure 2) is an educational well field on the CSU campus. Six wells were drilled on April 19th-20th, 2006. The field is a small, relatively flat field immediately adjacent (south) of Spring Creek, which is a perennial stream. There are four wells (GW5, GW1, GW2, and GW3) that run north-south in the field, and two wells (GW4 and GW6) that are oriented east-west. The closest well to Spring Creek is GW3, while the furthest away is GW5 (Figure 2). Each well is about 5.85 m deep, with casing constructed of PVC pipe (Figure 1b). GW4 and GW6 are 16 m apart, while GW5 and GW3 are 15.35 m apart, and GW3 is approximately 5.9 m from the creek. Vegetation on the northwest side of the well field next to the creek consists of a few trees, while the rest of the vegetation is mostly grasses.

The observatory was started for the purpose of giving CSU students a hands-on learning experience, and to provide local teachers with training workshops on groundwater. This project's objectives focused on a comprehensive characterization of the well field, including detailed description and analysis of the drilling cores, construction of cross sections of the wells and water table maps, and hydraulic conductivity/groundwater discharge calculations using data from two dates, from two different seasons. The results from all of these tasks produced a profile of groundwater-surface water interactions in the well field. As the well field had never before been characterized, the expected benefit of the characterization is a better understanding of the subsurface, the dominant flow paths for groundwater, and the interaction with surface water within Spring Creek.

Figure 1a. An aerial photo of the well field and surrounding area. The well field is the area enclosed by the red circle. Spring Creek runs immediately adjacent (north) to the field. Courtesy of USGS (1999).

Figure 1b. GetWET Observatory looking northwest. The groundwater wells are encased in steel risers with locking caps.

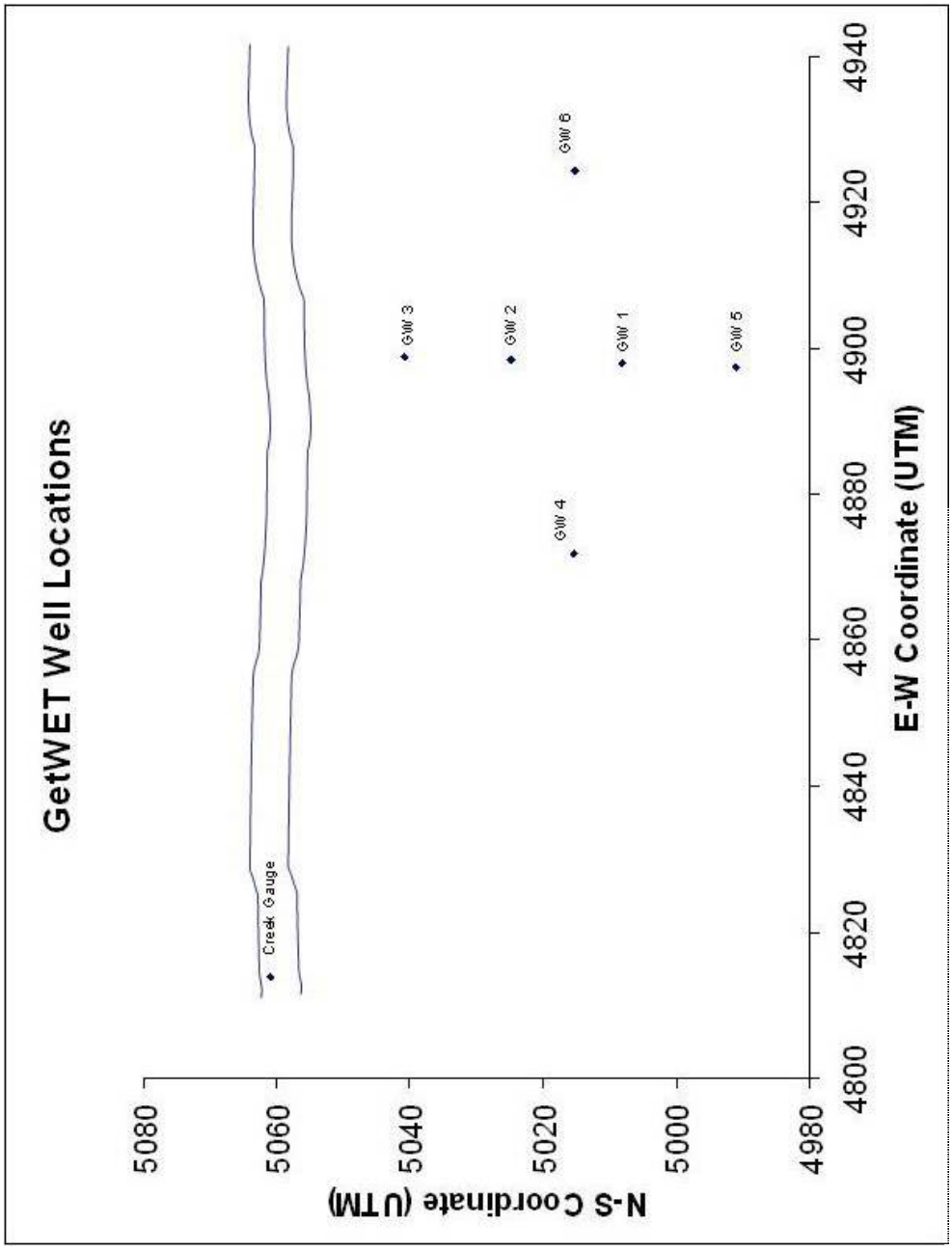


Figure 2. Well locations at the GetWET Observatory.

GEOLOGIC BACKGROUND

Fort Collins lies adjacent to the Front Range of the Colorado Rockies. These mountains were formed during the Laramide orogeny, which occurred from approximately 80 Ma (Late Cretaceous) to about 55 Ma (Paleocene) (English and Johnston, 2004). Two pulses of sedimentation occurred during the Laramide event, one spanning the Cretaceous-Tertiary boundary and the other occurring in the latest Paleocene and early Eocene. The first pulse, named D1 by Raynolds (2002), represents uplift of the part of the Front Range that is bounded by the Golden and Rampart Range faults. The second, called D2, involves sediment that came from the erosion of the mountains west of Colorado Springs (Raynolds, 2002). During this mountain-building event, the Front Range also developed a vertical relief of more than 6400 meters, which took place mostly along north-south oriented thrust faults (Raynolds, 2003).

The bedrock in this area is the Pierre shale, which is a unit of Cretaceous age. This unit is about 1200m thick near the southern Front Range, while it thickens significantly to 2400m in the northern portion of the Front Range (Kelley, 2002), to which Fort Collins is adjacent. Since Fort Collins is not part of a major basin aquifer system, I chose to look at another system, the Denver Basin, which is fairly close by and exhibits some similar characteristics in terms of subsurface material. The Denver Basin, which is south of my study area, provides a larger picture of what the Pierre shale looks like. In that basin, the Pierre shale has been observed as a steeply dipping unit that is part of a larger syncline, with the top of the unit being transitional into the base of the Fox Hills unit, a medium- to fine-grained, quartz-rich, well-sorted sandstone (Kelley, 2002, Raynolds, 2002). The transitional boundary is evidenced by the presence of sand lenses

near the top of the Pierre shale (Kelley, 2002). As observed in the subsurface of the GetWET Observatory, the Pierre shale is indurated, meaning that is hard and may reflect lithification of the unit. Its color was observed as mostly dark gray (a typical color for unweathered Pierre Shale) with some variations, with some exhibiting mottling. The boundary between the bedrock layer and the alluvial fill is not transitional in the observatory, but is rather clear.

HYDROGEOLOGIC BACKGROUND

As stated above, Fort Collins does not overlie a major aquifer or aquifer system. However, there is a shallow aquifer that consists entirely of Quaternary alluvial fill overlying the bedrock layer of Pierre shale. It is referred to as the shallow alluvial aquifer within the Spring Creek drainage basin (Rathburn, 2007), which covers an area of 25 km^2 (Ogden et al., 2000). The alluvial fill that makes up the aquifer consists mostly of fine to medium coarse sand. The material above the aquifer consists of finer-grained, siltier material. The fining-upward trend in grain size is typical of many alluvium deposits.

METHODS

Soil core were collected during drilling in a clear plastic sleeve. The drilling proceeded in 5-ft (1.52-m) runs, with the exception of the first, which was 4 ft (1.22 m). The amount of soil recovered in each run varied. Many of the runs included shoe samples, which consisted of extra material collected at the bottom of the run. A Dremel tool was used to cut open the sleeves lengthwise. Detailed descriptions of the cores involved documenting details of specific soil color, texture, and saturation (moisture content). Pictures of the core processing are provided in the appendix.

A Munsell rock color chart (GSA, 1991) was used to describe color, and provided specific hue, chroma and saturation descriptors such as 10YR 5/4 (moderate yellowish brown) that were applied to different sections of each core. Texture descriptors used (from Singer and Munns, 1996) included silty clay, sandy clay, clay surrounded by sand, etc. Gravel content was also included in the texture descriptions. Saturation of the core material was one of the most important aspects of the analysis, along with grain size description. Saturation indicated thickness of the aquifer, while grain size determined the ease with which water flowed through the material.

Water table levels for each well were measured on June 22nd, 2006 and November 1st, 2006 (after the conclusion of my project). They were used to construct the water table map used in my REU report, as well as a modified version of that same map and a new map, which were used in this project. Each water table map yielded some slightly unexpected results.

The well maps were constructed using UTM (Universal Transverse Mercator) coordinates that were entered into a spreadsheet. Contour lines were then drawn at 0.05 m intervals according to water table levels measured at each well on both June 22nd, 2006 and November 1st, 2006. Flow lines were also added in perpendicular orientation to the contour lines. These and the contour lines were used in gradient calculations, the results of which were used in other calculations that eventually yielded groundwater discharge (Q).

The equation used to calculate the hydraulic gradient was the difference in elevation between the two points (Δh, or h_1-h_2) divided by the distance between those two

points (Δx, or x_1-x_2). This produced a unit-less number, which was then inserted into an equation that yielded a value for q (specific discharge) in meters per second (m/s):

$$q = K(\Delta h/\Delta x)$$

where K is hydraulic conductivity in m/s. Darcy's law is then solved as follows:

$$Q = Aq$$

where Q is groundwater discharge in m^3/s per meter length and A is the cross-sectional area through which the water flows, calculated by multiplying the length of the cross section (1 m) by the saturated thickness. As stated earlier, q is the value for specific discharge, calculated using the hydraulic gradient ($\Delta h/\Delta x$) multiplied by a chosen hydraulic conductivity (K), selected from Freeze and Cherry (1979) based on type of material through which the water is running.

While snowmelt is the main factor that feeds Spring Creek, rainfall also plays a role. Therefore, rainfall data was compiled from the National Climatic Data Center (2006) for the periods of March 1st, 2006 to June 22nd, 2006 (the first measurement date) and from June 23rd, 2006 to November 1st, 2006 (the second measurement date). The measurement site is located at the Fort Collins-Loveland Municipal Airport, which is about 22.5 km north-northwest from GetWET. March was chosen as the first month for the first period despite its making the first period shorter than the second because it is the month in which spring starts.

RESULTS

Results of the well core descriptions yielded some important observations regarding layers that continued across the wells. The first such observed layer was the black clay (Figure 3a and b) that generally appears in the second run of each well, with

the exception of GW6, where it appears near the top of the third run (Figure 3a and b); the drilling advanced in 5-foot runs, with varying amounts of soil recovered in each run. This black layer is usually surrounded by a thin layer of light to moderate brown clay or sand, and is sometimes mixed with that same color of clay. In many places the black clay is often silty as well.

Another very important layer to the characterization of the well field was the sand and gravel that was found in every well (Figure 3a and b). The wells that have gravel are GW5, GW1, GW2, GW3, and GW6. Sand was found in all six wells, always below the black clay. The first occurrence of sand is usually at the beginning of the third run, with the exception of GW5 and GW4. These two wells both show a first occurrence of sand in their second layer. Most of the sand encountered was at least damp, if not saturated, indicating that this is the layer through which more groundwater is flowing. The color of the majority of this material is about 10YR 5/4 (moderate yellowish brown), and the grain size ranges from some fine sand to mostly medium to coarse sand.

The third important layer was the weathered bedrock/bedrock layer (Figure 3a and b). From the characteristics of this layer the bottom boundary of the saturated layer could be determined. If the clay was damp, then it was included in the saturated thickness. If it was drier and indurated, then it was characterized as bedrock. The bedrock is Cretaceous-aged Pierre shale, which most likely provides a good seal for the bottom of the saturated layer. Figure 3c illustrates a composite, simplified cross section of the wells.

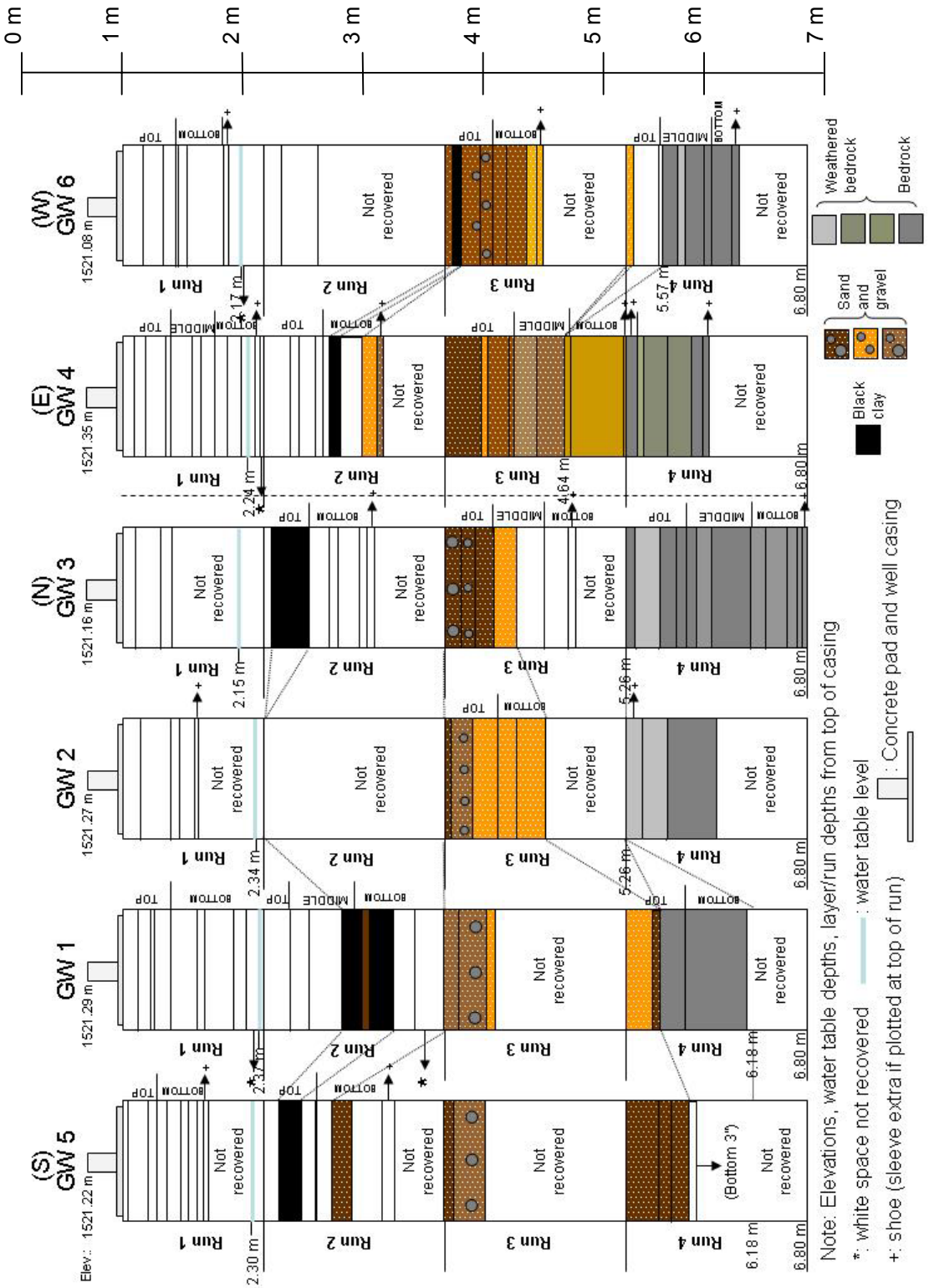


Figure 3a. Cross sections of core collected from each well with water table data from June 22nd, 2006. Layers correlated between wells where possible using dashed lines. Although GW2 does not show a black clay layer (because of lack of recovery in Run 2), the logs taken during drilling indicate that there was a black layer present. Uncolored portions at top of each cross section represent more layers, but are not colored because they are not major layers. Well casing and concrete pad not to scale.

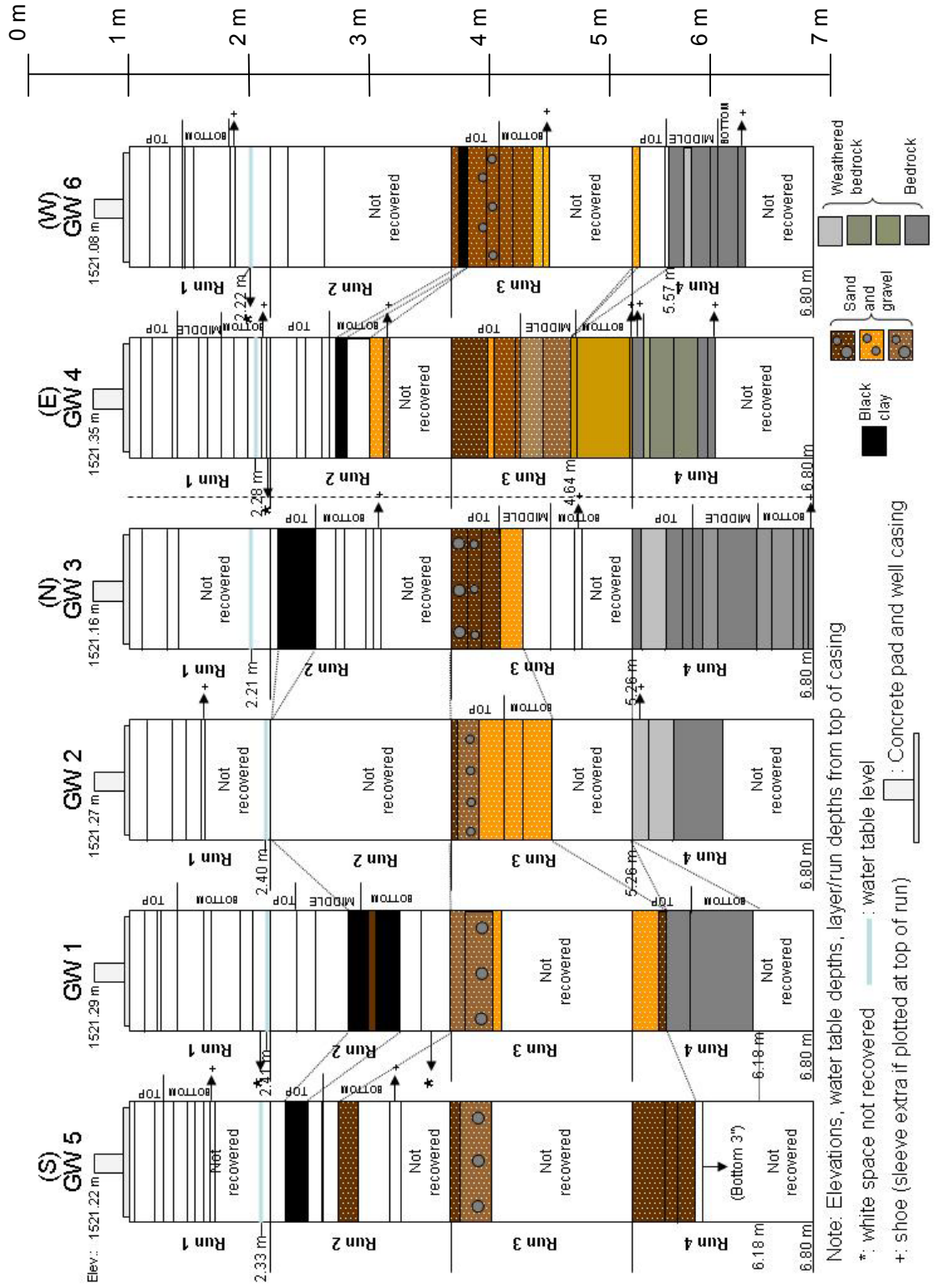


Figure 3b. Cross sections of core collected from each well with water table data from November 1st, 2006. Layers correlated between wells where possible using dashed lines. Although GW2 does not show a black clay layer (because of lack of recovery in Run 2), the logs taken during drilling indicate that there was a black layer present. Uncolored portions at top of each cross section represent more layers, but are not colored because they are not major layers. Well casing and concrete pad not to scale.

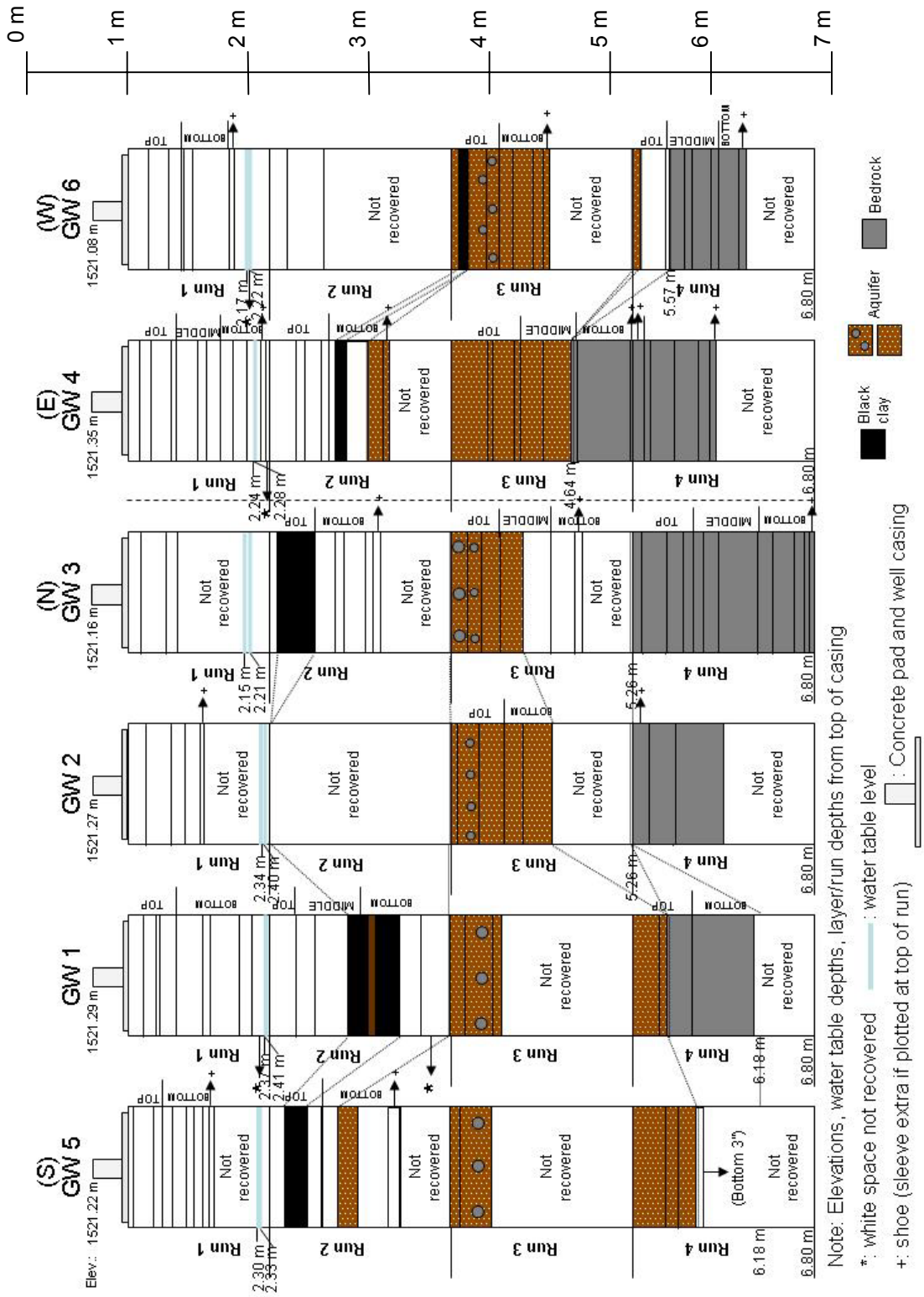


Figure 3c. Cross sections of core collected from each well with water table data from June 22nd and November 1st, 2006. Layers correlated between wells where possible using dashed lines. Although GW2 does not show a black clay layer (because of lack of recovery in Run 2), the logs taken during drilling indicate that there was a black layer present. Uncolored portions at top of each cross section represent more layers, but are not colored because they are not major layers. Well casing and concrete pad not to scale.

The water table elevations for the June 22nd measurements are listed in Table 1, with the November 1st data listed in Table 2.

Table 1. WELL ELEVATIONS AND CORRESPONDING WATER TABLE ELEVATIONS-JUNE 22ND DATA.

Well number	Elevation at top of casing (m)	Water table elevation from top of casing (m)
GW5	1521.22	2.30
GW1	1521.29	2.37
GW2	1521.27	2.34
GW3	1521.16	2.15
GW4	1521.35	2.24
GW6	1521.08	2.17

Table 2. WELL ELEVATIONS AND CORRESPONDING WATER TABLE ELEVATIONS- NOVEMBER 1ST DATA.

Well number	Elevation at top of casing (m)	Water table elevation from top of casing (m)
GW5	1521.22	2.33
GW1	1521.29	2.41
GW2	1521.27	2.40
GW3	1521.16	2.21
GW4	1521.35	2.28
GW6	1521.08	2.22

Water table levels from June 22nd, 2006 and November 1st, 2006 (Figure 4a, Figure 4b) plotted on a map of the wells indicate that the water table slopes gently away from Spring Creek in June (Figure 4a) and even less steeply in November (Figure 4b). In both cases, Spring Creek was found to be an influent (losing) stream. The average gradient between contours 1519.10 m and 1518.90 m (Figure 4a) is approximately 1.25% for June. The gradient calculated between contours 1519.05 m and 1518.85 m (Figure 4b) is approximately 1.15% for November. Each measurement period showed a water table that was steeper to the northwest and then leveled out (Figure 4a and 4b).

For specific discharge calculations, a K value of $1x10^{-5}$ m/s was used, taken from a chart in Freeze and Cherry (1979). This value corresponds with unconsolidated silty/clean sand. This is the material closest to the sandy layers encountered and

described in the project. The calculations for the June data yielded a specific discharge (q) value of 1.18×10^{-7}m/s for the northernmost flow line, 1.27×10^{-7}m/s for the middle flow line, and 1.29×10^{-7}m/s for the southernmost flow line (Figure 4a). Specific discharge values for the November data were calculated at 1.02×10^{-7}m/s for the northernmost flow line, 1.20×10^{-7}m/s for the middle line, and 1.22×10^{-7}m/s for the southernmost line (Figure 4b).

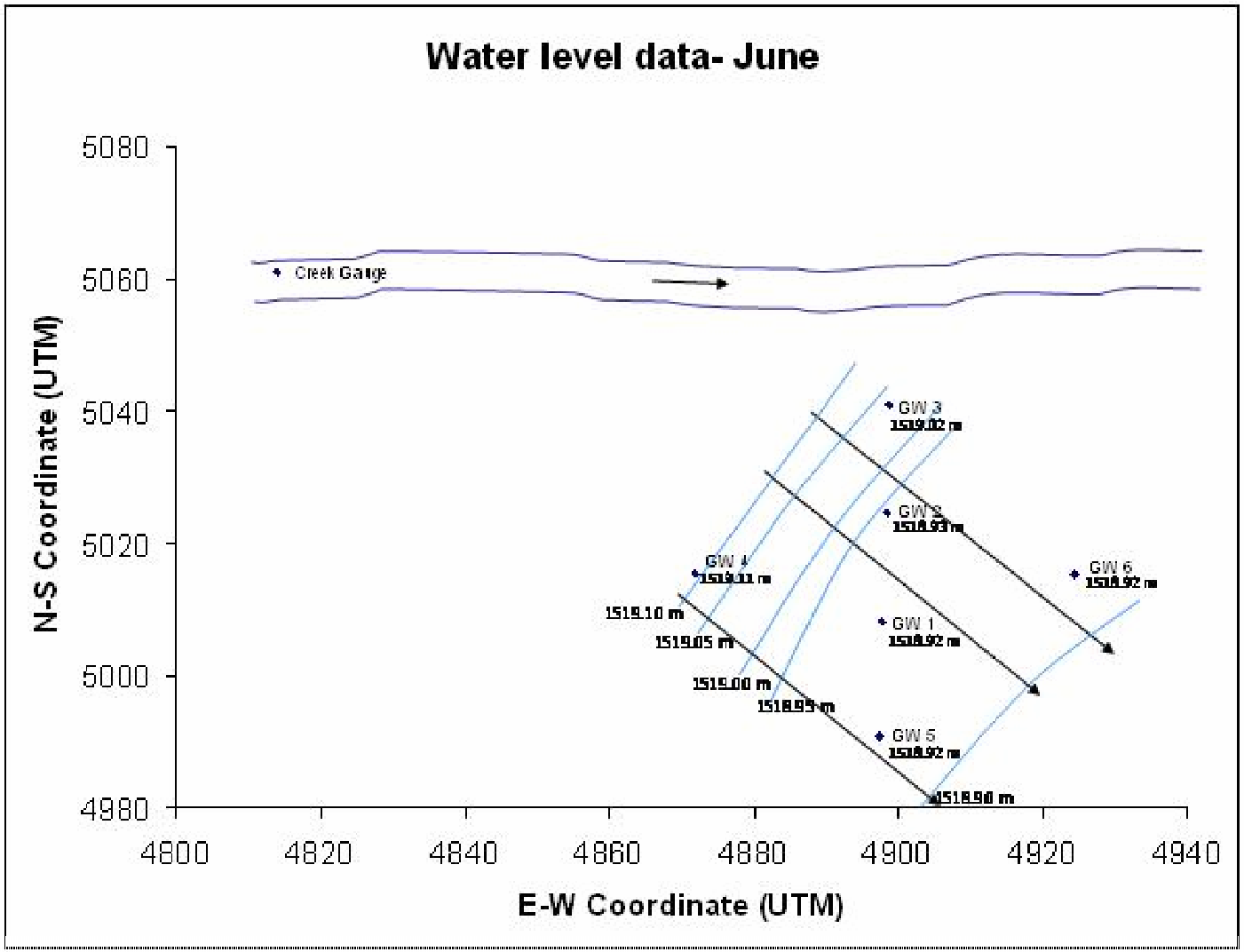


Figure 4a. Water table map for the GetWET Observatory. The flow lines are approximated, but have been drawn perpendicular to the contour lines, which have been drawn at 0.05 m intervals based on water table elevations from each well, measured on June 22nd, 2006. Water levels are displayed directly below each well number. Contour line labels are at the bottom of each line.

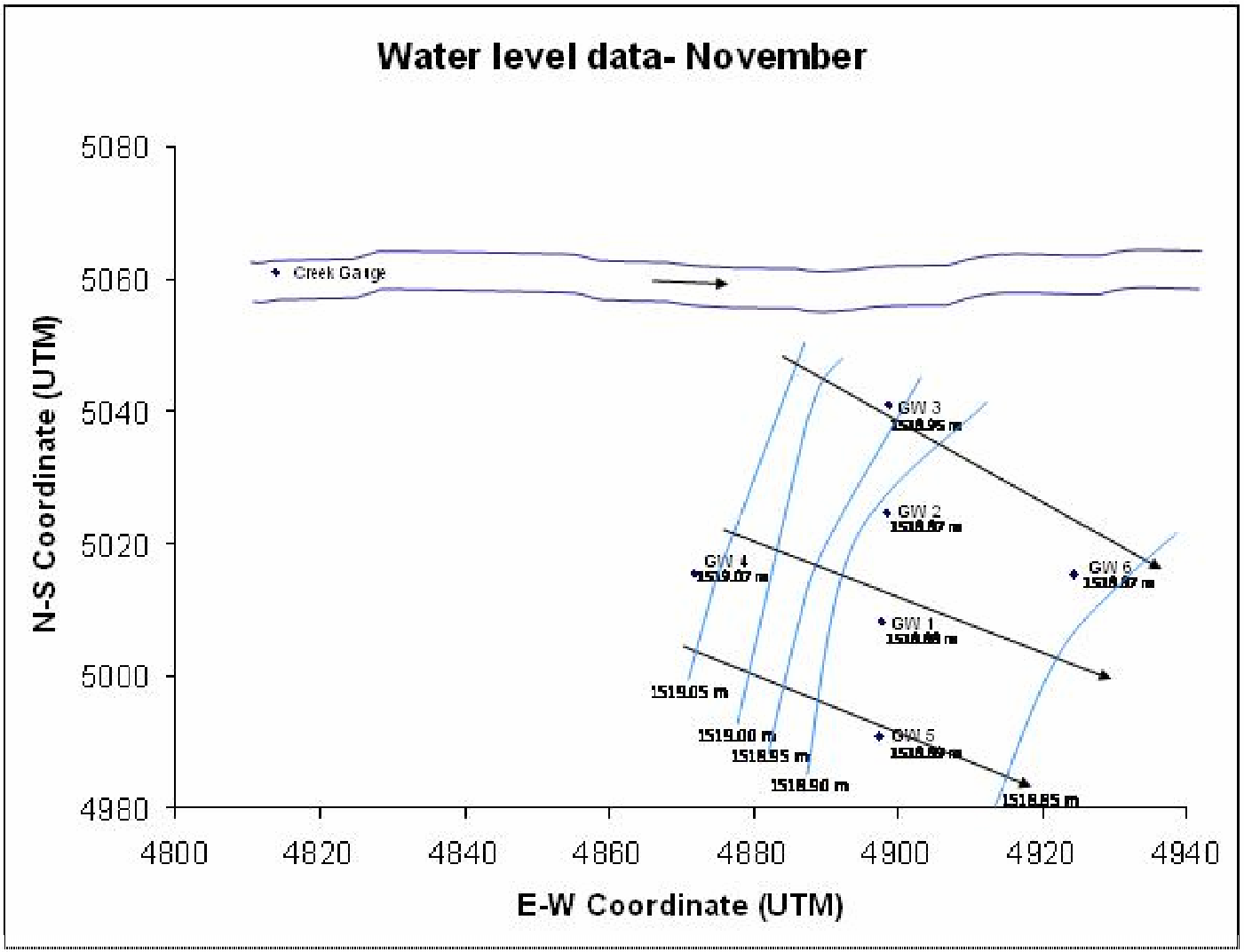


Figure 4b. Water table map for the GetWET Observatory. The flow lines are approximated, but have been drawn perpendicular to the contour lines, which have been drawn at 0.05 m intervals based on water table elevations from each well, measured on November 1st, 2006. Water levels are displayed directly below each well number. Contour line labels are at the bottom of each line.

The groundwater discharge (Q) value calculated that corresponds with the June values for specific discharge is approximately 2.07×10^{-7} m^3/s per one meter length of stream for the northernmost flow line, 2.22×10^{-7} m^3/s for the middle line, and 2.49×10^{-7} m^3/s for the southernmost line. The saturated thickness for GW2 (Figure 2), the value used in the calculations for the northernmost and middle lines, was 1.75 m. The saturated thickness for GW5 (Figure 2), the value used in the calculations for the southernmost line, was 1.92 m. The calculated Q values that correspond with the November specific discharge values are 8.50×10^{-8} m^3/s per meter length of stream for the northernmost flow line, 2.43×10^{-7} m^3/s per meter length of stream for the middle flow line, and 2.35×10^{-7} m^3/s for the southernmost line. The saturated thickness for GW3 (Figure 2), used in the calculation for the northernmost flow line, was 0.83 m. The saturated thickness for GW1 (Figure 2), the value used in the calculation for the middle flow line, was 2.02 m, and for GW5 was 1.92 m, the value used in calculations for the southernmost flow line. The saturated thickness used changed depending on which well the flow line was closest to. That is, the well from which the saturated thickness value was taken was chosen based on its proximity to the flow line.

Rainfall amounts were found to be lower in the first period (March 1st to June 22nd) than in the second period (June 23rd to November 1st). Average weekly rainfall for the first period amounted to 4.80 mm/week (Figure 5); average weekly rainfall for the second period amounted to 9.12 mm/week (Figure 5).

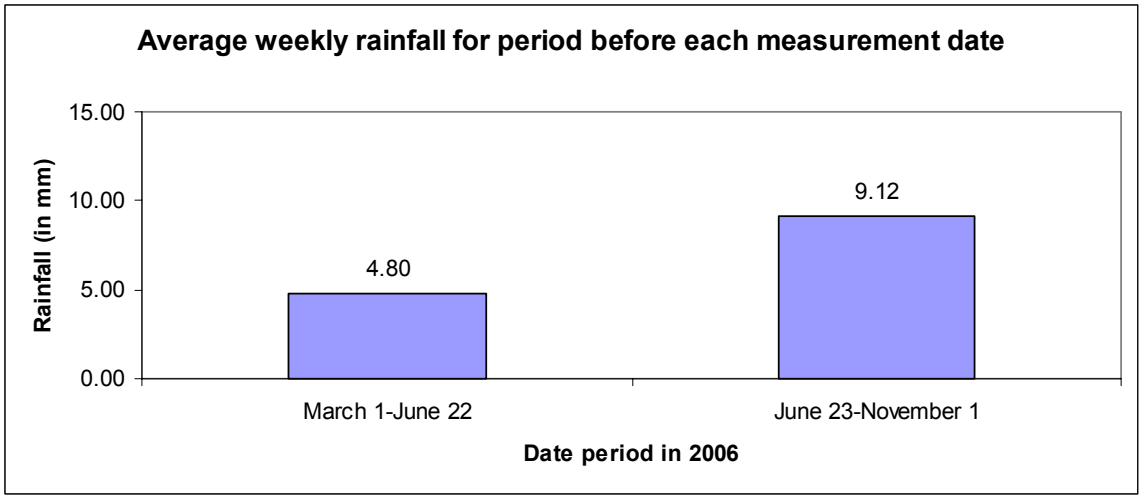


Figure 5. Average weekly rainfall (in mm) for the date range before each water table measurement date.

DISCUSSION

The data collected and the descriptions made in this project were the first to be done for the GetWET Observatory on the CSU campus. They allow for a more comprehensive understanding of the area, including the subsurface material, the water table level, and the relationship of these two aspects of the field to the water in the immediately adjacent Spring Creek.

The first and most important relationship observed was that between the sand and gravel layer and the water table. It was observed that the first appearance of sand in each well corresponded closely with the level of the water table in that well—the topography of the water table mimics the top of the sand and gravel layer. This is logical, as it is known that water flows more easily through material that has larger (and connected) pore spaces, as sand and gravel do because of their larger grain size compared to silt and clay (Fetter 1994).

Another observation made was that the black clay generally appeared in the second run (2.18 m to 3.72 m from the top of the well casing) of each well. It also

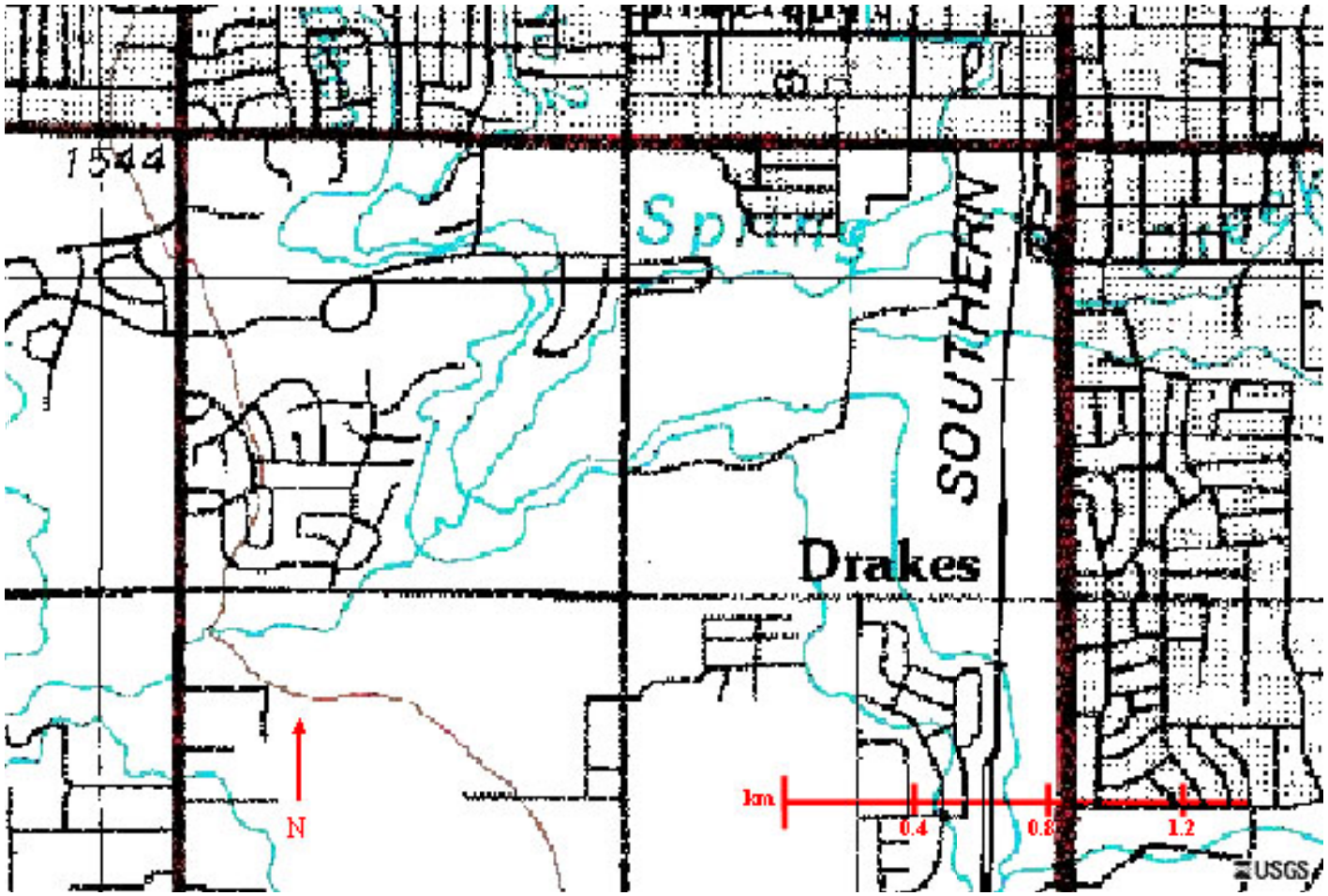
seemed to appear near the water table most of the time, and always below it. The moisture could cause weathering and indicate a zone in which alternating processes of reduction and oxidation have occurred, indicating a zone through which the water table level fluctuates. There is also likely a higher level of organic matter in this layer. This clay layer and the finer, silty material above it seem to be confining, thus making this a confined aquifer.

The last major observation that was made regarding the well core had to do with the bedrock. The first appearance of bedrock in each well tended to be weathered and significantly mottled, and usually with the same colors (olive gray with dusky yellow or similarly colored mottles). This weathering was most likely due to contact with the aquifer, or to weathering before the deposition of the alluvium. As depth increased, however, the bedrock became less weathered and mottled, as well as less moist (and harder). The color was usually close to olive gray.

The water table levels were most important for hydraulic gradient calculations. They also allow for determination of the interaction between groundwater and surface water, especially whether Spring Creek is influent or effluent. It had been initially assumed that Spring Creek was an effluent stream, meaning water would be flowing into it; this would be indicated by water table elevations that sloped down towards the level of the creek. However, it was discovered that this was not the case. Contrary to initial assumptions, the creek was discovered to be influent in both June and November, meaning that the water from the creek was flowing into the groundwater. Although the stratigraphy below the creek bed was not explored in this study it is assumed, based on the contour lines and approximated flow lines, that the water is seeping through the bed

of Spring Creek and moving away from it at an angle (Figure 4a and b). The general topography of the region (Figure 6) tends to slope a similar direction to the flow lines. Spring Creek is also receiving irrigation return flows further upstream during the first period of measurement.

40N 33' 25.56"



105W 06' 14.11" 105W 05' 6.09"

Figure 6. Topographic map of the area surrounding GetWET. GetWET's approximate location is indicated by the red circle. Blue lines represent different streams. The topography in this region is relatively flat. Courtesy of USGS (1980).

When hydraulic gradient was calculated, it was observed that it is very low, which implies that the water was probably not moving very quickly through the aquifer (sand and gravel); the hydraulic conductivity of the material also affects the velocity with which the water is moving through it. The water table is relatively flat, and subtly mimics the topography of the well field. Specific discharge and groundwater discharge calculations yielded values that confirmed this inference. Indeed, the water is moving at a rate of about 3.94 m/year (from June data calculations). November data calculations showed a lower rate of movement at 3.62 m/yr. It must be noted that clay (bedrock) layers, if measured, most likely would have had much lower discharge values.

Rainfall data that was compiled showed that the March 1st-June 22nd period was drier than the June 23rd-November 1st period. The difference in rainfall amounts could be the reason for the change in water table levels. Since the first period was drier, snowmelt from the Front Range was infiltrating the ground, rather than becoming runoff. Therefore, it did not play as much of a role in feeding Spring Creek as it typically does. Because of this, rainfall was the climatic parameter that I chose to analyze. A factor that could have also played a role in the water table level differences is the reality that Spring Creek receives irrigation return in the spring. However, this was not investigated within the scope of this project.

Any error in measurements or calculations in this project was human error. Therefore, some of the values, such as distance between contour lines, may be slightly different if measured again by another scientist.

CONCLUSIONS

The GetWET well field characterization produced by this study provides some important information for CSU students and local teachers. Descriptions of the subsurface material allow inferences to be made regarding groundwater activity as well as its interactions with Spring Creek. This could be applied to other measurements during different times of the year. Further research could be done in yet another season (or another year) to see whether or not the state of the stream (influent or effluent) would be different due to seasonal or annual climatic changes. This would be interesting to study, since the measurements for this project were made during the summer, which was dry and followed an exceptionally dry spring season, and in the fall after a significantly wetter period from the end of June through the beginning of November. However, Spring Creek has also been receiving more irrigation water and adding to the groundwater system. More research could also be done to either confirm or refute the results obtained from this project. That is, it would be beneficial to have more data from other times of the year, as well as other years entirely, so determinations could be made as to whether or not there is a pattern with regard to interactions between Spring Creek and the groundwater.

REFERENCES CITED

English, J.M. and Johnston, S.T., 2004, The Laramide Orogeny: What Were the Driving Forces?: International Geology Review, v. 46, p.833-888.

Fetter, C.W., 1994, Applied Hydrogeology: New York, MacMillan College Publishing Company, 691 p.

Freeze, R.A. and Cherry, J.A., 1979, Groundwater: Upper Saddle River, New Jersey, Prentice Hall, 604 p.

Geologic Society of America, 1991, Rock-Color Chart with genuine Munsell color chips, Boulder, CO, Geologic Society of America.

Kelley, S.A., 2002, Cretaceous shales and their influence on denudation estimates for the Southwestern United States: Geological Society of America Abstracts with Programs, v. 34, no. 4, p. 60.

Kelley, S.A., 2002, Unroofing of the southern Front Range, Colorado: A view from the Denver Basin: Rocky Mountain Geology, v. 37, no. 2, p. 189-200.

National Climatic Data Center, Quality Controlled Climatological Data for Fort Collins-Loveland. Available at: http://cdo.ncdc.noaa.gov/ulcdsw/ULCD?prior=N&callsign=FNL. Accessed February 26th, 2007.

Ogden, F.L., Sharif, H.O., Senarath, S.U.S., Smith, J.A., Baeck, M.L. and Richardson, J.R., 2000, Hydrologic analysis of the Fort Collins, Colorado, flash flood of 1997: Journal of Hydrology, v. 228, p. 82-100.

Rathburn, S.L., 2007, Aquifer question, *in* Spence, C.J., ed. (personal correspondence).

Raynolds, R.G., 2002, Upper Cretaceous and Tertiary stratigraphy of the Denver Basin, Colorado: Rocky Mountain Geology, v. 37, no. 2, p 111-134.

Raynolds, R.G., 2003, Evolution of Colorado's Front Range during the Laramide Orogeny: Geological Society of America Abstracts with Programs, v. 35, no. 5, p. 13.

Singer, M.J. and Munns, D.N., 1996, Soils - An Introduction, Third Edition, Upper Saddle River, New Jersey, Prentice Hall, 480 p.

USGS, 1980, Topographic map of Fort Collins, Colorado, United States 7/1/1980. Available at: http://terraserver.microsoft.com/usgsentry.aspx?T=2&S=13&Z=13&X=307&Y2805&W=1&qs=%7cFort+Collins%7cCO%7c. Accessed March 7th, 2007.

USGS, 1999, Aerial photo of 425 W. Prospect Rd., Fort Collins, Colorado, United States, 10/4/1999. Available at: http://terraserver.microsoft.com/usgsentry.aspx?T=1&S=10&Z=13&X=2465&Y=22451&W=1&qs=425+W.+Prospect+Rd.%7cFort+Collins%7cCO%7c&Addr=425+W+Prospect+Rd%2c+Fort+Collins%2c+CO+80526-2064&ALon=-105.0829920&ALat=40.5671000. Last accessed March 7th, 2007.

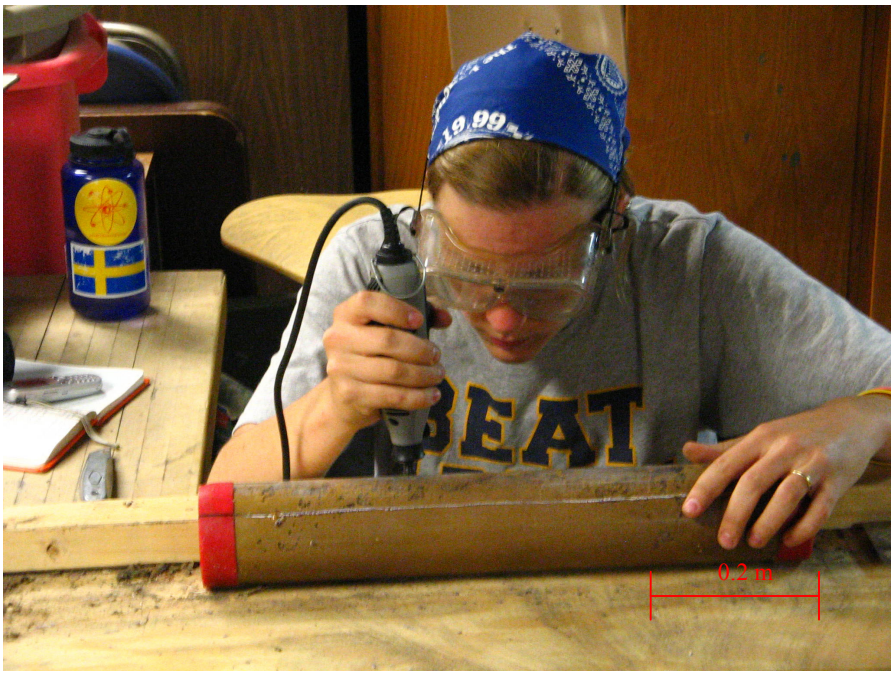
ACKNOWLEDGEMENTS

I am grateful to Dr. Mary Savina for her guidance throughout this project with regards to things big and small. I would also like to acknowledge Dr. Sara Rathburn for her assistance with this project, and her teaching assistants for collecting the data from fall of 2006.

My Research Experience for Undergraduates program, the results of which were the basis for this project, was funded by both the National Science Foundation and the United States Department of Defense. My study benefited greatly from the direction of my faculty mentor, Dr. Sara Rathburn, who offered her advice and expertise throughout the project, and from the assistance with calculations of Dr. Bill Sanford. I am also grateful to Dr. Ellen Wohl, who served as a substitute advisor in the initial unavoidable absence of Dr. Rathburn.

APPENDIX

An example of one of the cores still encased in the sleeve.



The process of cutting open the core's plastic sleeve.

Spring Creek GetWET
Well drilling core descriptions

Drilled April 19-20, 2006
Drillers Engineers, Inc.
8.25" OD
4.25" ID Auger
5 foot increments
Split spoon

GW 1
Run 1 (0-1.22 m)
Top
0-8 cm: many roots; mostly small, subangular blocky aggregates (fine-grained when crushed); color: 10YR 4/2 (dark yellowish brown)
8-16 cm: small, angular to subangular blocky aggregates (fine-grained when crushed); color: 10YR 4/2; <10% gravel (mostly ≤1 cm), one larger chunk (~ 3½ cm)
16-28cm: 10YR 5/4 (moderate yellowish brown) with some dark mottling; large chunks (~ 4 cm)- high clay content; <10% gravel; any aggregates (not many) are small to medium, angular to subangular blocky (fine-grained when crushed)
28-33 cm: slightly coarser grains; ~ 10-20% gravel; ~ 10YR 5/4 (moderate yellowish brown); some coarser sand, some silt
33-46 cm: 10YR 6/2 (pale yellowish brown) with some pink (k-spar?); 10R 7/4 (moderate orange pink); <10% gravel; fine- to medium-grained; angular to subangular blocky w a couple of rounded small pebbles

Bottom
0-8 (46-54) cm: aggregates larger (~½ - 2 cm), subangular blocky; one larger cobble (9 cm diameter at widest, 3-3½ cm thick)- gneiss?- dark, finely crystalline rock with small white bands; 10YR 4/2; very little (if any) clay; fine sand and silt; gravel <10%
8-13 (54-59) cm: fine sand and silt, more clay; one large (~ 4 cm thick) aggregate (8-11 cm: 5Y 5/2 light olive gray, 11-13 cm: 10R 6/6 moderate reddish orange); material underneath aggregate similar to 0-8 cm in color, size, etc.
13-16 (59-62) cm: four larger (2½ - - 4½ cm) aggregates, rest of aggregates ≤ 1½ cm, subangular blocky; two colors: 10YR 4/2, 10R 6/6 (oxidization?); very few fine roots; fine sand and silt
16-23 (62-69) cm: same two colors as 13-16 cm, though more of the 10R 6/6; clay; little fine sand/silt (all stuck together); one or two fine roots
23-47 (69-93) cm: 10YR 4/2; clay; almost no fine sand (some silt?); a couple of small 10R 4/6 (medium reddish brown) spots; some black spots
47-59 (93-105) cm: more sand; ≤10% gravel; subangular blocky, small aggregates; ~ 10YR 5/4; some (little) black and pink spots

Shoe Sample
Mottled; some oxidization; two main colors: ~10YR 4/2, 5Y 6/4 (dusky yellow); mostly clay, some fine silt

Run 2 (1.22-2.74 m)

Top
0-21(105-126) cm: mostly clay with some silt and little organic material; 10YR 4/2; a couple of very small oxidized spots and a couple of very small black spots

Middle
0-16 (126-142) cm: clay; some (very little) organic material; some oxidization; 10YR 4/2 (dark yellowish brown); good ribbon
16-40 (142-166) cm: mostly 5YR 6/4 (light brown) on fresh surface, but some 10YR 4/2; clay with very little organic material; good ribbon; unclear boundary
40-50½ (166-176½) cm: black on fresh surfaces, but even deeper mottling (includes black clay and 10YR 5/4 sandy clay) is present; clay (good/decent ribbon formed); slightly different smell than rest; clear boundary

Bottom
0-7 (176½ - 183½) cm: black clay with some silt
7-12 (183½-188½) cm: mostly sand with very little clay; 10YR 4/2; little mottling with black
12-32 (188½-208½) cm: moist- clay gives a little when pressed; very little silt- almost all clay (good ribbon formed); outer layer around black ~½ cm; mixture of two colors: 5YR 6/4 (light brown), ~ 10YR 4/2
32-50½ (208½-227) cm: very clear boundary (color); ~ 10YR 5/4

Shoe Sample
Clay; 10YR 5/4

Run 3 (2.74-4.27 m)
0-9 (227-236) cm: wet; medium coarse sand; <10% gravel; overall color between 5YR 4/4 (medium brown) and 10YR 5/4 (moderate yellowish brown)
9-26 (236-253) cm: ~ 50% gravel; overall color approximately the same as 0-9 cm; some of gravel is pink (k-spar?); some quartz gravel
26-30½ (253-257½) cm: same overall color; slightly finer texture; ~1/3 gravel?
30½-40 (257½-267) cm: finer texture with some clay; <1/3 gravel (10-20%?); 5YR 5/6

Shoe Sample
Sand and gravel with little clay; 10YR 5/4; ≥50% gravel

Run 4 (4.27-5.79 m)

Surface sample
Gravel (average size of ~ 3 cm)

Top
0-21 (267-288) cm: wet; 5YR 5/6 (light brown); fine to medium sand
21-28 (288-295) cm: transition; 10YR 4/2 (dark yellowish brown); almost no gravel (finer texture)
28-48 (295-315) cm: clay; 5Y 3/2 (olive gray); mottles: 5Y 6/4 (dusky yellow)

Bottom
0-45 (315-360) cm: clay; 5Y 3/2 with mottles of 5Y 4/4 (moderate olive brown); firmer than top (less moisture?)

Shoe Sample
Very fine clay; 5Y 3/2

GW 2
Run 1 (0-1.22 m)
0-4 cm: organic material; common fine roots; mostly silt, maybe some clay or very fine sand; 10 YR 5/4 (moderate yellowish brown)
4-14 cm: 10 YR 5/4; some aggregates-angular to subangular blocky, ~ 1 cm on average; <10% gravel; mostly silt; one medium root
14-23 cm: between 5YR 6/4 and 5YR 5/6 (light brown); more solidified (massive) than 0-4 and 4-14 cm; silty, but much more clay; aggregates subangular blocky; <10% gravel
23-34 cm: silty; about same amount of clay as 14-23 cm; 10YR 4/2 (dark yellowish brown); gravel- slightly more, but still <10%; some dark (black) spots, but doesn't look quite like mottling
34-43 cm: more clayey; silt still present; <10% gravel; any aggregates are slightly larger, but mostly massive, subangular blocky; 10YR 5/4
43-51 cm: mostly clay; some white spots; some small pieces of black material, one coarse chunk (coal?); mixture (mottling?) of 10 YR 4/2 and 10YR 5/4; massive
51-57 cm: clay; mottling: spots of ~10YR 5/4 and 10YR 4/2 in (between 10R 6/6 moderate reddish orange and 10R 4/6 moderate reddish brown); massive

Shoe Sample
Massive; clay with mottling (10YR 4/2 with spots of white and 10R 4/6)

Run 2 (1.22-2.74 m)
NO RECOVERY

Run 3 (2.74-4.27 m)
Top
0-5 (57-62) cm: wet; fine to medium sand with some silt and/or clay; some dark spots- gleying??; 10YR 5/4
5-15 (62-72) cm: wet; more clayey- somewhat sticky to the touch; ≤10% gravel; 5YR 6/4 (light brown)

15-23 (72-80) cm: gleying; less clayey than 5-15 cm; ~20-30% gravel; main color 5YR 6/4
23-45 (80- 102) cm: almost all coarse sand with very little clay or silt; 10 YR 6/6 (dark yellowish orange)

Bottom
0-16 (102-118) cm: wet; medium coarse sand (slightly finer than 23-45 cm) with little silt or clay; <10% gravel; 10YR 6/6 with very slight pinkish tint
16-45 (118-147) cm: 10 YR 6/6; wet; medium coarse sand with more clay (a little muddier); ~ 10% gravel

Shoe Sample
Wet; ~ 30% gravel; medium coarse sand; 10 YR 6/6; some (little) clay- slightly muddy

Run 4 (4.27-5.79 m) - soft bedrock
0-2 (118-120) cm: sandy with ~ 10% gravel; 5Y 5/2 clay inside
2-21 (120-139) cm: clay with some sand around outside (brought down from previous section?); clay color 5Y 5/2 (light olive gray) with mottles of 5Y 6/4 (dusky yellow); weathered bedrock
21-45 (139-163) cm: clay; some 5YR 4/4 (medium brown) clay around outside (≤ ~½ cm); 5Y 3/2 (but grayer) with mottles of 5Y 6/4; weathered bedrock
45-63 (163-181) cm: 5Y 3/2 is closest, but clay is slightly darker and grayer; mottles of 5Y 6/4; less weathered than previous layers of run 4

Shoe Sample and Sample Extruded From Sleeve
Mottling: ~5Y5/6 (light olive brown) mottles in clay that's about the same color as 45-63 cm; some oxidization on the end; smaller chunks are grayer, a little lighter

GW 3
Run 1 (0-1.22 m)
0-6 cm: 10YR 5/4; some organic material; massive; <10% gravel; piece of metal-reddish, ~ 3 cm at widest; some clay, silt
6-11 cm: small (usually ≤½ cm), subangular blocky aggregates, a few larger (3 cm) ones; silt; less clay; very little fine sand; a little lighter than 10 YR 4/2 (dark yellowish brown)
11-33 cm: some larger (coarse- ≤ 1½ cm) angular to subangular blocky aggregates; mostly massive; <10% gravel; one medium root; some white areas; clay with some silt; 5 YR 5/6 (light brown); looser stuff is close to 10YR 4/2
33-42 cm: ~ 10% gravel; some coarse sand; some coarse (2-3 cm) subangular blocky aggregates; mostly loose granules or smaller aggregates; one 7 cm - wide chunk; overall ~ 10YR 4/2

Sleeve Extra
One 7 cm chunk, one 5½ cm chunk; ~ 10% gravel; rest is subangular blocky and granular aggregates; one medium root; fair amount of clay (especially in aggregates and chunks); some sand; more silt; ~10YR 4/2, but grayer

Run 2 (1.22-2.74 m)

Top
0-8 (42-50) cm: slightly darker than 10YR 4/2; one spot of sand (~ 3 cm wide, slightly more yellow than 10YR 5/4 (moderate yellowish brown); clay with some sand
8-31 (50-73) cm: silty clay with little sand; different smell (like GW 1 Run 2 middle); 10YR 2/2 (dusky yellowish brown) to almost black; ribbon formed; some fine mica flakes; around outside: ~ ¼ cm 10YR 4/2 (but slightly browner) clay with sand
31-42 (73-84) cm: more sandy (sand is a little darker than 10YR 5/4); little organic material; layer outside ~ 1-2 mm (same color as layer on 8-31 cm); rest of clay is 10YR 2/2 to black; ribbon formed

Bottom
0-17 (84-101) cm: ribbon formed; closest to 10YR 2/2 (but grayer); clay with some silt, little sand
17-25 (101-109) cm: much sandier; slightly grayer than 10YR 5/4; 10-20% gravel; still clayey; some (grayer than 10YR 2/2) clay
25-44 (109-128) cm: in between 5YR 5/6 (light brown) and 10YR 5/4 (moderate yellowish brown); clay; some black spots
44-46 (128-130) cm: 10 YR 6/6; clay with some black spots
46-49 (130-133) cm: closest to 5Y 5/2 (light olive gray) but a little grayer (less green); clay with black spots
49-51 (133-135) cm: ~10YR 5/4; clay with a couple pieces of gravel

Shoe Sample
10YR 5/4 with slight pinkish tint; clay with some sand

Run 3 (2.74-4.27 m)

Top
0-15 (135-150) cm: wet; 5YR 4/4 (moderate brown); sandy clay with a couple of cobbles; ~10% gravel
15-25 (150-160) cm: wet; ~30% gravel; rest is very sandy clay; 5YR 4/4
25-41(160-176) cm: sandy clay; 5YR 4/4 but a little pinker; <10% gravel

Middle
0-19 (176-195) cm: ~5YR 5/6 (light brown) but a little more yellow; 20-30% gravel; one cobble ~8 cm; rest is fine to coarse sand with some clay
19-21 (195-197) cm: sandy clay (much more clay); ~5YR 6/4 (light brown)

21-41(197-217) cm: gleying (?); clay- good ribbon; trace of 5YR 6/4 clay around outside; mottled: 10Y 6/2 (pale olive) but slightly grayer, and 5Y 5/6 (light olive brown)

Bottom
0-41(217-258) cm: gleying (?); clay- good/decent ribbon; mottling: 10Y 6/2 (pale olive) but slightly grayer, and 5Y 5/6; trace of 5Y 4/4 (moderate brown) clay around outside

Shoe Sample
Clay- good/decent ribbon; mottling: 5Y 5/6 (light olive brown) and 5Y 5/2 (light olive gray); very little organic material

Run 4 (4.27-5.79 m)

Top
0-8 (258-266) cm: mottles: ~5Y 4/4 (moderate olive brown) but a little browner; 5Y 3/2 but grayer, not quite as dark; clay (weathered bedrock); good ribbon
8-27(266-285) cm: clay (weathered bedrock); slightly more mottling; mottles: 5Y 5/6 (light olive brown) but a little browner; overall color mostly 5Y 5/2 (light olive gray); good ribbon
27-41(285-299) cm: clay (weathered bedrock); good ribbon; mottles 5Y 5/6 but a little browner); overall color 5Y 3/2 (olive gray) but grayer
41-51(299-301) cm: clay (weathered bedrock); good ribbon; less mottling (=less weathered?); mottles: 5Y 4/4 (medium olive brown) but a little browner; overall closest to 5Y 3/2 but grayer and a little darker

Middle
0-10 (301-311) cm: clay (weathered bedrock); good ribbon; small amount of fine sand ~10YR 5/4 (moderate yellowish brown); mottles: ~5Y 5/6 (light olive brown); overall color: 5Y 3/2 but a little lighter
10-18½(311-319½) cm: clay (weathered bedrock); good ribbon; between 5Y 5/2 (light olive gray) and 5Y 3/2 (olive gray) but a little browner; mottles: ~5Y5/6; trace of ~10YR 5/4 clay around outside
18½-52(319½-353) cm: 5Y 3/2 but a little lighter and grayer; mottles ~5Y 5/6 but slightly browner; clay (weathered bedrock); good/decent ribbon

Bottom
0-5 (353-358) cm: clay (weathered bedrock); good/decent ribbon; small amount of fine sand (10YR 5/4- moderate yellowish brown) on outside; mottles: 5Y 5/6; between 5Y 5/2 and 5Y 3/2
5-11 (358-364) cm: clay (weathered bedrock); good/decent ribbon; mottles: 5Y 5/6; 5Y 3/2 but a little lighter and grayer
11-31 (364-384) cm: clay (weathered bedrock); slightly more mottling- 5Y 5/6 but browner; 5Y 3/2 but grayer; good/decent ribbon

31-40 (384-393) cm: clay (weathered bedrock); good/decent ribbon; almost no mottling; any mottles are small, 5Y 4/4 (moderate olive brown)- hard to tell because of faintness and size
40-47 (393-400) cm: clay (weathered bedrock); good ribbon; more mottling: 5Y 5/6 but a little browner
47-52 (400-405) cm: almost no mottling; clay (weathered bedrock); good ribbon; any mottles close to 5Y 6/4 (dusky yellow) but hard to tell because of faintness and size; 5Y 3/2 but a little grayer

Shoe Sample
Mottles ~5Y 4/4; 5Y 3/2 but slightly grayer; clay (weathered bedrock); good/decent ribbon

GW 4
Run 1 (0-1.22 m)
Top
0-10 cm: some organic material (few medium roots, few fine roots); closest to 10YR 6/2 (pale yellowish brown); <10% gravel; fine to coarse angular to subangular blocky; silt and clay, not much sand
10-18 cm: massive; 10YR 5/4 (moderate yellowish brown) with some 5YR 6/4 (light brown); slightly more sand (?)
18-33 cm: mostly massive (any aggregates fine, subangular blocky); overall color closest to 10YR 4/2 (dark yellowish brown); other colors: spots of black, white material, a few 10R 6/6 (moderate reddish orange) spots, a couple of slight 5Y 6/4 (dusky yellow) streaks; ~10% gravel (rest is about same composition as 10-18 cm)
33-38½ cm: overall color 10YR 4/2 (dark yellowish brown); 10-20% gravel; silty clay with some sand; a couple of 5 YR 6/4 (light brown) spots, etc.

Middle
0-5 (38½-43½) cm: <10% gravel; 10YR 4/2; silty clay with some sand; mostly fine angular to subangular blocky; some larger chunks (3-5 cm); one 4-cm piece of gravel
5-8 (43½-46½) cm: massive; mostly clay (silty with little sand); 10YR 5/4;
8-17 (46½-55½) cm: dominantly 10R 6/6 (moderate reddish orange); a couple of 10YR 4/2 spots; massive; about same composition as 5-8 cm
17-25 (55½-63½) cm: 10YR 4/2; massive; slightly more clay; silty clay; a couple of 10R 6/6 spots
25-31 (63½-69½): dominantly 10R 6/6 with some 10YR 4/2 (mottling?); massive; slightly more clay; silty clay
31-36 (69½-74½) cm: massive; 10YR 4/2; silty clay; a couple of small white spots

Bottom

0-5 (74½-79½) cm: silty clay; decent ribbon; massive; 10YR 4/2; one medium fine root

5-9 (79½-83½) cm: silty clay; <10% gravel; 5YR 5/6 (light brown) but a little darker and yellower (oxidization), and 10YR 4/2; massive, but partially granular

9-12 (83½-86½) cm: silty clay; <10% gravel; mostly massive but partially granular; 10Y 7/4 (moderate greenish yellow)- gleying, 10R 6/6, 10YR 4/2; good/decent ribbon

12-22 (86½-96½) cm: massive; good/decent ribbon; <10% gravel; between 10R 6/6 and 10R 4/6 (moderate reddish brown), some white spots, a couple of 10Y 7/4 spots, 10YR 4/2 but a little browner, small amount of 10YR 2/2 (dusky yellowish brown)

22-28 (96½-102½) cm: mottling: 5Y 6/4 (dusky yellow) but a little browner, 10YR 4/2; silty clay, but slightly more clay; good ribbon

28-30 (102½-104½) cm: massive; silty clay; good ribbon; 10YR 4/2 but a little lighter and yellower; a few spots of 10R 6/6

30-36 (104½-110½) cm: 10YR 4/2, faint mottles of 5Y 6/4 (but a little browner); massive; silty clay; good ribbon

Shoe Sample

Cobble- brick? (~10R 4/6- moderate reddish brown, but slightly lighter); traces of (brick?);clay; good ribbon; <10% gravel; 10YR 4/2 with small spots of 10YR 6/6 (dark yellowish orange)

Run 2 (1.22-2.74 m)

Top

0-21½ (110½-132) cm: some brick residue, a few chunks (pebbles/cobbles) of brick (10R 4/6); some organic material; 5Y 3/2 but a little lighter and much grayer, some ~5Y 6/4; non-brick material is clay with <u>little</u> silt

21½-27 (132-137½) cm: silty clay with some sand; good ribbon; between 10YR 4/2 and 10YR 2/2

27-41½ (137½-152) cm: ~10YR 2/2; clay; good ribbon

41½-48 (152-158½) cm: ≤10% gravel; ~10YR 2/2; a couple of <u>small</u> 10YR 7/4 (grayish orange), ~10R 6/6 spots

Bottom

0-5 (158½-163½) cm: sandy clay; poor ribbon; 10-20% fine gravel/coarse sand; 10YR 4/2 with some black

5-16 (163½-174½) cm: mostly black with ~½ cm of 10 YR 4/2 around outside; sandy clay (but a little less sand) different smell; poor ribbon

16-22 (174½-180½) cm: sandy clay; dominantly 10YR 4/2 with some black (mottling?)

22-37 (180½-195½) cm: between 10YR 4/2 and 10YR 2/2; mostly clay with little or no silt; good ribbon

37-43 (195½-201½) cm: mostly fine to medium sand with some clay; 10YR 5/4 but slightly grayer

43-47 (201½-205½) cm: still mostly sand, but more clay; damp; <10% gravel; ~ ¼ -½ cm 10YR 4/2 clay around outside; 10YR 6/6 (dark yellowish orange) but a little darker (sandy portion)

Shoe Sample
Wet fine to medium sand with some clay sticking it together; between 10YR 6/6 and 10YR 5/4

Run 3 (2.74-4.27 m)

Top
0-10½ cm: saturated, very clayey fine to medium sand; 10YR 5/4 but a little grayer
10½- 31 cm: 10YR 4/2 but a little lighter; saturated fine to medium sandy clay; one spot 10YR 6/6(dark yellowish orange) but a little more orange
31-36.3 cm: ~10YR 6/6 mostly, but with some of same color from 0-10½ cm and **10½ -31**: saturated fine to medium sand (slightly clayey)
36.3-47 cm: (like 10½ -31); more clay; saturated fine to medium sandy clay; 10YR 4/2 but a little lighter
47-53½ cm: saturated, very clayey sand (finer sand); 10YR 5/4 but a little darker
53½ -58 cm: saturated clayey fine to medium sand (less clay); 10YR 5/4 but a little darker

Middle
0-17½ (58-75½) cm: saturated fine to coarse sand with little clay; ~10% gravel; 10YR 5/4
17½-25 (75½-83) cm: 10YR 6/2 (pale yellow brown) but a little darker; fine to coarse sand, but less of the coarse sand; saturated with almost no clay
25-42½ (83-99½) cm: fine to coarse sand (saturated); 10-20% gravel; almost no clay; ~10YR 5/4
42½-47 (99½-104) cm: moist clay with very little (if any) sand; good ribbon; 5Y 5/6 (light olive brown); weathered bedrock?

Bottom
0-47 (104-151) cm: clay (drier- indurated?); good/decent ribbon; trace of 10YR 5/4 clay around outside; mottling: 5Y 5/6 but a little browner, and ~5Y 5/2 (light olive gray)

Shoe Sample
Similar (same) texture to bottom section; 5Y 5/6 and ~5Y 5/2 (mottling); trace of 5Y 4/4 (moderate brown) clay around outside; mostly large chunks with some smaller pieces/aggregates

Run 4 (4.27-5.79 m)
0-5½ (151-156½) cm: small amount of 5YR 4/4 (moderate brown) clay and fine sand around outside; inside is clay (good ribbon); 5Y 5/2 (light olive gray)

5½-26 (156½-177) cm: more fine sand around outside (2-3mm)- 5YR 4/4; mottled clay (weathered bedrock): 5Y 5/6 but slightly more yellow, and ~5Y 5/2 but very slightly darker and browner; good/decent ribbon
26-43½ (177-194½) cm: same coloring (mottling) as 5½-26 cm; no sand; clay (weathered bedrock); good/decent ribbon (same texture as 5½-26 cm)
43½-56 (194½-205) cm: clay (weathered bedrock) with very slightly more moisture; 5Y 3/2 but slightly darker and grayer, mottled with 5Y 5/6 but browner; *less mottling*

Sleeve Extra
0-5 (205-210) cm: almost no mottling; clay; good/decent ribbon; 5Y 6/4 mottles? Hard to tell because of faintness; ~5Y3/2
5-10 (210-215) cm: mottling- lots: 5Y 5/6 but slightly browner, with ~5Y 3/2; same texture as 0-5 cm

Shoe Sample
Harder clay (slightly less weathered bedrock?); hard to make ribbon (dry); 5Y 6/4; with ~5Y 3/2; 5Y 4/4 on top (lots of spots)

GW 5
Run 1 (0-1.22 m)

Top
0-1 cm: organic material
1-5 cm: dry silty clay; good ribbon formed when damp; massive, but partially very fine granular when crushed (easily crushed); few fine roots; 10YR 6/2 with pinkish tint
5-22 cm: mostly massive with a few fine to medium angular to subangular blocky aggregates; silty clay (dry, less easily crushed); <10% gravel; few white spots; dominantly 5YR 6/4; a couple of 5Y 6/4 spots; some 10YR 6/2 mixed in with 5YR 6/4; one or two fine roots
22-29 cm: one or two fine roots; very fine granular and some fine to medium subangular blocky aggregates; ~10% fine gravel; silty clay; 5YR 6/4 (similar coloring to 5-22 cm)

Bottom
0-7 (22-29) cm: silty clay (lots of clay); massive; a couple pieces of organic material; kind of hard to crush (very firm); 5YR 6/4 with 5Y 6/4 but slightly darker
7-10 (29-32) cm: one large white spot; predominantly 5YR 6/4 (light brown); mostly massive, but some fine granular aggregates
10-18½ (32-40½) cm: silty clay (more clay); mostly massive, with some fine to (a few) coarse angular to subangular blocky aggregates; mostly 10YR 5/4 with a few spots of 10YR 2/2 (mottling?) and 5YR 6/4
18½-25½ (40½-47½) cm: 5Y 6/4 and 5YR 6/4 with a couple spots of ~10YR 2/2; massive; silty clay; hard

25½-32 (47½-54) cm: 10R 4/6 but a little lighter with ~2 cm spot of white and fine muscovite crystals; <5% gravel; silty clay (mostly clay- hard, dry)
32-37 (54-59) cm: ~10YR 4/2 but a little darker; mostly clay with some silt; <10% gravel; some 10R 6/6, a couple of white spots

Shoe Sample
Very little (one or two pieces) organic material; 10YR 4/2 with a few spots of 5Y 5/6; silty clay; some fine granular aggregates; some coarse subangular blocky chunks, one larger chunk

Run 2 (1.22-2.74 m)

Top
0-8½ (59-67½) cm: somewhat moist clay; one or two pieces organic material; good/decent ribbon; 10YR 4/2
8½-13 (67½-72) cm: mostly clay; good ribbon; 10YR 4/2 with a slight pinkish tint
13-31½ (72-90½) cm: black clay, 10YR 4/2 (but a little lighter) clay; a couple of 5YR 5/6 spots; moist- good ribbon
31½-34½ (90½-93½) cm: moist clay; good ribbon; a couple of small gravel pieces; ~10YR 5/4 (moderate yellow brown)
34½-48 (93½-107) cm: moist clay; good ribbon; 10YR 4/2 with a couple of black spots; faint black streak

Bottom (had to dig ~2 cm to get to darker middle)
0-13 (107-120) cm: moist clay; good ribbon; 10YR 6/2 with faint streaks of 10YR 4/2; a couple of small chunks of ~5Y 6/4 (but lighter) rock (gravel)
13-30 (120-137) cm: ~10YR 5/4 with darker middle (10YR 4/2 with some black); moist clay; good ribbon; somewhat defined rim of ½-1 cm 10YR 5/4
30-51 (137-158) cm: moist clay; good ribbon; 10YR 5/4 with streaks of 10YR 4/2 to 10YR 2/2
51-55½ (158-162½) cm: 10YR 5/4 but a little lighter; moist clay; good ribbon; a couple of black spots

Shoe Sample
Clay; gleying (a couple spots of 5GY 7/4- moderate yellowish green mixed with 5G 5/6- moderate green); mostly 10YR 5/4 with a little 5YR 5/6 on same end as green spots; good ribbon; some 10YR 8/2 (very pale orange) spots

Run 3 (2.74-4.27 m)
0-3½ (162½-166) cm: sandy clay; wet; some black and 5YR 5/6, but mostly 10YR 5/4
3½-7 (166-169½) cm: sandy clay, but a little less moisture; 10YR 4/2
7-32½ (169½-195) cm: saturated sand (fine to medium); 10YR 5/4 but a little lighter (between 10YR 5/4 and 10YR 6/6); coarse gravel at bottom (overall <10%)

Shoe Sample
~20% coarse gravel; saturated sand (fine to medium); between 10YR 6/6 and 10YR 5/4)

Run 4 (4.27-5.79 m)

Top
0-27(195-222) cm: damp, fine to medium-coarse sand; overall color predominantly 10YR 5/4

Bottom
0-10½ (222-232½) cm: fine to coarse damp sand; a few small pieces of gravel (≤10%) and a few larger ones (deeper); 10YR 5/4)
10½-24 (232½-246) cm: 10YR 5/4; damp, fine to medium sand (overall finer than 0-10½) with some small pieces of gravel and a couple of larger ones (overall ≤10% gravel); one spot 10R 4/6 but slightly lighter

Bottom .08 m recovery
Clay surrounded by sand and gravel; clay: 5Y 3/2 but a little grayer and darker (slightly weathered bedrock)- 7-7½ cm before broken; good/decent ribbon; ≥20% gravel (fine to very coarse); sand: 10YR 6/6 (moderate yellowish orange)- mostly fine with some medium

Shoe Sample
Clay broken into large chunks; hard to make a ribbon (dry); slightly weathered bedrock; 5Y 3/2 but slightly grayer and darker

GW 6

Run 1 (0-1.22 m)

Top
0-2 cm: organic material
2-18½ cm: massive; silt with clay; a few pieces of small gravel; 10YR 5/4
18½-24 cm: mostly massive with some angular to subangular blocky (fine) aggregates; <10% small gravel; 10YR 5/4 but a little darker
24-35 cm: 10YR 5/4 but a little darker; massive with some broken pieces; silt with clay; one small bug
35-45 cm: massive; silt with clay (slightly more?); one 10YR 8/2 (very pale orange) spot; a few small pieces of gravel

Bottom
0-4 (45-49) cm: silty clay; good/decent ribbon (dry); ~10YR 5/4 and 10YR 4/2 (10YR 4/2 is more clayey); massive
4-11 (49-56) cm: massive; clay; good/decent ribbon; a few small white spots; mostly ~10YR 2/2 with a little 10YR 5/4 (streaks) at the top
11-41 (56-86) cm: some small white spots; massive; clay- very slightly mottled (mostly 5YR 4/4, some 10YR 2/2 at the top); good/decent ribbon

Shoe Sample
Clay; massive; ~5½ cm; a few pieces of organic material at the rounded end; moister; good ribbon; very slightly mottled (5YR 4/4 but slightly lighter)

Run 2 (1.22-2.74 m)
**don't see "alternating black layers" noted in field notes for this run*
0-4 (86-90) cm: a few pieces of medium gravel; clay; massive; good ribbon; 10YR 5/4 but slightly darker
4-13½ (90-99½) cm: clay; massive; 10YR 5/4 but slightly darker with some faint 10YR 4/2 streaks and 10YR 7/4 (grayish orange) but slightly lighter spots; good ribbon
13½-22 (99½-108) cm: clay; massive; good ribbon; streaky: 10YR 5/4 but a little lighter and some faint 10YR 4/2
22-28 (108-114) cm: mostly 10YR 6/6 but slightly darker and browner; faint streaks of ~10YR 5/4; clay; massive; good ribbon
28-44 (114-130) cm: clay; massive; good ribbon; 10YR 6/6 but slightly browner; a few 10YR 2/2 to black spots; a few ~10YR 7/4 spots
44-45 (130-131) cm: sandy (fine) clay with a few <u>small</u> pieces of gravel; ~10YR 6/6

Shoe Sample
Fine sand with some clay; sand sticks when pressed together; a few pieces of gravel; 10YR 5/4 but more yellow

Run 3 (2.74-4.27 m)
Top
0-5 (131-136) cm: wet, slightly clayey fine sand (thin layer of clay on top); closest to 10YR 5/4
5-9 (136-140) cm: 1-2 cm of fine, wet sand on sides (same color as 0-5 cm); black, saturated, very sandy clay in the middle
9-21 (140-152) cm: slightly clayey sand; a couple of black spots; a few (<10%) pieces of coarse sand/fine gravel; ~10YR 5/4; one glob of clay (~5YR 5/6)
21-26 (152-157) cm: ~10YR 5/4, but very slightly darker than 9-21 cm; fine to coarse sand (wet); one or two clay globs (10YR 5/4); a couple of black spots
26-30 (157-161) cm: one large (~4 cm) glob of sandy clay- 5YR 5/6 but a bit lighter; 10-20% gravel; rest is fine to coarse wet sand; ~10YR 5/4
30-36 (161-167) cm: 10-20% gravel; one cobble (6 cm); rest is fine to coarse wet sand- 10YR 5/4

Bottom
0-12½ (167-179½) cm: fine to coarse wet sand with clay and <10% gravel; ~10YR 5/4
12½-32 (179½-199) cm: fine to medium wet sand (overall finer texture than 0-12½ cm); less clay; <10% gravel; ~10YR 5/4

32-35 (199-202) cm: fine to medium wet sand with more clay; one large chunk of gravel (~3 cm); dominantly 5Y 5/6 but slightly browner
35-40½ (202-207½) cm: moist clay; good ribbon; 5Y 4/4 ad 5Y 3/2 (spots)

Shoe Sample
10YR 6/6 but a little more yellow, and 5Y 3/2 (mottling); clay; massive; drier, but still good ribbon

Run 4 (4.27-5.79 m)

Top
0-7½ (207½-215) cm: very fine sand with some clay (thin layer of clay on top); 10YR 6/6 but a little darker
7½-26½ (215-234) cm: mottled clay (same colors as Run 3 shoe, but fewer 10YR 6/6 mottles); moist; good ribbon; fine sand around outside (10YR 6/6 but a little darker)

Middle
0-5 (234-239) cm: ~5Y 5/6 and 5Y 5/2 but a little darker; good ribbon; thin layer (trace) of 10YR 5/4 clay around outside
5-16½ (239-250½) cm: thin layer (trace) of 10YR 5/4 clay around outside with some fine sand; clay (very slightly less moisture); good/decent ribbon; weathered bedrock (less?); 5Y 3/2 but grayer
16½-23½ (250½-257½) cm: mottled clay: 5Y 5/6 and between 5Y 5/2 and 5Y 3/2; slightly moister; good ribbon; same trace clay around outside
23½-27½ (257½-261½) cm: (same as 5-16½ cm)
27½-38 (261½-272) cm: trace clay and fine sand around outside (same color); mottled clay: 5Y 5/6 but darker and browner, and 5Y 3/2 but darker and grayer; good/decent ribbon
38-46 (272-280) cm: trace clay and sand (same color); good ribbon; 5Y 3/2 but grayer and darker; a couple of faint (5Y 5/6) mottles

Bottom (weathered bedrock)
0-16 (280-296) cm: trace 5Y 4/4 clay on outside; mottled clay: 5Y 4/4 but slightly browner, and 5Y 3/2 but darker and grayer; good/decent ribbon
16-46 (296-326) cm: 5Y 6/4 and 5Y 3/2 but darker and grayer (fainter mottling); good/decent ribbon

Shoe Sample
Same coloring (mottling) as 16-46 cm with some small white spots; good/decent ribbon

***Parenthetical depths given are amounts of recovery (w/o shoe samples), not necessarily actual depth in the hole. Most of the time, recovery was less than 1.52 m for each run. Depth values given after each run, such as "Run 1 (0-1.22 m)" are depths from the ground surface.