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GROUNDWATER-STREAM INTERACTIONS AND WATER QUALITY OF FORMER DAM RESERVOIRS IN NORTHEAST, OHIO (105 pp.)

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Over the past decade, dam removals have become increasingly popular, as the water quality and ecological effects of impoundments are recognized and many dams near the end of their life expectancy. However, the hydrological functioning of former reservoirs has not been well documented. This study aims to develop understanding of groundwater-stream interactions and water quality in small, former reservoirs.

In 2009, low head dams (~2 m) were removed from Plum Creek (Kent, Ohio) and Kelsey Creek (Cuyahoga Falls, Ohio). Plum Creek reservoir underwent channel restoration in 2011, while Kelsey Creek reservoir is unrestored and consists of a stream channel flowing through a riparian wetland.

From May 2013 to August 2014, water samples were collected semi-weekly upstream and downstream of the reservoirs for measurement of pH, temperature, specific conductance, oxygen stable isotopes and chloride, nitrate, sulfate and phosphate concentrations. At Kelsey

Creek, 20 piezometers and 3 wells were installed in the stream and riparian areas, for hydraulic and water quality measurements.

Upstream to downstream water quality measurements revealed no evidence of water quality changes as the streams flowed through the former reservoirs. Overall, water quality was higher at Plum Creek, which has a less urbanized watershed. At Kelsey Creek, specific conductance and chloride concentrations were elevated, with the highest concentrations occurring during the late winter months. Nitrate concentrations were also high for most of the year.

At Kelsey Creek, hydraulic conductivity measurements ranged from $\sim 10^{-4}$ to 10^{-8} m/s and the overall geometric mean for the site was determined to be 2.35 x10^{-5} m/s. Sediment samples were found to have a median grain size (d_{50}) of 1.72 mm and were poorly sorted. Groundwater flux per unit cross-sectional area revealed values between 1.32^{-08} m/s to 9.04^{-08} m/s.

Potentiometric surface maps show the groundwater is moving generally in westerly direction, while the surface water is moving north. This suggests that there is a limited potential for stream water quality changes due to interaction with groundwater in the riparian wetlands, but that surface water quality may influence groundwater to the west of the stream.

Wells to the west of Kelsey Creek showed some differences in water quality. The well closest to the stream was most similar to stream water quality and isotopes, while there was a ~64-day lag time for flow to the furthest well, which also was the most dissimilar water quality.

The Kelsey Creek and Plum Creek sites demonstrate that former reservoir reaches cannot mitigate watershed-level influences on water quality, especially in urban stream settings.

Without channel restoration, the former reservoir at Kelsey Creek provides shallow groundwater recharge and interaction with a wetland area. This suggests that small, former reservoirs may have a greater impact on local groundwater quality than on stream water quality.

GROUNDWATER-STREAM INTERACTIONS AND WATER QUALITY OF FORMER DAM RESERVOIRS IN NORTHEAST, OHIO

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by

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CHAPTER 1 - INTRODUCTION

1.1 Motivation for Research

Dam removal is a promising and increasingly popular river restoration technique, particularly for rivers and streams impounded by small dams that no longer fulfill their intended function (Kibler et al, 2011; O'Connor et al, 2015). By 2020, it is calculated that 85% of the 80,000 or more dams listed on the U.S. Army Corps of Engineers National Inventory of Dams (NID) will be at risk for dam failure (Bennett et al, 2013). However, the NID only includes dams that pose any significant threat to human lives or property, and there are nearly 2 million smaller or less threatening dams in the United States (Papanicolaou et al, 2011). There were virtually no dam removals in the US before 1975, but that in each decade since there's been an increasing number of removals, with 147 removals happening between 1986 and 1995, 298 removals happening between 1996 and 2005, and 548 removals between 2006 and 2014 (O'Connor et al, 2015). The number of dam removals are still small compared to the number of dams built, but if current trends continue, one day the number of dams being removed will surpass the number of new dams being built (Papanicolaou et al, 2011).

During the 17th to 20th centuries, dams were constructed along waterways to provide power and irrigation water and to reduce downstream flooding (Graf, 2005). These dams created a trap for sediments and other compounds. Dams decrease a river's slope and increase the channel cross-section area within a reservoir. As a result, the ability of the flow to transport sediment is diminished and many sediments settle out within the reservoir (Van Metre at al., 2004; Peck & Kasper, 2013). Reservoirs typically have an annual loss of water storage capacity of 0.1% to 4% worldwide due to sedimentation (Bennett et al, 2013). Even when dams are no longer in use, or even remembered, their effects on streams and sediments continues. Sediment retention behind thousands of small dams has changed the geomorphology of streams in many eastern U.S. watersheds (Walter and Merritts, 2009). Compared to preindustrial time, it is estimated that sedimentation within small reservoirs has reduced the modern global sediment flux to the world's oceans by 6% (Syvitski et al, 2005).

The accumulation of sediment over the lifetime of a dam can cause concern when a dam is removed. Depending on the accumulated sediment quantity within the reservoir, the size and shape of the reservoir, and how fast the dam is removed, reservoir sediments can change the geomorphic setting left to remain after dam removal (Grant, 2001). With altered geomorphology, it is probable that hydrologic flowpaths and water quality are also affected by dam removal.

The scientific literature provides limited information on hydrology and hydrogeology following dam removals, because most studies performed on dam removals focus on ecology, chemistry, or geomorphic changes (Graf, 1999). With an increasing number of dam removals anticipated in the near future, this present study was motivated by the need to develop an understanding of hydrologic flow paths and water quality in former reservoirs following dam removal.

1.2 Background Information

1.2.1 Responses to Dam Removal

The responses to dam removals are extremely complex, mainly because the combination of history, design, and geomorphic setting of each dam is essentially unique. Small dams and large dam outcomes differ, so it is important to consider the size of the dam when developing restoration goals, designs, monitoring, and management strategies (Poff and Hart, 2002).

Removing a dam from a stream increases the stream gradient within the reservoir and causes reservoir sediment to be eroded and transported downstream (Peck & Kasper, 2013). The geomorphic adjustment to the slope in the reservoir following dam removal is not normally evenly distributed throughout the reservoir. It usually begins with the formation of head cut in the channel, which migrates further upstream and adjusts and widens over time (Stanley & Doyle, 2002).

Channels that are carved into shallow, small dam deposits may quickly reach tough, pre-dam materials and geomorphic conditions with only minor changes relative to pre-dam morphology, while erosion in deeper deposits behind large dams generally takes a longer time and produces more major changes to pre-dam conditions (MacBroom, 2011; Skalak et al, 2011). Upstream responses from the dam removal also depend on variables like grain size, flow, channel geometry, sediment deposition and how the dam was removed (Grant, 2001).

Dam removal has occurred on several streams in northeastern Ohio over the last 15 years. Of the northeastern Ohio removals, the best studied is the 2005 removal of the Munroe Falls Dam on the Cuyahoga River, roughly 2 km northeast of this study's Kelsey Creek site. The removal of this 3.6 m high dam provided the opportunity to assess channel changes and predict impacts for future dam removals (Peck & Kasper, 2013). Munroe Falls reservoir was underlain by Sharon sandstone with deposits of glacial till and outwash sediments, into which the river eroded. Over a five-year study, Peck and Kasper (2013) noted lowered base level and an increase in flow velocity upstream of the former dam site. Immediately after removal the river channel returned to its pre-dam substrate. In the months following removal, dewatering and vegetation of the exposed reservoir sediments continued. Two and a half years after removal, sand bars and gravel-armored beds could be seen upstream, while aggraded meander bend chutes formed downstream. At the end of the five-year study, a sandy deltaic feature accumulated 3.3 km downstream in the reservoir of the next dam (Peck & Kasper, 2013).

In Ohio, dam removal is often precipitated by water quality measurements associated with total maximum daily load (TMDL) programs in streams that do not meet federal or state water quality goals under the federal Clean Water Act (Section 303(d)) (Krieger & Zawiski, 2013). While dam removal is considered a great start for improving stream ecosystems, sometimes channel restorations, like steam designed pools and riffles, and rock armoring are added in an effort to improve chemical and biological outcomes and ensure geomorphic stability. How much restoration is needed to improve the overall success of dam removal outcomes is an active area of research (Richardson et al, 2011). Despite water quality concerns driving some dam removals, in the dam removal research community, little emphasis has been placed on groundwater/surface water interactions and their potential impact on water quality.

1.2.2 Groundwater-Stream Interactions

Many studies indicate groundwater contributions to headwater streams play a very important role in the overall health of the streams (Winter, 2007). The movement of surface water and groundwater is controlled to a large extent by the geomorphology and geology of an area. In addition, climate and precipitation affect the distribution of water to (and removal from) landscapes (Winter, 2007). Local flow systems are the shallowest and most dynamic flow systems; therefore, they have the greatest interchange with surface water. Because of the residence times of water within shallow flow paths and the (bio)geochemical processes that occur in the subsurface, the chemistry of groundwater discharge can be substantially different than surface water (Winter, 2007). Understanding processes occurring near and beneath rivers becomes particularly relevant when making restoration decisions. Knowing if shallow flow paths are close to the surface may help determine if stabilization, drainage, or remediation systems need to be added to the channel or surrounding areas.

The exchange between groundwater and the stream depends on stream stage, groundwater hydraulic head, and connectivity of the stream and groundwater, which results in gaining, losing, flow-through, and/or parallel flow streams (Winter et al., 1998). A gaining stream is one that receives water from groundwater, while a losing stream loses water to the saturated groundwater zone. In a flow-through system the head on one side of the stream bank is higher than the other side of the bank, and parallel flow occurs when no exchange occurs, where stream and groundwater run parallel to each other (Winter et al., 1998). The connectivity is driven by the permeability of the stream and aquifer, the channel position relative to groundwater recharge and the size of the interface area (Krause et al, 2007). Groundwater-stream interactions can be divided into several types: (1) bank storage and release; (2) riparian zone interactions; and (3) hyporheic exchange.

Bank storage and baseflow in streams are important components of groundwater-stream interactions. During baseflow, the amount of groundwater discharged to the stream is directly proportional to the hydraulic gradient toward the stream (Fetter, 2001). However, in a stream that gains groundwater during low flow, in high flow events the stream stage may rise above the groundwater level in the bank and temporarily reverse the normal hydraulic gradient toward the stream. As a result, water will move from the stream to the shallow groundwater, until normal hydraulic head gradients are restored (Hantush,2005). Bank storage can affect water quality by immobilizing dissolved nutrients in sediments during flood events and releasing them from storage gradually (Hantush,2005).

Groundwater-surface water interactions in wetlands and riparian zones play an important role with respect to spatial and temporal availability of both surface water and groundwater in a watershed (Schot & Winter, 2006). The riparian zone (land between upland and stream) connects flow paths between stream and groundwater and is influenced by geological characteristics, like topography, stratigraphy and sediment properties (Vidon & Hill, 2004). Wetlands typically develop in topographically low areas where groundwater and/or surface water collects (Schot & Winter, 2006). The water-table is generally shallow under the riparian zone and becomes deeper under hillslopes (Hayashi & Rosenberry, 2001). Riparian zones and wetlands provide flood control, nutrient retention and removal, erosion control, water quality maintenance, open space, and wildlife habitat (Richardson et al, 2011). Some studies have indicated that riparian areas are highly effective in removing nutrients such as nitrate from shallow groundwater flow paths (Shabaga & Hill, 2010; Stanley & Doyle, 2002). Even though riparian zones are efficient at removing nitrate, uncertainty exist about the relative importance of the two major removal mechanisms: vegetative uptake and denitrification (Hayashi & Rosenberry, 2001).

Like riparian zones, hyporheic zones can be viewed as the mixing zone between stream and groundwater. The hyporheic zone however occurs along the stream length where hydraulic connection to shallow groundwater occurs (Winter et al. 1998). Nutrient and organic matter uptake occur during the exchange between the groundwater and stream water. With the difference in pH, solutes, and materials, new water conditions are formed in the interface area (Bencala, 2000). Hydrochemical changes and supporting hydraulic gradients indicate that the hyporheic zone may be dominated by upwelling or down welling groundwater with parameters such as conductivity, dissolved oxygen, and nitrate varying between upwelling and downwelling zones (Malcolm et al., 2003). The chemical composition of downwelling waters should be similar to surface waters, and upwelling groundwater shows the largest difference in temperature, pH, and conductivity (Fowler and Scarsbrook, 2002).

1.2.3 Indicators of Water Quality and Groundwater-Stream Exchange

Temperature can act as a water flow tracer at the groundwater/surface water interface and is affected by seasonal and diurnal temperature fluctuations. (Anderson, 2005). Temperature of shallow groundwater is very stable relative to stream water and groundwater temperature is close to the average temperature of the ground surface and a few degrees warmer than the annual mean air temperature (Hayashi & Rosenberry, 2001). Seasonally, in-stream temperatures should differ depending on the location's groundwater interactions. In the summer, an upwelling zone should have cooler water input into the streambed (Westhoff et a., 2011). Temperature, when measured in addition to water-level measurements, may be used as a method to estimate groundwater/surface water interactions (Anderson, 2005).

The pH is a measure of the acid-base relationship, or H+ ion, in the stream. The pH levels may be impacted by runoff laden with pollution, acid rain, and other sources. The pH of stream water not influenced by pollution ranges from 6.5 to 8.5, while pH in groundwater usually ranges from 6.0-8.5 (Wilde, 2008). Temperature has an impact on the pH and the H+ ion behavior so seasonal pH mixing of steam water and groundwater maybe easily seen (Barron, 2006).

Dissolved oxygen (DO) measures the quantity of oxygen (in milligrams) dissolved in a liter of water. Dissolved oxygen is one of the most important parameters in water quality; its presence is essential in aquatic ecosystem and the abundance of oxygen controls many biogeochemical processes (Parashor et al., 2007). DO is affected by temperature, pressure, a stream's geomorphology, and biological processes within the stream. As temperature decreases, the saturation amount of DO in streams increases. As pressure increases with weather or elevation changes, the saturation DO increases. The morphology of the stream changes the level of DO, increasing in the riffle zones where there is greater mixing with atmospheric oxygen in the stream. As the depth of water increases with distance from atmospheric water the DO level decreases (Heiskary et, al, 2013).

Electrical conductivity is used as a measured of dissolved solids in a stream or groundwater. As the temperature increases, the conductivity also increases (Wilde, 2008), which is why specific conductance is often reported instead. Specific conductance is electrical conductivity at a reference temperature of 25°C and is measured in micro-Siemens per centimeter (Wilde, 2008). Local geology affects the conductivity. For example, the higher the clay content in the sediments, the higher the conductivity. Groundwater typically has higher conductivity than surface water and conductivity tend to be higher with low flow in the stream, because of the greater influence of groundwater (Cox et al, 2007). Road salt application for deicing exerts a strong influence on conductivity, through the chloride anion. (Corsi et al, 2015). Groundwater contributions to streamflow can elevate chloride concentrations and conductivity even in the spring and summer (Ledford et al, 2016).

Anion concentrations, such as chloride, sulfate, nitrate and fluoride may also contribute to the conductivity of a stream. These anions may be a result of water passing through naturally occurring sources or as a result of urbanization. Chloride is usually a result of road salt application and leaky water pipes, sulfate is usually a result of residential and industrial waste, nitrate is commonly a result of fertilizer application and leaky sewer pipes and fluoride is usually either naturally released or from leaky water pipes. Nitrate have an U.S. EPA Maximum Contaminant Level standard of 10 mg/L (U.S. EPA, 2014). While chloride has a secondary maximum contaminant level (SMCL) recommended by the United States Environmental Protection Agency (U.S. EPA, 2014) of 250 mg/L and even an aquatic ecotoxicity chronic limit of 230 mg/L and an acute limit of 860 mg/L (U.S. EPA, 1988).

1.3 Site Description

This study focuses on two former reservoir sites that are tributaries to the middle Cuyahoga River in northeast Ohio (Figure 1.1). This study area is in the humid continental climate zone. On average Cuyahoga Falls has 127 days of precipitation contributing to an average 39 inches rainfall and 45 inches snowfall. The average high temperature in July are around 28°C and can drop to -5.4°C in January (SterlingsBestPlaces.net, 2014).

Kelsey Creek was dammed to create a 0.6-hectare reservoir used for fishing and recreation. Based off USGS maps the dam was constructed sometime between 1906 and 1953, to be 9 meters wide and 1.5 meters high. Backwaters from the structure extended approximately 120 meters upstream and approximately 56 meters wide (Figure 1.2). In 2009, the City of Cuyahoga Falls removed the dam to eliminate flood waters from breaching the dam crest and running into the Water Works Park across the street (Rebecca McCleary, per comm., 2014). In August 2013, Kelsey Creek underwent a full stream restoration of approximately 1000 feet upstream from the study area. Due to significant bank erosion from the 2009 dam removal, the stream restoration included, pools, riffles, and glides within the stream and riparian vegetation plantings. The focus of this study involves the drained, re-vegetated reservoir each of Kelsey Creek.

The drainage area to the former dam in Kelsey Creek covers about 8.37 km^2 of the city of Cuyahoga Falls. The study area at Kelsey Creek is ~6720 m^2 of the whole 8.37 km^2 watershed (Figure 1.3). The watershed land use is predominantly commercial and residential with approximately 57% urban surface. The former reservoir is now dominated by herbaceous vegetation with a few planted trees.

Plum Creek dam was originally built in 1887 and consisted of an embankment, which Mogadore Road sits on, and a spillway, which was constructed of a concrete base with wooden gates on top. Later it was redesigned with a culvert that ran under a bridge. Backwaters from this dam created a 1.4-hectare reservoir, which extended approximately 475 meters upstream, with an average of 30-meter-wide banks (Figure 1.4). Plum Creek is located roughly 7.5 km east of Kelsey Creek, in the city of Kent. The drainage area to the former Plum Creek reservoir covers about 33.67 km^2. The study area at Plum Creek is ~14, 250 m^2 of the whole 33.67 km^2 watershed (Figure 1.5). Land use in this area is about 38% urban, 11.4% wetland/water, 21% open grassland, and 29.6% forest.

This dam was also removed in 2009 not only to improve water quality, but to eliminate fixing the culvert and headwalls that needed replacement. One main difference between this site and Kelsey Creek is that from 2010 to 2011 Plum Creek underwent a stream restoration that extended 670 meters upstream from the former dam. For my study, this site will help me better gage if stream restorations of a former reservoir improve water quality, compared to the unaltered former reservoir.

The study areas are physiographically situated within the Glaciated Allegheny Plateaus, or more specifically, within the Akron-Canton Interlobate Plateau (ODNR, 2005). The significant formation of these study areas was conducted in the Quaternary glacial deposits of northeast Ohio (ODNR, 2005). The primary lithology of these study areas glacial deposits includes fines with sand and gravel, sand with gravel and fines, till, and till with sand and gravel (ODNR, 2005). The hydrogeologic settings of Plum Creek and Kelsey Creek include a mixture of buried valley, complex, and thin upland aquifers (ODNR, 1994).

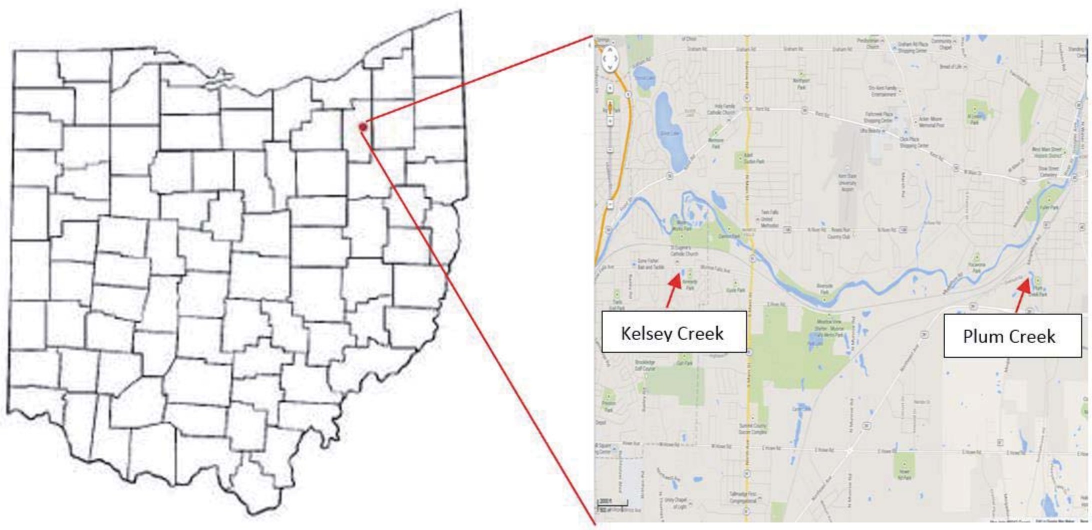

Figure 1.1: Location of Kelsey Creek in Summit County, Ohio and Plum Creek in Portage County, Ohio.

Figure 1.2: Left image is 2006 Google image of Kelsey Creek Reservoir and at right is 2012 Google image of Kelsey Creek.

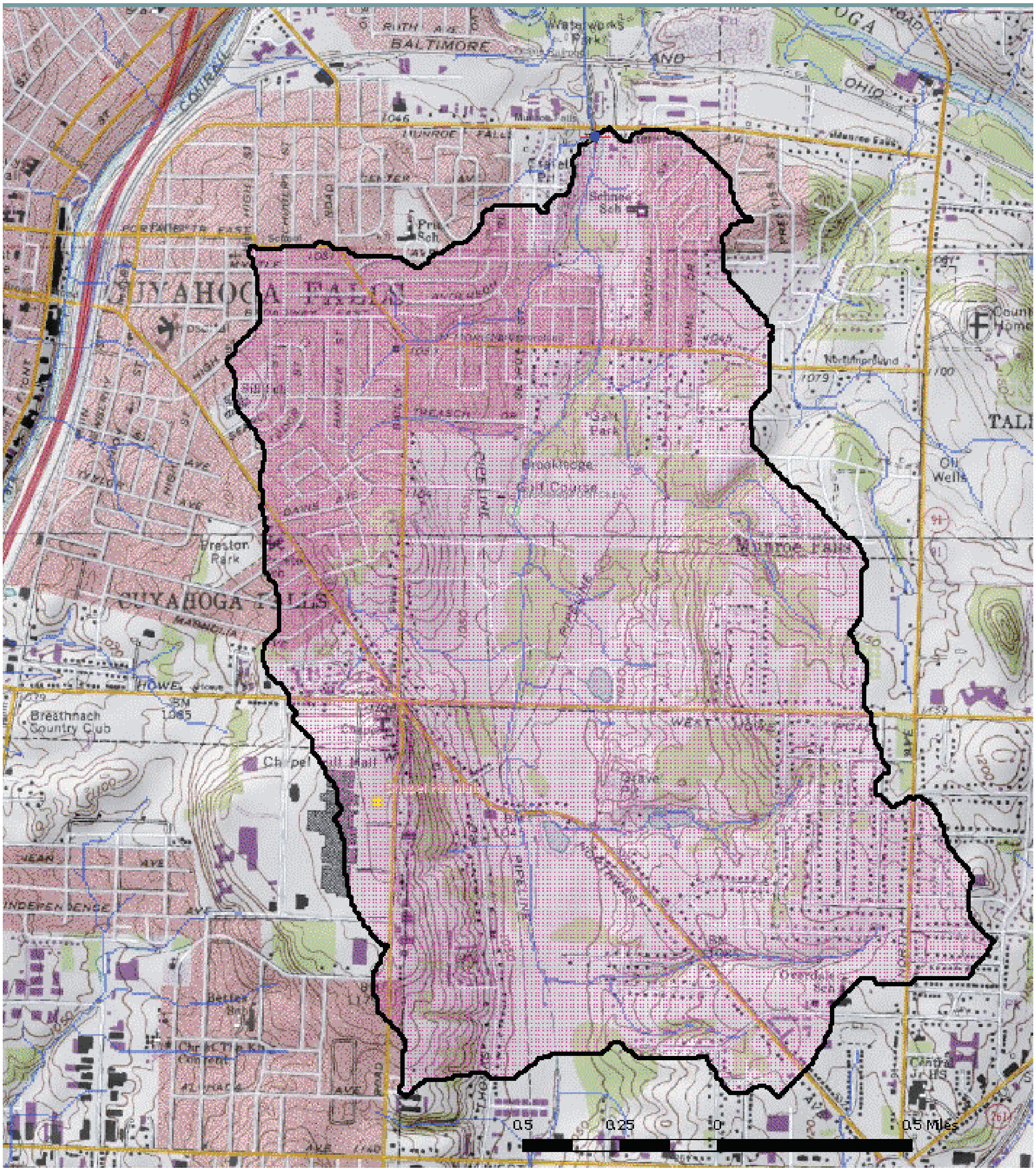

Figure 1.3. Kelsey Creek Watershed. Red star depicts study area and surface water is flowing towards the north Watershed boundary delineated using USGS StreamStats program.

Figure 1.4 Left image is 2006 Google image of Plum Creek Reservoir and at right is 2012 Google image of Plum Creek.

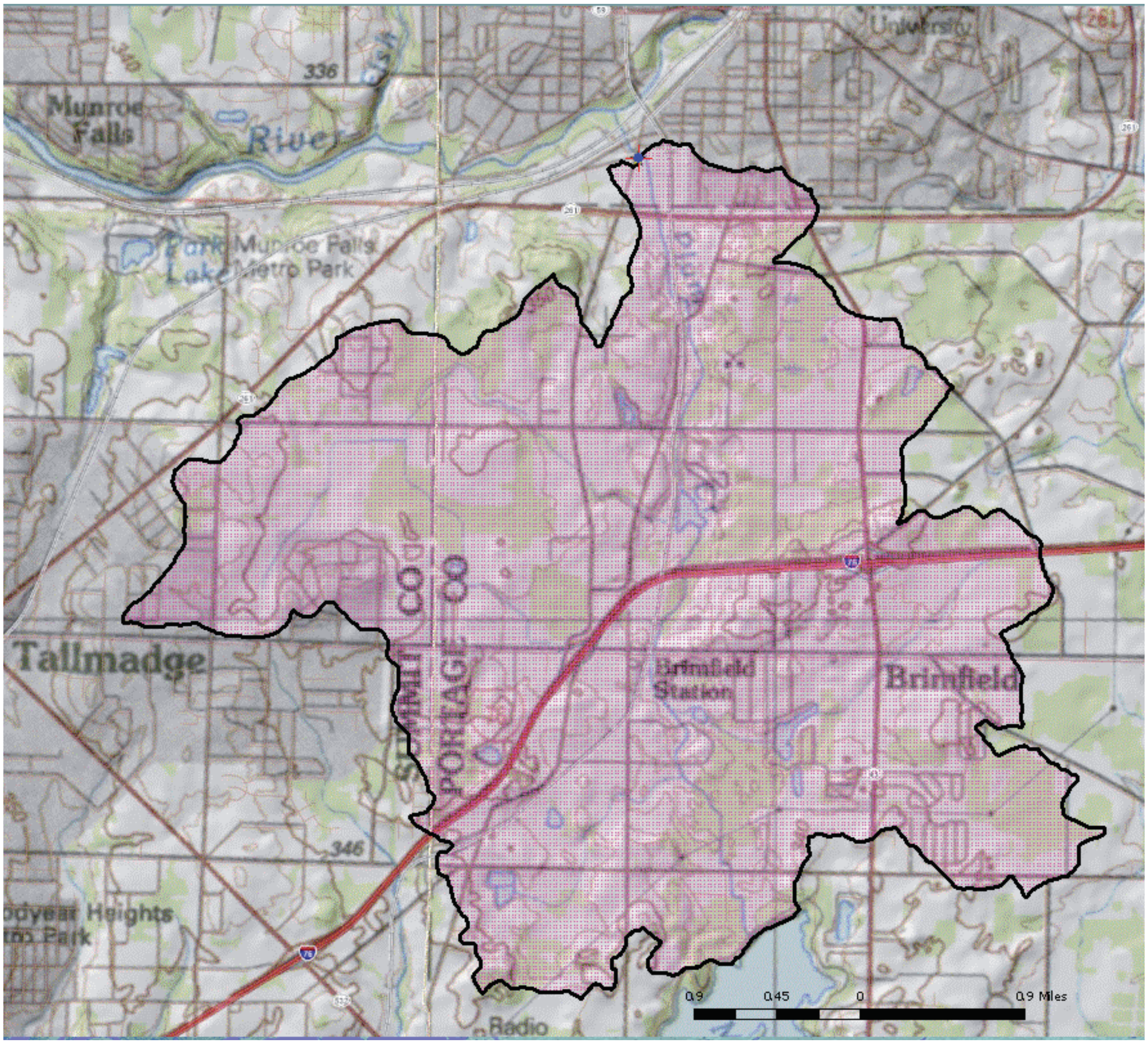

Figure 1.5. Plum Creek Watershed. Red star depicts study area and surface water is flowing towards the North. Watershed boundary delineated using USGS StreamStats program.

1.4 Research Questions and Hypotheses

The study of the hydrology and water chemistry of two former reservoir sites will increase understanding of hydrologic responses to dam removal and provide information for future dam removal restoration projects, particularly where water quality improvement is a goal of the dam removal. The research questions my project seeks to address are:

1. How does stream water quality change as it flows through former reservoirs?
2. Does stream restoration enhance water quality within former reservoirs?
3. How does a stream interact with groundwater in an unrestored former reservoir at Kelsey Creek?

I hypothesized that there will be no change in stream water quality as water flows through the former reservoirs, because the length of the former reservoir reach is small relative to the upstream stream length and drainage area. Consequently, I hypothesized that there is no distinguishable effect of stream restoration on water quality within former reservoirs. Finally, I hypothesized that groundwater contributed to Kelsey Creek from both the east and west sides of the reservoir, based on the broader hydrogeologic setting of the study area.

CHAPTER 2 - RESEARCH METHODOLOGY

This chapter describes field sample collection, monitoring, laboratory methods, and analysis methods. The first section describes stream characteristic measurements and the methods used to obtain water and sediment samples and the last section covers laboratory analyses used to determine sediment size and water quality. Stream water and groundwater were monitored for 11 months and observed for any interactions between groundwater and surface water. Fieldwork began in May 2013 and continued until August 2014.

2.1 Field Methodology

2.1.1 Topographic Survey at Kelsey Creek

On June 22, 2014, along with Akin Land Surveying, I collected 350 data coordinate points using a Lecia® model TCRP 1205 robotic total station and a Leica GS 15 RTC GPS to generate a surface elevation map of the study area. The data points included the upland areas surrounding the former dam, dam buttresses, monitoring well and piezometer locations, geomorphologic features of the former reservoir, and other geomorphic features of the former reservoir (including channel position and lag bars). The Leica System used the ODOT C.O.R.S. as a base station during the collection at Kelsey Creek. The system also maintained 12-15 satellites from the Global Navigation Satellite System (GNSS) receiver that uses the United States' GPS and the Russian GLONASS satellite navigation systems during the surveying day.

This total station has a nominal distance standard deviation of ±2 mm and an angle measurement accuracy is 0.15 mgon. and a direction standard deviation of ±1 arcsecond .

2.1.2 Piezometer and Well Construction, Installation, Development, and Water Level Monitoring

Piezometers were installed in order to monitor water levels of near surface groundwater and stream water and to conduct hydraulic conductivity measurements of the legacy sediments remaining at Kelsey Creek. The measurements were then used to construct a potentiometric map that helped interpret the direction of shallow groundwater movement.

Piezometers were constructed out of 3.81 cm diameter PVC-1120 Schedule 40 pipe. The PVC was cut into sections ranging from 101-183 cm. The bottoms were capped with rounded PVC caps and then screened over a 16 cm interval at the bottom by drilling with a 1.6 mm drill bit spaced 3 cm apart (Figure 2.1) The length of each piezometer was determined by the static water table down the hand augered bore hole, located 30 cm south of each proposed piezometer location (Table 2.1).

Once static water level was determined the piezometers were driven with a post driver 30-45 centimeters into the water table. Stick up for each piezometer is determined based on estimated potential for flooding. Four piezometers were place along the length of the stream and fifteen more were placed along five transects throughout the 6720m² Kelsey Creek reach (Figure 2.2).

Immediately following installation, water was removed from the piezometers and wells by using an Environmental Sampling Peristaltic Pump at a pumping rate of 1 L/min until water was running clear and free of sediment.

Table 2.1: Piezometer dimensions by location

Piezometer	Diameter (cm)	Total Length (cm)	Screened Interval (cm)	Stick Up (cm)
1A	3.81	182.88	16	38.1
1B	3.81	121.92	16	58.42
1C	3.81	162.56	16	54.61
2A	3.81	101.6	16	42.55
2B	3.81	162.56	16	86.36
2C	3.81	121.92	16	81.28
2D	3.81	162.56	16	91.44
3B	3.81	121.92	16	29
3C	3.81	121.92	16	89
3D	3.81	121.92	16	30
3F	3.81	121.92	16	33.5
3E	3.81	121.92	16	30
4A	3.81	101.6	16	40.64
4B	3.81	121.92	16	80.01
4C	3.81	121.92	16	30.48
4D	3.81	121.92	16	75
5A	3.81	152.4	16	63.5
5B	3.81	137.16	16	69.215
5C	3.81	152.4	16	48.26

Table 2.2: Well dimensions by location

Well	Diameter (cm)	Total Length (cm)	Screened Interval (cm)	Stick Up (cm)
A	3.81	304.8	152.8	41
B	3.81	203.2	152.8	37
C	3.81	304.8	152.8	10

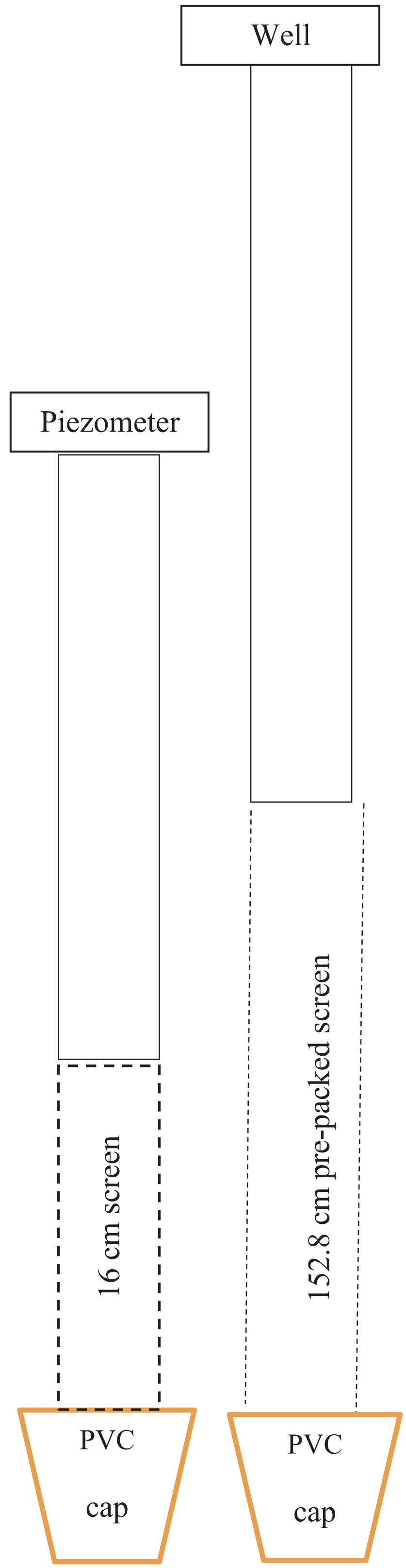

Figure 2.1. Well/Piezometer Construction

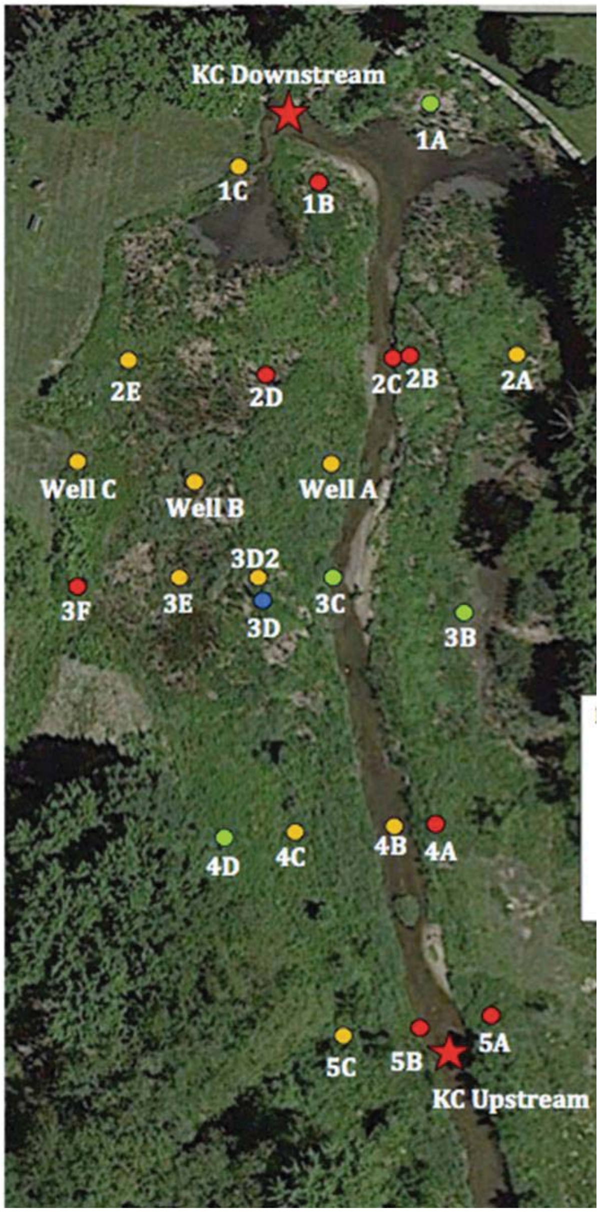

Figure 2.2: Kelsey Creek Piezometer and Monitoring Well Locations. Color dots denote hydraulic conductivity values (discussed in section 3.4.3).

2.1.3 Piezometer Water Level Measurements

Depth to water was measured semi-weekly in fall 2013 to spring 2014 and monthly during the 2014 summer to determine seasonal changes in the potentiometric surface at the site. Depth to water inside the piezometer was measured using a Heron® electrical tape from a notch placed on the north side at the top of each piezometer casing. The water level measurements were accurate to 3 mm. For piezometers in the stream the standing water depth to water outside the piezometer was also measured with the electrical tape on the downstream side of the casing.

Like piezometers, monitoring wells were set up to monitor water levels in the sediments remaining at Kelsey Creek. Well casings and screens were purchased from Environmental Service Products in Irvine, California, where each well screen was constructed from an outer layer of 65 mesh stainless steel screen, sand packed with 20x40 mesh silica sand over 0.25 mm slotted schedule 40 PVC Screen. Each well was screened over a 152.4 cm interval across the water table with 4 cm inner diameter and 6.1 cm outer diameter. Casing for each well was made from Schedule 40 PVC with 4 cm inner diameter and the length was determined based on estimated potential for flooding (Table 2.2).

Three wells were installed through a mid-transect of the former Kelsey Creek reservoir. The first well (well A) was installed in a natural levee adjacent to the active stream channel, the second (well B) in a wetland area, and the third (well C) in the riparian hill slope area (Figure 2.2).

2.1.4 Hydraulic Conductivity Determination

To determine hydraulic conductivity (K), slug tests were performed on March 27, 2014 and July 9, 2014 in the piezometers and analyzed using the partially penetrating condition of the unconfined aquifer solution of the Hvorslev method. This method considered that most of the piezometers only reach the topmost portion of the water-bearing layer (Hvorslev, 1951; Fetter, 2001). Slug test performed in the wells were analyzed using the Bouwer-Rice method for wells with screening in both partially and fully penetrating unconfined aquifers (Fetter, 2001; Bouwer, 1979). In the field, water levels were checked in each piezometer and well with an electrical tape prior to the slug being added. Then a HOBO® U20 Water Level logger (analytical uncertainty 0.3 cm to 0.6 cm) was placed into the piezometer 30 cm below the static water level and left to equilibrate (about 4 minutes). After static water level returned to normal in the piezometer, a slug of one 1L of water was added into the piezometer or well. By adding this known volume of water to the piezometer/well, the instantaneous change in head could be calculated. Water levels at timed intervals (1 second) were recorded by the Hobo as the level fell back toward static water level. After the water level returned to the original static water level, as verified by the electrical tape, I could remove the logger from the piezometer and download the information to the Onset HOBOware Pro 3.4.1 software. In the software program, I corrected for the barometric pressure from an additional logger, which was hung in a tree within the Kelsey Creek reach, which collected data every 5 minutes during the slug testing period. To verify accurate estimations of K, I repeated 30% or 7 slug tests on randomly selected piezometers and wells on September 29, 2014. I then exported the data into Excel where I computed these measurements along with the piezometer dimensions to determine the hydraulic conductivity from each piezometer using the following Hvorslev method equation:

$$K = \frac{r^2 In\,(\frac{L_e}{R})}{2L_e t_{37}}$$

where

K is hydraulic conductivity (m/s)
r is radius of the well casing (m)
R is the radius of the well screen (m)
L_e is the length of the well screen (m)
t_{37} is the time it takes for the water level fall to 37% of the initial change (s)

For each of the wells I calculated hydraulic conductivity using the following Bouwer-Rice method equation:

$$K = \frac{rc^2 In\,(\frac{R_e}{R})}{2L_e}\,\frac{1}{t}\,In(\frac{Ho}{Ht})$$

Where

K is hydraulic conductivity (m/s)
Rc is the radius of the well casing (m)
R is the radius of the gravel envelope (m)
Re is the effective radial distance over which head is dissipated (m)
Le is the length of the screen where water can enter (m)
Ho is the drawdown at time t=0 (m)
Ht is the drawdown at time t=t (m)
t is the time since H=Ho (s)

To better determine the hydraulic conductivity for the whole Kelsey Creek reach and not each single piezometer a harmonic mean was calculated from 31 collected hydraulic conductivity measurements throughout the site. It is assumed that the flow is uniform, and the reach is relatively homogenous but mildly heterogenous along the well. The harmonic mean (H) (Schwartz, 2003) of a set of numbers is given as:

$$\mathrm{H} = \frac{N}{\sum_{i=1}^{N}\frac{1}{Xi}}$$

Where

H is harmonic mean
N is the number of measurements in a sample
X*i* is the individual measurement

2.1.5 Water Sampling and Monitoring Methods

In order to determine if delays occurred between water level changes in the stream and wells, water levels were continuously monitored for a 1-month period. From November 22, 2013 to December 22, 2013 temperature and water level readings of the wells and stream were monitored at 15-minute intervals with HOBO® U20 Water Level loggers. The loggers were also compensated to atmospheric conditions, using an additional baro logger that was hung in a tree adjacent to the site. The loggers were downloaded to the Onset HOBOware Pro 3.4.1 software, where both stream and well auto loggers were corrected using the baro logger as in section 2.1.4. The loggers were secured inside each well casing with zip-ties and rope and in the stream with a PVC pipe drilled with holes and zip-tied to gabion baskets at the underpass of Monroe Falls Avenue. In addition to continuous temperature/water level readings from the loggers, a multiparameter sonde YSI® professional plus meter was used during each of the two site visits to monitor temperature and a Heron® electrical tape was used to measure water levels.

2.1.6 Water Quality Sampling Collection and Monitoring

Water quality samples were collected semi-weekly from fall 2013 through spring 2014 and monthly during summer 2014. At Kelsey Creek, samples were collected from an upstream and downstream site and the three groundwater wells and at an upstream and downstream site from Plum Creek. Water was sampled in-situ with the YSI® for temperature, pH, dissolved oxygen (DO), and specific conductance (SC).

On the same dates, samples were collected in duplicate using a 60 mL syringe, after three rinses with water from the site. A 0.7µm filter with holder was added to the syringe and rinsed with 20 mL of sample water, and the remaining 40mL was filtered into a 50 mL Falcon® tube. Each Falcon® tube was labeled with a site identification, sample collection number, and date of collection then placed on ice until all sites were collected. These samples were then frozen at Kent State University in McGilvrey Hall lab 338 until later analysis.

Temperature, specific conductance, pH, and dissolved oxygen were monitored during each of the 15-site visit with a multiparameter YSI® Professional Plus meter and grab samples. The meter was used to determine temperature (ºC) with a thermistor to +/-0.2ºC accuracy, pH with a glass electrode to +/-0.2 units, DO (% and mg/L) when the difference in potential voltage between the anode and cathode to measure to get the amount of dissolved oxygen to an accuracy of +/- 0.2% YSI reading, and conductivity (µS/cm) was measured by alternating four electrode cells resistant to the effect of polarization to +/-0.5% YSI reading (YSI Incorporated, 2009).

In the streams, the YSI probe was allowed to equilibrate for at least five minutes prior to recording the values. Three well volumes were pumped from each well and the well water was immediately measured to get accurate groundwater readings.

2.1.7 Stable Isotope Collection

Stable Isotope water samples were collected at the same time as the water quality samples under the same methods, but each sample was placed in a 20 mL glass scintillation vial. Each vial was labeled and placed on ice until all site samples were collected. The samples were then placed in the refrigerator in lab 338 in McGilvrey Hall until analysis. The watershed hydrology lab (McGilvrey Hall 333) analyzed my samples within a week of collection using a Picarro L-

2130*i*, with post-processing using van Geldern and Barth (2012). The analytical uncertainty of Picarro in the Watershed Hydrology lab is +/- 0.08% for the oxygen isotope ration ($\delta^{18}O$) and +/- 1.0% for hydrogen isotope ratio ($\delta^{2}H$).

2.1.8 Stream Gauging

On the dates of water level monitoring and water quality sampling, discharge of Kelsey Creek was measured in two locations. A Marsh McBirney 2000 Flo-Mate flow meter (accurate to +/- 2% reading and +/- 0.02 m/s) was used to measure discharge bi-weekly at the upstream site. Discharge was also measured periodically at the downstream site to quantify discharge fluctuations within the reach.

The partial discharge (q_i) for a partial section at a given observation point *i* can be calculated using the following formula: $q_i = v_i(\frac{b_{i+1}-b_{i-1}}{2})d_i$

Where

q_i is the discharge (m^3/s) through a partial section *i*,
v_i is the mean velocity (m/s) at observation point *i*,
$b_{i=}$ is the distance (m) from initial point to observation point *i*,
b_{i-1} is the distance (m) from initial point to proceeding location,
b_{i+1} is the distance (m) from initial point to next location,
d_i is the depth (m) of stream water at location *i*.

Total discharge Q= $\sum_{i=1}^{n} q_i$

The Error equation for the velocity-area method as described by Herschy, 2009 uses the flowing formula: $u(Q) = [Um^2 + Us^2 + (\frac{1}{m})(Ub^2 + Ud^2 + Up^2 + (\frac{1}{n})(Uc^2 + Ue^2))]^{½}$

Where

u (Q) is the relative % combined standard uncertainty in discharge
Um is the % uncertainty of mean velocity, due to limited number of verticals
Us is the relative % uncertainty due to calibration errors

m is the number of verticals used in the gauging
Ub is the uncertainty in width measurements
Ud is the uncertainty in depth measurements
Up is the % uncertainty in mean velocity, due to limited number of points in the vertical
n is the number of depths in the vertical at which velocity measurements are made
Uc is the % uncertainty of the meter rating
Ue is the uncertainty in point velocity due to limited exposure time

2.1.9 Sediment Sampling

Sediments were collected 30 cm south of each piezometer location (Figure 6). Each sample was collected with a 10.2 cm diameter hand auger in 30 to 40 cm depth segments until refusal. Each sediment sample description including depth, color, sediment size and approximate percent of each size was recorded in a field notebook and then collected in a labeled one-gallon plastic bags, where it was stored in a refrigerator until later laboratory sediment analysis.

2.2 Laboratory Methodology and Data Analysis

2.2.1 Anion Concentrations with Ion Chromatography (IC)

Anions of interest for this project were fluoride, chloride, bromide, nitrate, and sulfate and their concentrations were measured using ion chromatography (IC). While phosphate was initially an anion of interest, the detection limit was too high on the Dionex® ion chromatograph to yield detectable phosphate concentrations in the samples. Bromide results are also not reported in this study.

Certified stock solutions were purchased from Thermo Scientific® at 1000 mg/L concentration and were used to make standard solutions. The stock solutions were then mixed and diluted with de-ionized water to create enough for 6 known standard concentrations found in

Table 2.3. These known standards were later used to obtain calibration curves for each ion chromatography run.

Water quality samples that had previously been collected and frozen were thawed and then diluted based on preliminary runs. Out of 190 samples, 29 samples were diluted 2 to 1, 55 samples were diluted 6 to 1, and 106 were diluted 20 to 1 with DI water to make a solution for each sample. The samples were stored in 20 mL tubes then taken to Cunningham Hall lab 117, where the Thermo Scientific® Dionex® ICS-2100 RFIC/EG ion chromatography equipment was housed. The diluted samples were then poured into 5 mL PolyVials, labeled, and closed with a filtered cap. The samples were loaded into the Dionex® AS-DV autosampler in a predetermined order already programmed into the computer before each IC analysis. To determine the concentrations of each sample, the software program Chromeleon® 7 from Thermo Fisher Scientific® was used. The area under each curve and the retention times were compared with the known standard concentrations to analyze the concentrations of the unknown samples. Using the slope of the standard calibration curve, unknown ion concentrations in each sample were calculated from the equation of a straight line (y=mx), with an assumed intercept of 0.

Table 2.3. Six standards and their concentrations used to obtain the calibration curve for each ion chromatography run.

Standard Name	Fluoride Conc. (mg/L)	Bromide Conc. (mg/L)	Chloride Conc. (mg/L)	Nitrate Conc. (mg/L)	Sulfate Conc. (mg/L)
Standard 1	0.05	0.05	0.2	0.2	0.2
Standard 2	0.5	0.5	2	2	2
Standard 3	2	2	8	8	8
Standard 4	4	4	12	12.01	12
Standard 5	5	5	20	20.01	20
Standard 6	0	0	50	0	0

2.2.2 Topography Mapping with AutoCAD®

After land surveying at Kelsey Creek, data points were taken back to the office of Akins Land Surveying, in Alliance, Ohio where we used AutoCAD with Carlson Survey 2014 with Embedded AutoCAD to construct a map with topography and geographical features (bridge, trees, and high wall) from the points collected. Piezometer and well, as well as, north and south points were connected at each transect to project cross sections through-out the reach. The contour intervals are 1 foot. The boundaries for the map created in AutoCAD were Munroe Falls Ave. to the north, piezometer transect 5 to the south, a paved walking trail to the west, and the boundary of former reservoir to the east, adjacent to the City of Cuyahoga Falls Water Treatment Plant.

2.2.3 Topography and Potentiometric Surface Mapping with Surfer 10®

A topography map was created using well and piezometer ground elevations (meters) and again the x-axis coordinates are given in easting (feet) and the y-axis coordinates are given in northings (feet) in the Ohio State Plane coordinate system. The contour interval is 0.05 meters. The topographic map created in Surfer used the wells and piezometers as the boundaries of the map. Topographical cross-sections were also created through six east-west transects that corresponded to transects 1-5 with one additional south of transect 5 and through one north-south transect. The x-axis coordinates are instrument stationing (feet) and the y-axis coordinates are given in the elevation (feet). The contour interval is 1 foot, so fine detail is not represented.

Potentiometric surface (water table) maps were created of the Kelsey Creek study area using Surfer 10®. Static water levels determined from the wells and piezometers within the reach were used to create a map from each of the 14 water level collection dates. The contour interval was set at 0.05 m. The x-axis coordinates are given in easting (feet) and the y-axis coordinates are given in northings (feet). For both the topographic and the potentiometric surface maps the spreadsheet with the x, y, and z coordinates were created into a data report, under the grid pull down tab. The data report was then saved and later used to plot a new contour map, under map tab. Once the contour map was created a post map of the wells and piezometers was overlaid. The groundwater flowline directions were then interpreted by me.

2.2.4 Sediment Size Measurements

Sediment samples were taken from the labeled gallon bags and placed into aluminum pie plates where they were placed into laboratory ovens to dry at 60 ºC for 48 hours. Once dry and left to cool, samples were placed into new plastic gallon bags and disaggregated with a rubber mallet. Sediments were later split with a Humboldt, small, riffle-type sample splitter to yield a random 250-300 mL subsample.

The sediment subsamples were then passed through a laser particle-size analyzer known as the Retch Camsizer. Each sample was poured into a funnel that drops the sediment onto a vibrating horizontal chute. Sediments then fell over the end of the channel between a light source and 2 digital full-frame CCD cameras. The wide-angle camera registers and analyses large sediment grains and the zoom camera analyses small sediment grains. The digital images were processed in real time at 60 frames per second with high precision obtained between 30µm to 30mm. Data obtained from the Camsizer was used to determine grain size distribution, median grain size (d_{50}), and sorting coefficients of grain size distribution (Retch Technology, 2005).

2.2.5 Loss on Ignition (LOI)

Loss on Ignition (LOI) is a commonly used method to determine the organic matter within a sediment sample. A randomly subsampled portion of dried sediment, produced by splitting as above, was used for LOI analysis. I followed the Loss on Ignition standard operating procedures from the LacCore, National Lacustrine Core Facility at the University of Minnesota (LacCore, 2013). I weighed an empty crucible and recorded its weight and number in my lab notebook. Using a spatula, approximately 5 to 8 g was added to the crucible and reweighted and recorded. This was repeated for 14 more crucibles. The 15 samples were then placed into a muffle furnace for 4 hours at 550ºC. The samples were then cooled, reweighed, and recorded. The final weight subtracted for the initial weight yields an estimate of the total organic matter with each sample. The total organic matter content divided by the initial weigh of sediment yields the percent total organic matter.

CHAPTER 3 - DATA PRESENTATION AND RESULTS

3.1 Water Quality

Water temperature, pH, specific conductance, dissolved oxygen, chloride, fluoride, sulfate, and nitrate were examined using biweekly monitoring in wells and in the stream from September 2013 to August 2014. These parameters were used to examine the variations between upstream and downstream surface water quality at Kelsey Creek and Plum Creek, and they were also used to examine patterns of groundwater-surface water interaction at Kelsey Creek. Table 3.1 provides abbreviations for the following tables and figures.

Table 3.1. Abbreviations for the following tables and figures

Abbreviation	Meaning
KC	Kelsey Creek
PC	Plum Creek
DS	Downstream
US	Upstream
DF	Degrees of Freedom

3.1.1 Discharge Measurements

Discharge at Kelsey Creek ranged from 0.005 to 0.183 m^3/s on the dates monitored (Figure 3.1). The highest measured discharge was on May 16, 2014 (0.183 m^3/s) following a 10.47 cm rain event that started on May 13, 2014. The dates that have the lowest flow rates

(~0.006 m^3/s) are on September 26, 2013, October 9, 2013, and August 26, 2014. On dates that discharge was measured both upstream and downstream at Kelsey Creek, I found measurements that differed by 0.11% to 29.67% (Table 3.2), with no consistent pattern of gaining or losing discharge in the downstream direction.

When the Kelsey Creek discharge values were plotted with daily discharge measurements in the Cuyahoga River at Old Portage, we can see that they follow a similar trend in low and peak discharge (Figure 3.1). More prolonged recessions following peaks occur December 25, 2013 through March 28, 2014, maybe due to colder conditions and snowfall/melt. Since the Kelsey Creek discharge values are discrete and the Cuyahoga River discharge values are continuous it is hard to perfectly align them. Similar to Kelsey Creek peak discharge on May 16, 2014, the Cuyahoga River shows a peak discharge on May 13, 2014 of 155.65 m^3/s, and flow had receded to 47.54 m^3/s on May 16, 2014. The May 13, 2014 discharge was the highest recorded in the study period. It is likely that the peak flow in Kelsey Creek was missed, and that the May 13, 2014 event was the largest in Kelsey Creek as well.

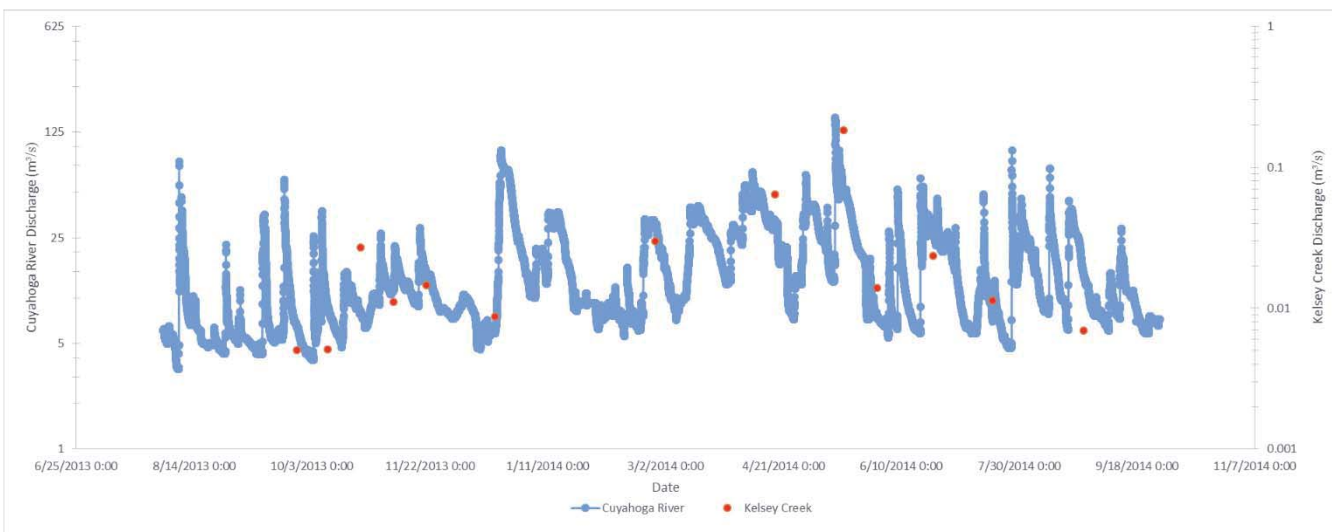

Figure 3.1. Discharge measurements over the study period (9/26/13- 8/26/14) for Kelsey Creek and the Cuyahoga River 0.60 km downstream from Kelsey Creek. Cuyahoga River discharge is from the USGS gage 04206000 at Old Portage, Ohio. Note the different scales on the two y axes.

Table 3.2. Kelsey Creek discharge with percent differences
and percent error based on Herschy (2009). Note the negative (-) differences
represent a losing stream, while positive differences are consistent with a gaining stream.

Date	Upstream Q (m^3/s)	Downstream Q (m^3/s)	Difference (%)	Error (%)
9.26.13	0.005	n/a	n/a	6
10.10.13	0.005	n/a	n/a	6
10.23.13	0.027	n/a	n/a	6
11.06.13	0.013	0.013	0	6
11.20.13	0.015	n/a	n/a	6
12.07.13	0.034	0.027	-20.59	5.5
12.19.13	0.004	n/a	n/a	6
2.25.14	0.031	0.044	29.55	6
4.17.14	0.066	0.084	21.43	5.5
5.16.14	0.183	0.138	-24.59	4.5
5.30.14	0.023	0.022	-4.35	6
6.23.14	0.026	0.027	3.71	4.5
7.18.14	0.011	n/a	n/a	4.5
8.26.14	0.007	n/a	n/a	4

3.1.2 Temperature

The stream and groundwater temperatures showed strong seasonal patterns (Figure 3.2.A and 3.2.B). From October 2013 to late March 2014, groundwater temperatures at Kelsey Creek were warmer than the stream water. In April 2014, the stream water became warmer than the groundwater. The coldest mean daily water temperature for both the stream and groundwater occurred in late February and ranged from 0-4°C, with the warmest daily water temperature in streams occurring in late June at 23.4°C and in groundwater late August at 17°C. The range of temperatures across all sites is <5ºC from fall to spring and increases during the summer months to about 9ºC. The mean temperature during this study was 12.1°C (n=13) for Kelsey Creek stream water and 11.1°C (n=13) for groundwater. Kelsey Creek had similar upstream-downstream temperatures most of the time, but on some dates (February 25, May 30, June 23, and July 18, 2014) showed an increased temperature of about 1ºC downstream compared to upstream. At Plum Creek, the stream water showed no differences between the upstream and downstream sites. The mean temperature for Plum Creek during this study was 11.1°C (n=13) (Figure 3.2).

Paired-samples t-tests were conducted to determine if differences exist between temperatures at upstream and downstream sites at Kelsey Creek and Plum Creek, between Kelsey Creek downstream site and Well A, B and C, and between Kelsey Creek and Plum Creek upstream sites and downstream sites (Table 3.3). Even though I found no physically significant differences (defined as two times the analytical uncertainty of the instrument, +/- 0.2°C) in water temperature at Plum Creek, there was a statistically significant difference in the water temperatures between Plum Creek upstream and Plum Creek downstream ($p = 0.01$). None of the other pairs exhibited significant differences ($p > 0.05$). A one-way ANOVA also found no significant difference in the temperature of surface water and groundwater at Kelsey Creek for the four sites [$F (3, 48) = 0.15$, $p = 0.93$] (Table 3.4).

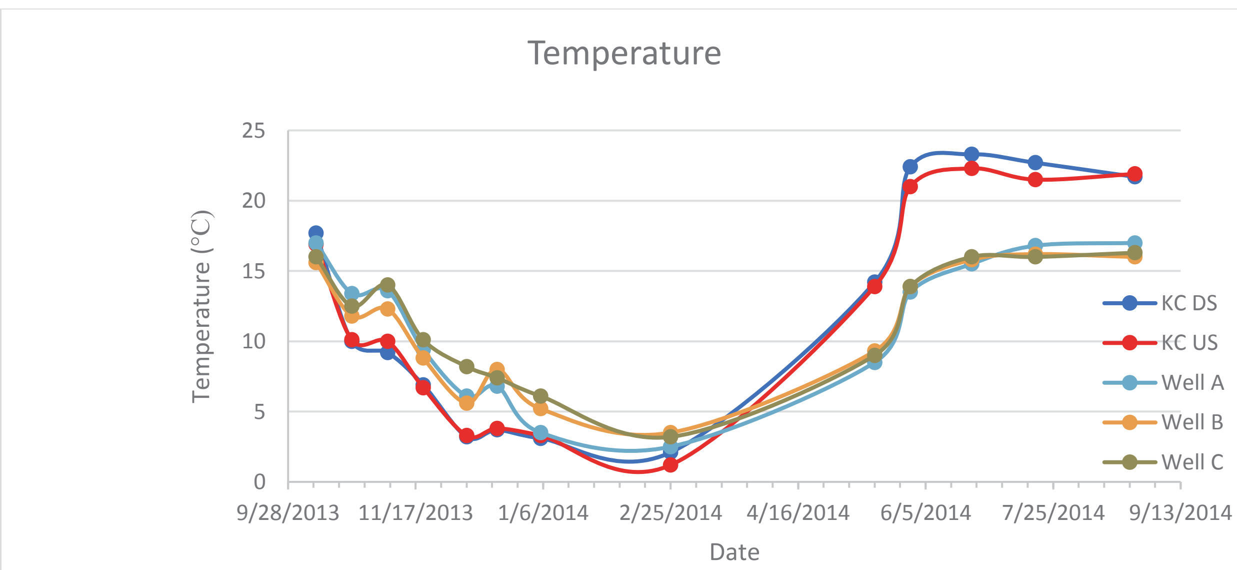

Figure 3.2.A Seasonal patterns of temperature at Kelsey Creek and Kelsey Creek wells, with location abbreviations following Table 3.1. Instrument error bar is smaller than symbol size.

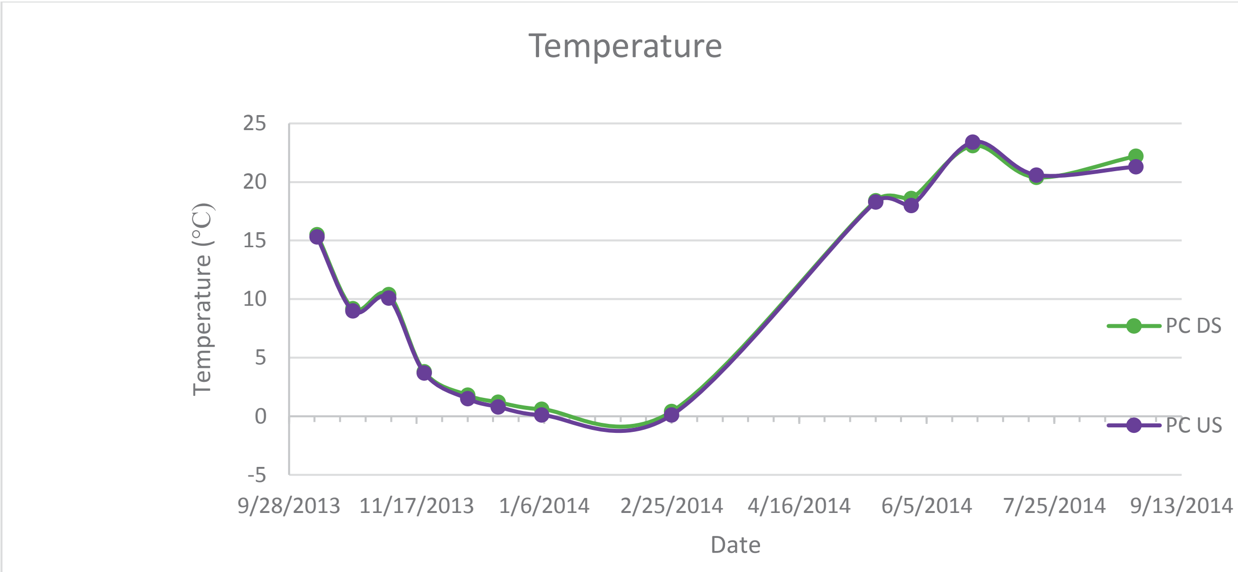

Figure 3.2.B Seasonal patterns of temperature at Plum Creek, with location abbreviations following Table 3.1. Instrument error bar is smaller than symbol size.

3.1.3 pH

The pH values at Kelsey Creek varied and ranged from 7.56 to 8.76 for stream water and 6.29 to 8.84 for groundwater (Figure 3.3.A). The pH values for groundwater gradually increased from December to May and peaked in mid-June, when pH in the stream was also elevated. As reported in Table 3, there was a statistically significant difference in pH from upstream to downstream water at Kelsey Creek ($p = 0.03$) and between Kelsey Creek downstream and all wells ($p = <0.0005$). However, the difference between upstream and downstream water is unlikely to be physically significant because the pH difference p-value falls within two times the uncertainty of the instrument (pH = +/- 0.2). As Table 3.3 shows, Well A has pH that is neither similar to stream water nor to the other wells, whereas Wells B and C are not significantly different ($p = 0.22$). A one-way ANOVA was also conducted to compare pH across surface water and groundwater at Kelsey Creek, and a significant difference across sites was observed [F (3, 48) = 23.59, p = <.0001] (Table 3.4).

The pH range of Plum Creek was 6.96 to 8.18, which is lower than the overall pH at Kelsey Creek (Figure 3.3.B). Unlike Kelsey Creek, Plum Creek exhibited pH differences of 0.36 to 1.0 between its upstream and downstream sites. On a majority of the dates, the upstream site had higher pH values compared to downstream, except during May to July, when pH values were higher at the downstream site. Overall, there was no statistically significant difference in pH between upstream and downstream sites at Plum Creek (p = 0.39).

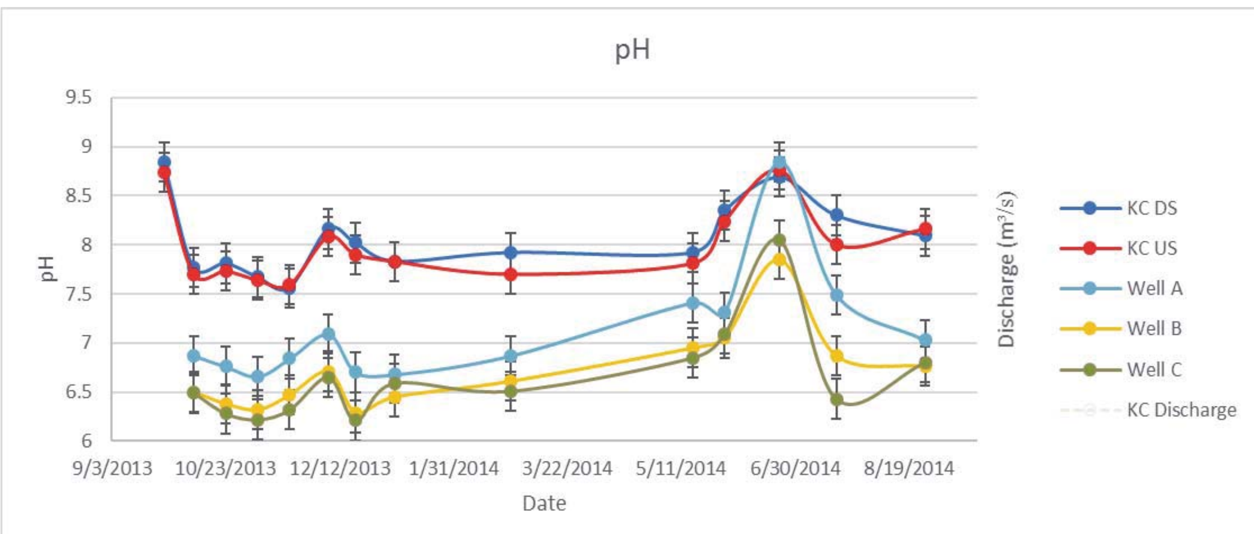

Figure 3.3.A Seasonal pH patterns at Kelsey Creek and Kelsey Creek wells. See Table 3.1 for abbreviations.

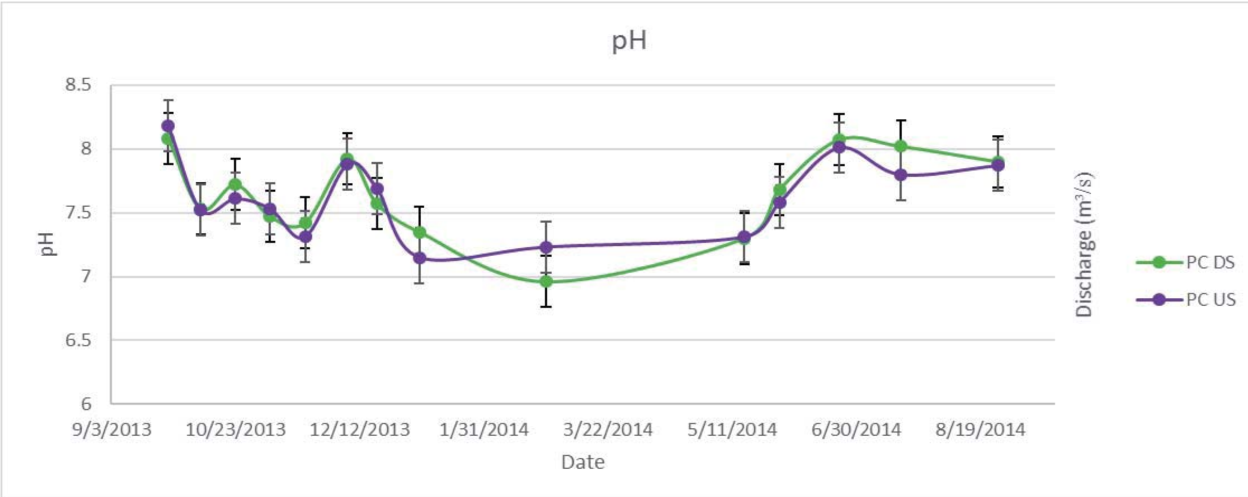

Figure 3.3.B Seasonal pH patterns at Plum Creek. See Table 3.1 for abbreviations.

3.1.4 Specific Conductance

Specific conductance was one of the most interesting parameters to look at, because the values were very high throughout the whole reach at Kelsey Creek. Specific conductance showed distinct seasonal patterns that varied between the streams and groundwater (Figure 3.4.A). The stream water specific conductance at Kelsey Creek ranged from 450 µS/cm to 2665 µS/cm. Specific conductance peaked in mid-December, when the sites were likely exposed to runoff affected by winter road salt. From December 19, 2013 to May 5, 2014 the downstream site had a 17.4% higher specific conductance on average then the upstream site, possibly due to the parking lot salt runoff from the west side of the former reservoir.

Groundwater at Kelsey Creek displayed similarly high specific conductance that ranged from 152 µS/cm to 1976 µS/cm (Figure 3.4.A). Each groundwater well exhibited different patterns of specific conductance throughout the study period. Wells A and B had peaks in mid-fall and winter at around 1800 µS/cm, with a lower conductance period between the peaks. In November 2013, well B dropped to 234 µS/cm before rising back to 1800 µS/cm, and during the same time in November well C peaked at 1976 µS/cm. Well A follows a seasonal pattern of the stream more than the other well, with its highest specific conductance on December 19, 2013, the same data as the streams. In August 2014, the stream water specific conductance was higher at ~740 μS/cm compared to the groundwater at 179.5 μS/cm, which is the lowest specific conductance recorded for groundwater over the study period. At the end of August 2014, groundwater had a lower range of 179.5 μS/cm to 456.9 μS/cm compared to the beginning of the previous water year in October, which ranged 716 μS/cm to 1144 μS/cm. Stream water specific conductance on the other hand in August 2014 is lower compared to most dates, at 752 μS/cm, but still higher than the 477 μS/cm on October 9, 2013.

Paired-samples t-test were also conducted to determine if any differences existed between upstream and downstream sites at Kelsey Creek and Wells A, B and C (Table 3.3). No pairs exhibited statistically significant differences, but physically significant differences exist. The wells and stream are behaving differently at different times. Sometimes when the stream has high specific conductance, the wells are low and vice versa, so it seems that the differences cancel each other out statistically. Comparing measured discharges at Kelsey Creek with specific conductance in the stream, there appears to be an inverse relationship between the two parameters (Figure 3.4). During the winter when the mean discharge is low (0.01 m^3/s), the specific conductance is high (750-2265 μS/cm) and follows the trend of discharge measurements. Similarly, when the mean discharge was higher in the summer (0.18 m^3/s at Kelsey Creek), the specific conductance at Kelsey Creek was at a lower range following the event (254-1500 μS/cm).

The specific conductance in stream water at Plum Creek ranged from 211 to 1072 μS/cm (Figure 3.4.B). As Table 3.3 shows, there were significant differences in specific conductance between Plum Creek and Kelsey Creek (upstream: $p = 0.0011$; downstream: $p = 0.0008$). Over the period of study, there was no difference in specific conductance from the upstream site to the downstream sites at either stream (Kelsey Creek p=0.11 and Plum Creek p= 0.89). Specific conductance due to winter road salt is lower at Plum Creek, potentially due to a smaller urbanized watershed. Additionally, reduced salt loading in the winter could also help explain why specific conductance was lower in the summer. A one-way ANOVA was also conducted to compare specific conductance across surface water and groundwater at Kelsey Creek, and no significant difference across sites was observed [F (3, 48) = 0.4219, p=0.7381] (Table 3.4).

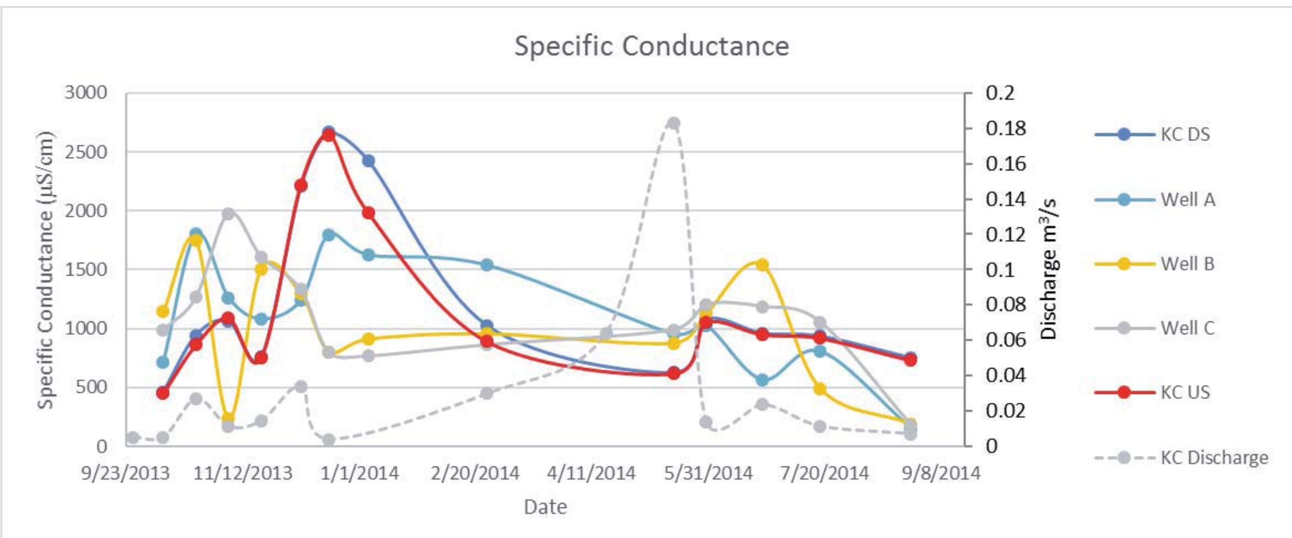

Figure 3.4.A Seasonal specific conductance at Kelsey Creek and Kelsey Creek well, with location abbreviations on Table 3.1.

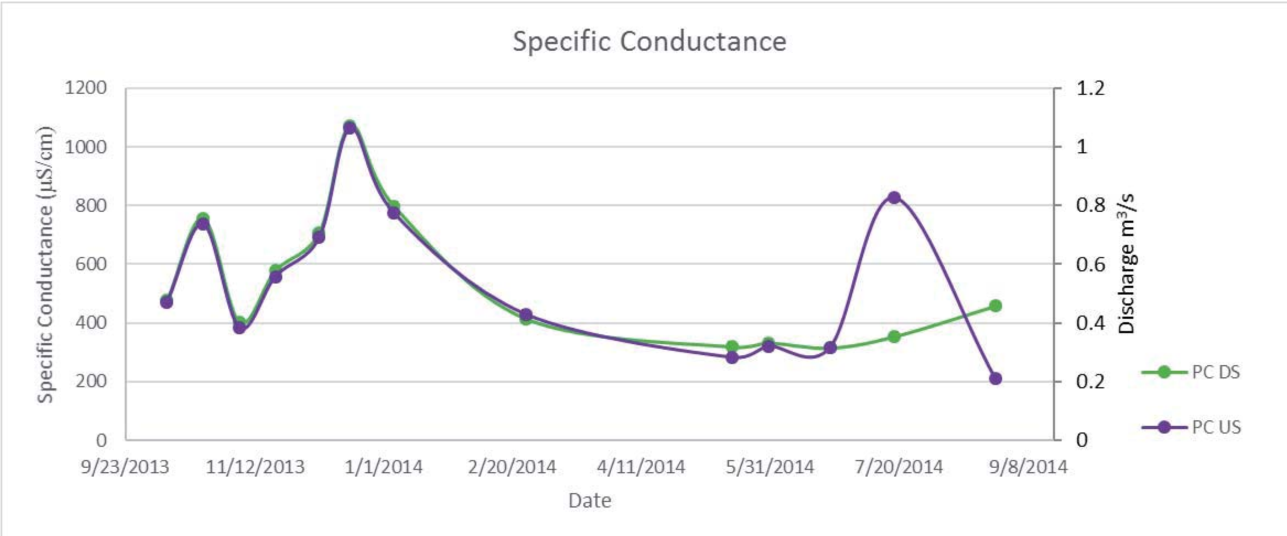

Figure 3.4.B Seasonal specific conductance at Plum Creek, with location abbreviations on Table 3.1.

3.1.5 Dissolved Oxygen

The dissolved oxygen (DO) at Kelsey Creek ranged from 1-20% of saturation for groundwater wells A, B, and C, with one high value in well C of 62.7% oxygenated water on January 5, 2014 (Figure 3.5). This high value may be due to equipment or field errors or water that has rapidly moved from the surface to well C. These values show that during most of the study period the groundwater conditions were oxygen depleted (hypoxic or anoxic). Surface water at both Kelsey Creek and Plum Creek ranged from 75-140% of saturation at both upstream and downstream sites, showing oxic conditions persisted throughout the study period. In this study, dissolved oxygen values have large uncertainty bands because of difficulty maintaining equipment calibration and changing environmental conditions within each day. However, even with large uncertainty around the measurements, the differences between stream and groundwater environments are clear. Due to the uncertainty associated with these measurements, no statistical comparisons are reported.

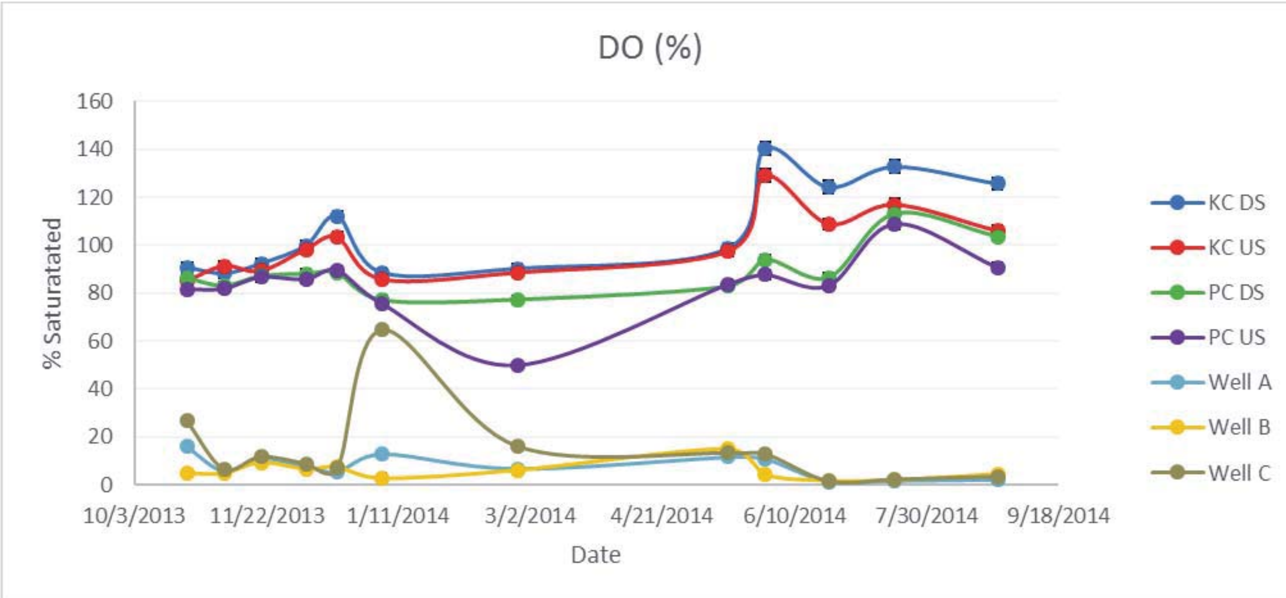

Figure 3.5. Percent dissolved oxygen at Kelsey Creek, Plum Creek, and Kelsey Creek wells, with locations following Table 3.1 abbreviation. Instrument error bars are smaller than symbol size, but the calibration is highly uncertain.

Table 3.3: Paired t-test by date for all in-situ water parameter measurements at each study sites from September 2013-August 2014. Significant test at levels α = 0.05 are in red cells. Use Table 3.1 for site abbreviations.

Variable 1	Mean 1	Standard Deviation	Variable 2	Mean 2	Standard Deviation	Parameter	Test type	p-value	t-value	DF	Uncertainty
KC DS	12.3	8.4	KC US	12	8	Temp	t-test	0.098	1.79	12	0.2
PC DS	11.2	9	PC US	10.9	9	Temp	t-test	0.011	2.99	12	0.2
PC US	10.9	9	KC US	12	8	Temp	t-test	0.095	-1.81	12	0.2
PC DS	11.2	8.9	KC DS	12.3	8.3	Temp	t-test	0.083	-1.89	12	0.2
KC DS	12.3	8.4	Well A	11	5.2	Temp	t-test	0.346	0.98	12	0.2
KC DS	12.3	8.4	Well B	10.9	4.5	Temp	t-test	0.293	-1.1	12	0.2
KC DS	12.3	8.4	Well C	11.4	4.4	Temp	t-test	0.541	0.63	12	0.2
Well A	11	5.2	Well B	10.9	4.5	Temp	t-test	0.691	-0.41	12	0.2
Well A	11	5.2	Well C	11.4	4.4	Temp	t-test	0.219	-1.3	12	0.2
Well B	10.9	4.5	Well C	11.4	4.4	Temp	t-test	0.065	2.02	12	0.2
KC DS	8	0.31	KC US	7.93	0.32	pH	t-test	0.03	2.47	12	0.2
PC DS	7.61	0.32	PC US	7.58	0.59	pH	t-test	0.392	0.89	12	0.2
PC US	7.58	0.27	KC US	7.93	0.32	pH	t-test	<.0001	-5.7	12	0.2
PC DS	7.61	0.32	KC DS	8	0.31	pH	t-test	1E-04	-5.54	12	0.2
KC DS	8	0.31	Well A	7.12	0.59	pH	t-test	<.0001	8.6	12	0.2
KC DS	8	0.31	Well B	6.71	0.42	pH	t-test	<.0001	-20.65	12	0.2
KC DS	8	0.31	Well C	6.65	0.49	pH	t-test	<.0001	-15.59	12	0.2
Well A	7.12	0.59	Well B	6.71	0.42	pH	t-test	<.0001	-7.33	12	0.2
Well A	7.12	0.59	Well C	6.65	0.49	pH	t-test	<.0001	-6.73	12	0.2
Well B	6.71	0.42	Well C	6.65	0.49	pH	t-test	0.223	-1.29	12	0.2
KC DS	1224.2	717.5	KC US	1165.3	672.7	S.Conductance	t-test	0.113	-1.71	12	0.50%
PC DS	537.2	232.4	PC US	543.1	255.7	S.Conductance	t-test	0.892	0.14	12	0.50%
PC US	543.1	255.7	KC US	1165.3	672.7	S.Conductance	t-test	0.001	-4.25	12	0.50%
PC DS	537.2	232.4	KC DS	1224.2	717.5	S.Conductance	t-test	8E-04	-4.47	12	0.50%
KC DS	1224.2	717.5	Well A	1119.9	494.2	S.Conductance	t-test	0.529	-0.65	12	0.50%
KC DS	1224.2	717.5	Well B	985.9	483.4	S.Conductance	t-test	0.344	0.98	12	0.50%
KC DS	1224.2	717.5	Well C	1092.9	434.1	S.Conductance	t-test	0.601	0.54	12	0.50%
Well A	1119.9	494.2	Well B	985.9	483.4	S.Conductance	t-test	0.425	-0.826	12	0.50%
Well B	985.9	483.4	Well C	1092.9	434.1	S.Conductance	t-test	0.498	0.699	12	0.50%
Well A	1119.9	494.2	Well C	1092.9	434.1	S.Conductance	t-test	0.866	-0.172	12	0.50%

Table 3.4. One-way ANOVA between surface and groundwater at Kelsey Creek upstream, downstream and Wells A, B, and C sites. Significant test at levels α = 0.05 are in red cells

Parameter	**Test Type**	**p value**	**F value**	**DF**
Temp	ANOVA	0.9275	0.1526	(3, 48)
pH	ANOVA	<.0001	23.5948	(3, 48)
S. Conductance	ANOVA	0.7381	0.4219	(3, 48)
Chloride	ANOVA	0.2151	1.5444	(3, 48)
Fluoride	ANOVA	0.8357	0.2854	(3, 48)
Sulfate	ANOVA	0.0015	6.0174	(3, 48)
Nitrate	ANOVA	0.3382	1.151	(3, 48)

3.2 Anion Concentrations

3.2.1 Chloride

Of all the anions studied, chloride was found with the highest concentrations within my samples. Many of the samples were found at or above the 250 mg/L secondary maximum contaminant level (SMCL) recommended by the United States Environmental Protection Agency (U.S. EPA, 2014) and the aquatic ecotoxicity chronic limit of 230 mg/L (U.S. EPA, 1988). Surface water concentrations ranged from 46-872 mg/L of chloride in 52 samples, with the highest concentrations occurring during the late winter months. Over the study period, surface water at Kelsey Creek had a mean chloride concentration of 290 mg/L, while Plum Creek had a mean concentration of 96 mg/L (Figure 3.6). Groundwater concentrations spanned a smaller range (96-451mg/L) within 78 samples, with the highest concentrations during the mid-summer months (Figure 7). The mean chloride concentration of groundwater over the study period was 238 mg/L for well A, 277 mg/L for well B and 179 mg/L for well C.

Paired-samples t-tests were conducted to determine if any differences existed between chloride concentrations at upstream and downstream sites at Kelsey Creek and Plum Creek, between Kelsey Creek downstream site and Well A, B and C, between each pair of wells, and between Kelsey Creek and Plum Creek upstream sites and downstream sites. There was a significant difference in chloride concentrations between Kelsey Creek and Plum Creek (upstream: p= 0.004; downstream: p = 0.004), but no significant differences between upstream and downstream points within the same stream (Table 3.5). There was also a significant difference in chloride concentrations between Well B and Well C (p = 0.005), but not between any of the other well pairs. A one-way between subjects' ANOVA was also conducted and there was no significant difference across the Kelsey Creek stream and well sites (p = 0.22) (Table 3.4), although this analysis obscures the strong seasonal differences apparent in the data (Figure 3.7).

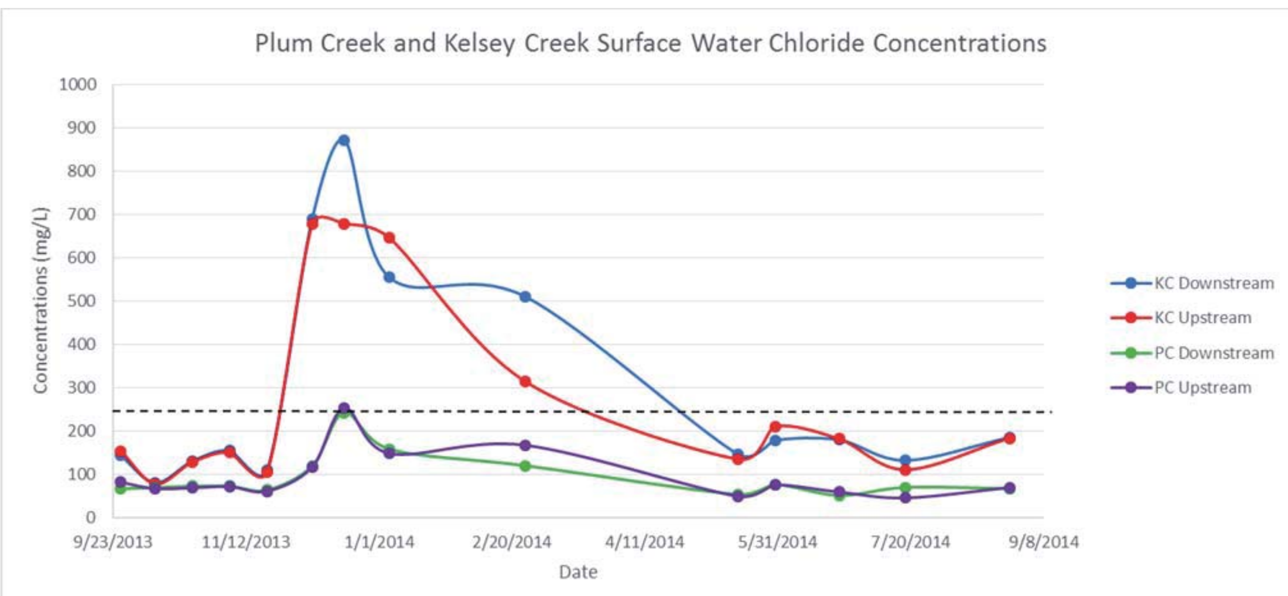

Figure 3.6. Chloride concentrations from stream water at Plum Creek and Kelsey Creek. See Table 3.1 for site abbreviations. Black dashed line represents US EPA secondary maximum contaminant level for drinking water. Instrument error bars (+/- 0.026 mg/L) are smaller than the symbol size.

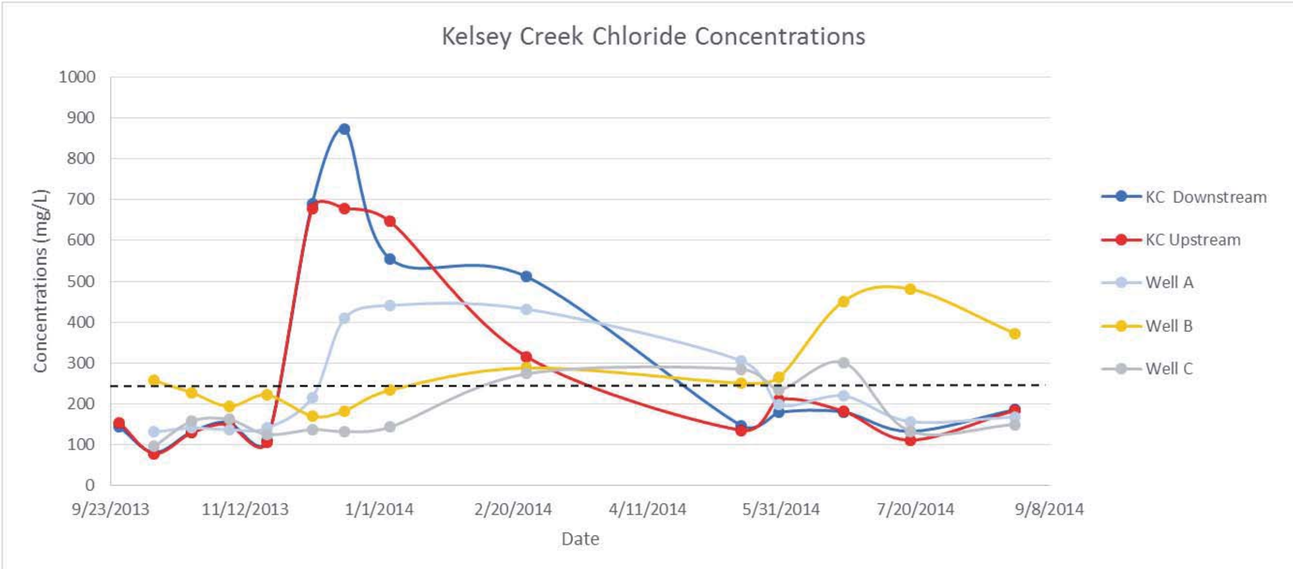

Figure 3.7. Chloride concentrations from stream and wells at Kelsey Creek. See Table 3.1 for site abbreviations. Black dashed line represents US EPA secondary maximum contaminant level for drinking water. Instrument error bars (+/- 0.026 mg/L) are smaller than the symbol size.

3.2.2 Sulfate

Sulfate had the second most abundant concentration of the analyzed anions within most of the stream and groundwater samples. Surface water at both Kelsey Creek and Plum Creek exhibit the same seasonal trend, where they start off around 40-57 mg/L in October 2013 and oscillate for a few months until they peak around December 19, 2013. They then have a prolonged recession until May 16, 2014, before oscillating again in the summer. Kelsey Creek has a slightly higher mean sulfate concentration (39.0 mg/L) than Plum Creek (33.5 mg/L) (Figure 3.8). Sulfate concentrations in groundwater at Kelsey Creek are quite different at each well site (Figure 3.9). Well C has the highest mean concentration (72.5 mg/L), with the highest concentration of 127.0 mg/L in November 2013 and the lowest concentration of 27.0 mg/L in October 2013 and July 2014. Well B has the lowest overall mean of 27.2 mg/L, with a seasonally high concentration of 147.3 mg/L in November 2013 and an otherwise steady concentration of ~9.5 mg/L for all other dates. Well A has an intermediate mean concentration (36.89 mg/L), similar to the stream water. Well A has a high concentration of 59.5 mg/L in October 2013 and a low concentration of 16.5 mg/L in July 2014, but remains fairly steady, only changing 28% in concentration over the study period. Overall, Well A was almost identical to the stream sulfate concentration on every date, Well B was consistently lower than the stream, while Well C was generally higher. On many dates the downstream and upstream sulfate concentrations differed, with no consistent trend on which one was higher for either stream. However, both upstream and downstream at both sites displayed the same seasonal pattern.

Paired-samples t-test were conducted to determine if any differences existed between sulfate concentrations at upstream and downstream sites at Kelsey Creek and Plum Creek, between the Kelsey Creek downstream site and Well A, B and C, between each pair of wells, and between Kelsey Creek and Plum Creek. There was a significant difference in sulfate concentrations between Kelsey Creek and Plum Creek (upstream: $p = 0.02$; downstream: $p = 0.03$), but not between sites within each stream (Table 3.5). Due to the high sulfate concentrations in Well C, there were significant differences between Well C and Kelsey Creek downstream ($p = 0.002$), Well A ($p = 0.0003$), and Well B ($p = 0.0009$). These differences also appeared significant in the one-way ANOVA ($p = 0.0015$) (Table 3.4).

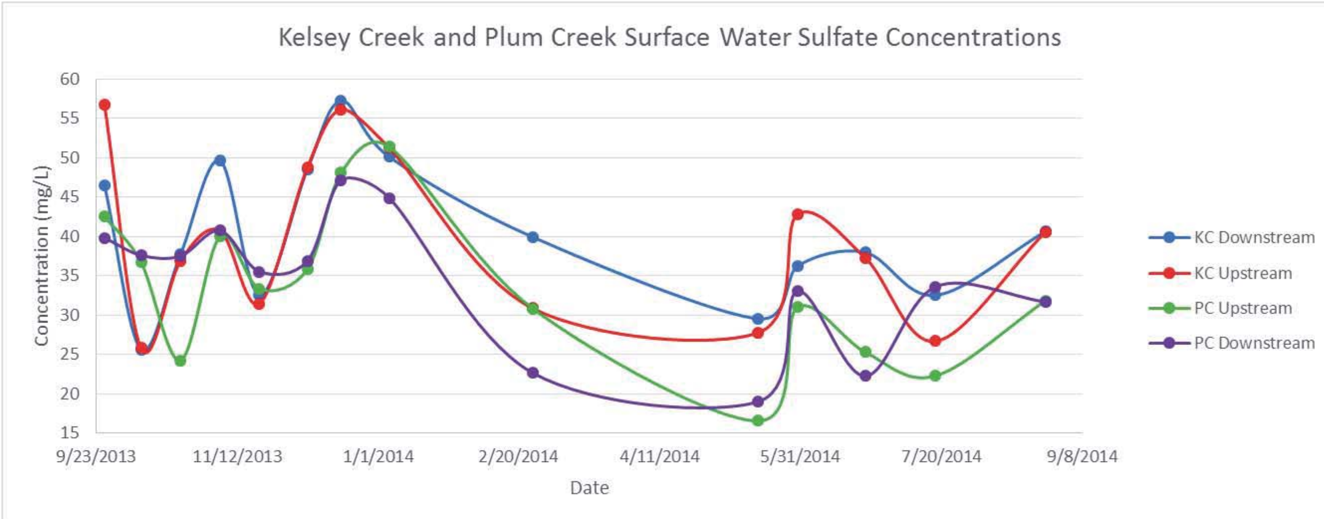

Figure 3.8. Sulfate concentrations from stream water at Plum Creek and Kelsey Creek. See Table 3.1 for site abbreviations. Instrument error bars (+/- 0.015 mg/L) are smaller than the symbol size.

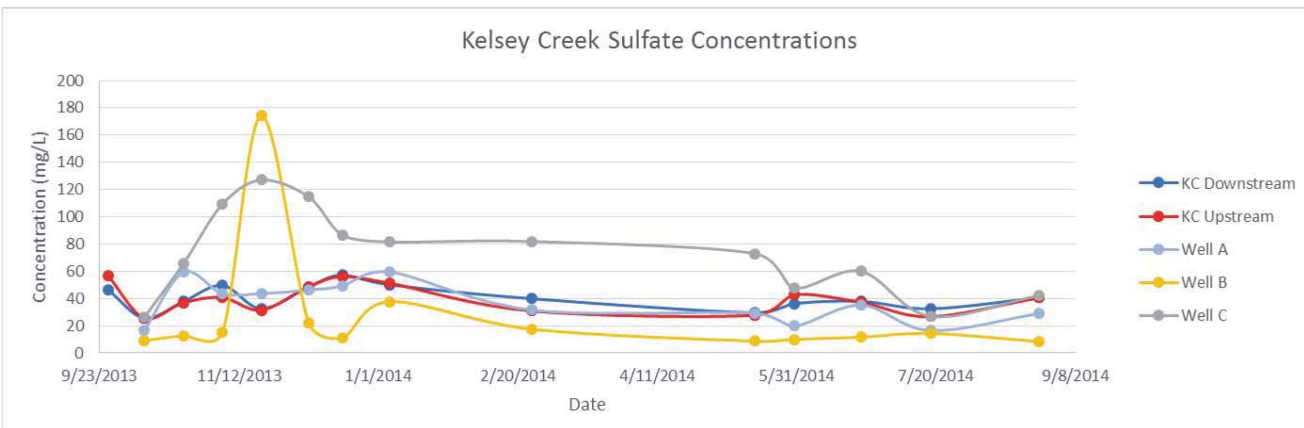

Figure 3.9. Sulfate concentrations from stream and wells at Kelsey Creek. See Table 3.1 for site abbreviations. Instrument error bars (+/- 0.015 mg/L) are smaller than the symbol size.

3.2.3 Nitrate

Nitrate showed substantial changes in stream and groundwater concentrations over the course of the study, with surface water concentrations at Kelsey Creek often around the 10 mg/L U.S. EPA Maximum Contaminant Level (U.S. EPA, 2014). Nitrate concentrations in the surface water at Kelsey Creek were low (~ 2 mg/L) until December 7, 2013, when they rose to 9.7 mg/L and then remained stable with only minor fluctuations through the following summer. This resulted in a mean nitrate concentration of 7.1 mg/L within the Kelsey Creek reach over the study period (Figure 3.10). Plum Creek surface water was similar to Kelsey Creek, but the rise in nitrate concentration was gradual over winter into the spring. The nitrate concentrations at Plum Creek remain steady, at ~8.3 mg/L, for most of the spring and summer, but the downstream site exhibited a higher than expected concentration of 13.3 mg/L on July 18, 2014. At Plum Creek, the mean nitrate concentration at both upstream and downstream sites was 5.3mg/L. Groundwater at Kelsey Creek had an overall mean nitrate concentration of 5.6 mg/L, which is ~1.5mg/L lower than the surface water (Figure 3.11). At Well A, the highest mean concentration (6.5 mg/L) was observed and the lowest mean (4.9 mg/L) was seen at Well B.

Paired-samples t-tests were conducted to determine if any differences existed between nitrate concentrations at upstream and downstream sites at Kelsey Creek and Plum Creek, between Kelsey Creek downstream site and Well A, B and C, between each pair of wells, and between Kelsey Creek and Plum Creek upstream sites and downstream sites. There was a significant difference in nitrate concentrations between Plum Creek upstream and Kelsey Creek upstream ($p = 0.03$) (Table 3.5). A one-way ANOVA was also conducted, and there was not a significant difference between the surface water and groundwater sites at Kelsey Creek ($p = 0.34$) (Table 3.4).

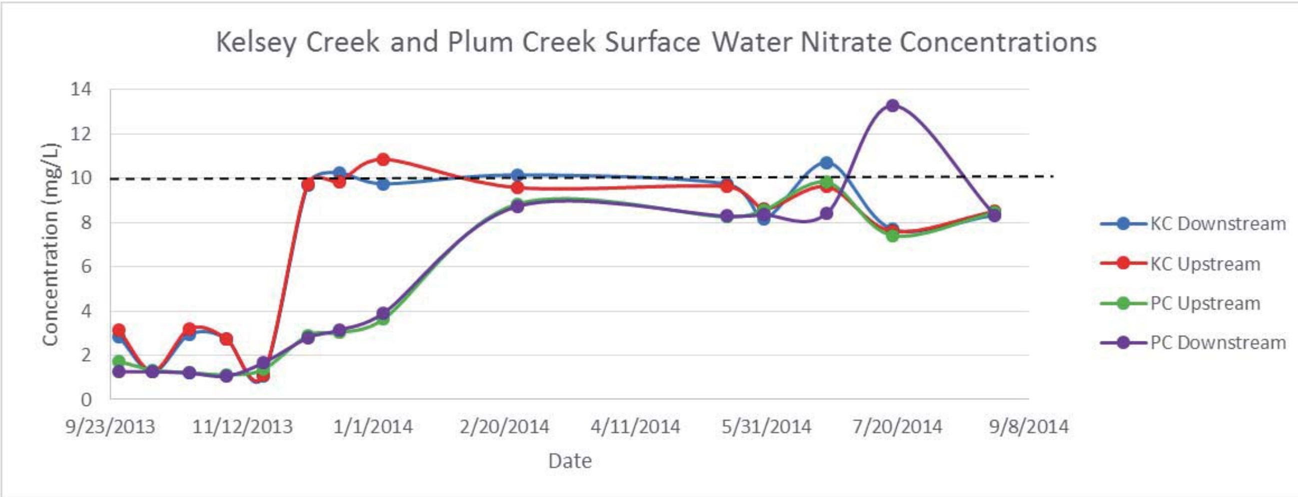

Figure 3.10. Nitrate concentrations from stream water at Kelsey Creek and Plum Creek. See Table 3.1 for site abbreviations. Black dashed line represents US EPA maximum contaminant level for drinking water. Instrument error bars (+/- 0.002 mg/L) are smaller than the symbol size. (Some of the results may be affected by dilution below the range of the nitrate standards, in order to ensure adequate dilution for chloride).

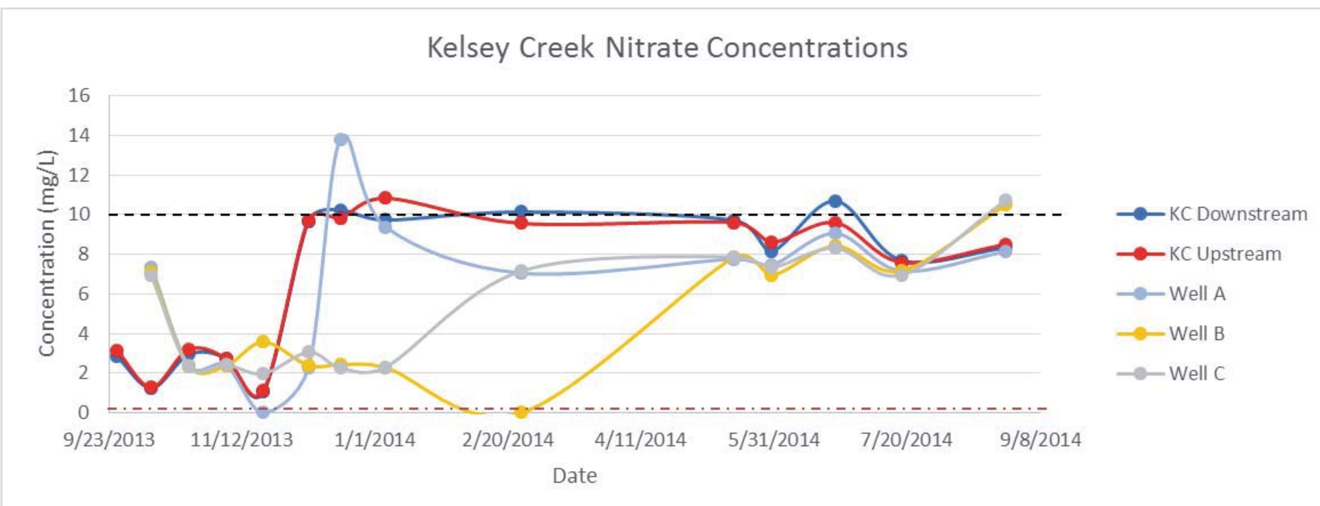

Figure 3.11. Nitrate concentrations from stream and wells at Kelsey Creek. See Table 3.1 for site abbreviations. Black dashed line represents US EPA maximum contaminant level for drinking water. Instrument error bars (+/- 0.002 mg/L) are smaller than the symbol size and the red dashed line is the instrument detection limit. (Some of the results may be affected by dilution below the range of the nitrate standards, in order to ensure adequate dilution for chloride).

3.2.4 Fluoride

Fluoride concentrations in both surface and groundwater at Kelsey Creek ranged from 0.20-1.60 mg/L across the 130 samples collected (Figure 3.12). The highest concentrations occurred in June 2014 and the lowest concentrations occurred in surface water samples during fall and in groundwater during late winter. Surface water at Kelsey Creek had a mean of 0.67 mg/L of fluoride, while Plum Creek surface water had a lower mean at 0.55 mg/L (Figure 3.12). Average fluoride concentrations in the groundwater at Kelsey Creek were similar to the surface water, at 0.64 mg/L. Over the study period, Wells A and B showed similar fluoride concentration patterns, while Well C follows its own pattern that has peak fluoride concentrations after other sites at Kelsey Creek peaked (Figure 3.13).

Paired-samples t-test were conducted to determine if any differences existed between fluoride concentrations at upstream and downstream sites at Kelsey Creek and Plum Creek, between Kelsey Creek downstream site and Well A, B and C, between each separate well, and between Kelsey Creek and Plum Creek upstream sites and downstream sites (Table 3.5). There was a significant difference in fluoride concentrations between upstream and downstream sites at Kelsey Creek ($p = 0.05$). No other significant differences were found. A one-way ANOVA was also conducted for surface water and groundwater at Kelsey Creek, and no significant differences were found ($p = 0.84$) (Table 3.4).

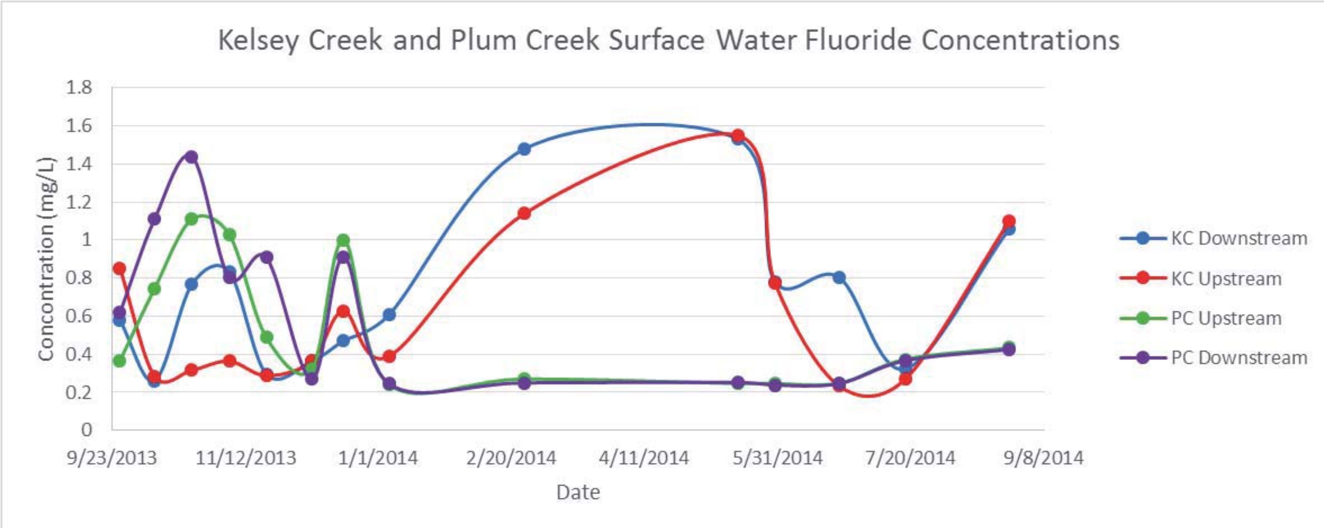

Figure 3.12. Fluoride concentrations from stream water at Kelsey Creek and Plum Creek. See Table 3.1 for site abbreviations. Instrument error bars (+/- 0.003 mg/L) are smaller than the symbol.

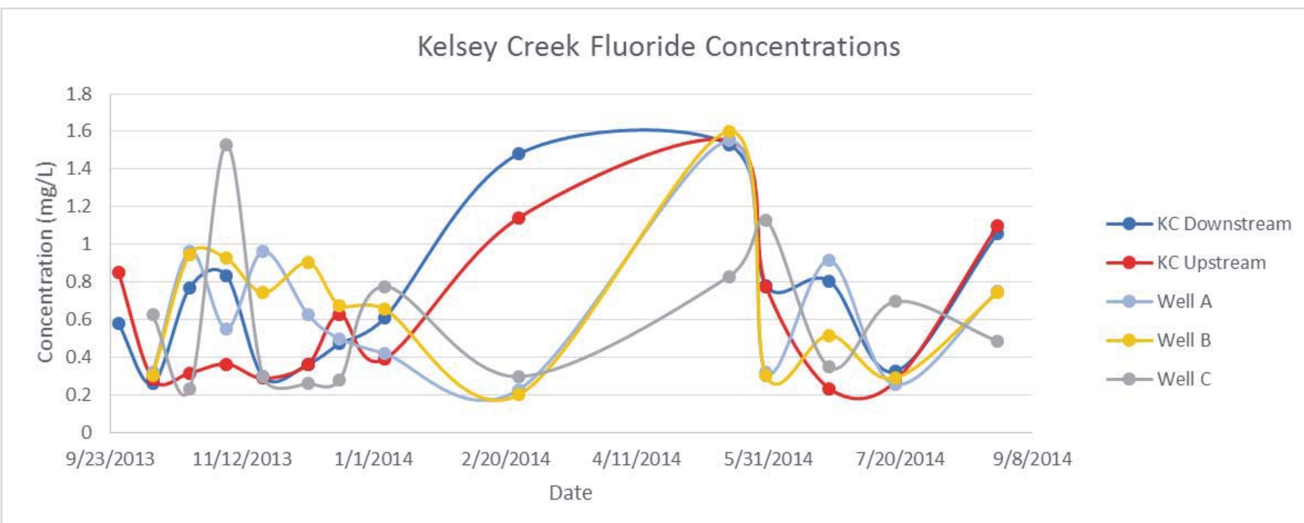

Figure 3.13. Fluoride concentrations from stream water and wells at Kelsey Creek. See Table 3.1 for site abbreviations. Instrument error bars (+/- 0.003 mg/L) are smaller than the symbol.

Table 3.5: Paired t-test by date for all laboratory anion water parameter measurements at each study sites from September 2013-August 2014. See Table 3,1 for location abbreviations. Significant test at levels α = 0.05 are in red cells

Variable 1	Mean 1	Standard Deviation	Variable 2	Mean 2	Standard Deviation	Anion	Test Type	p-value	t-value	DF	Uncertainty
KC DS	302.63	260.74	KC US	277.67	230.13	chloride	t-test	0.2857	1.12	12	0.003
PC DS	95.97	53.9	PC US	97.1	60.17	chloride	t-test	0.8048	0.25	12	0.003
PC DS	95.97	53.9	KC DS	302.63	260.74	chloride	t-test	0.0043	-3.52	12	0.003
PC US	97.1	60.17	KC US	277.67	230.13	chloride	t-test	0.0042	-3.52	12	0.003
KC DS	302.63	260.74	Well A	238.25	117.97	chloride	t-test	0.2472	-1.22	12	0.003
KC DS	302.63	260.74	Well B	276.63	98.71	chloride	t-test	0.7712	-0.3	12	0.003
KC DS	302.63	260.74	Well C	179.48	68.88	chloride	t-test	0.135	-1.6	12	0.003
Well A	238.25	117.97	Well B	276.63	98.71	chloride	t-test	0.4264	0.82	12	0.003
Well B	276.63	98.71	Well C	179.48	68.88	chloride	t-test	0.005	-3.43	12	0.003
Well A	238.25	117.97	WellC	179.48	68.88	chloride	t-test	0.0941	-1.82	12	0.003
KC DS	39.86	9.21	KC US	38.22	9.73	sulfate	t-test	0.1847	1.41	12	0.003
PC DS	34.03	8.53	PC US	32.86	9.87	sulfate	t-test	0.493	0.71	12	0.003
PC DS	34.03	8.53	KC DS	39.86	9.21	sulfate	t-test	0.025	-2.57	12	0.003
PC US	32.86	9.87	KC US	38.22	9.73	sulfate	t-test	0.0221	-2.63	12	0.003
KC DS	39.86	9.21	Well A	36.89	14.76	sulfate	t-test	0.3542	-0.96	12	0.003
KC DS	39.86	9.21	Well B	27.15	44.92	sulfate	t-test	0.351	-0.97	12	0.003
KC DS	39.86	9.21	Well C	72.51	32.16	sulfate	t-test	0.0015	4.1	12	0.003
Well A	36.89	14.76	Well B	27.15	44.92	sulfate	t-test	0.439	-0.8	12	0.003
Well B	27.15	44.92	Well C	72.51	32.16	sulfate	t-test	0.0009	4.35	12	0.003
Well A	36.89	14.76	Well C	72.51	32.16	sulfate	t-test	0.0003	5.11	12	0.003
KC DS	7.11	3.68	KC US	7.09	3.6	Nitrate	t-test	0.9333	0.09	12	0.003
PC DS	5.41	3.97	PC US	5.07	3.47	Nitrate	t-test	0.4847	0.72	12	0.003
PC DS	5.41	3.97	KC DS	7.11	3.68	Nitrate	t-test	0.1	-1.78	12	0.003
PC US	5.07	3.47	KC US	7.09	3.6	Nitrate	t-test	0.0268	-2.52	12	0.003
KC DS	7.11	3.68	Well A	6.48	3.75	Nitrate	t-test	0.4889	-0.71	12	0.003
KC DS	7.11	3.68	Well B	4.87	3.22	Nitrate	t-test	0.1119	-1.72	12	0.003
KC DS	7.11	3.68	Well C	5.36	3.02	Nitrate	t-test	0.1312	-1.62	12	0.003
Well A	6.48	3.75	Well B	4.87	3.22	Nitrate	t-test	0.1957	-1.37	12	0.003
Well B	4.87	3.22	Well C	5.36	3.02	Nitrate	t-test	0.4149	0.84	12	0.003
Well A	6.48	3.75	Well C	5.36	3.02	Nitrate	t-test	0.3147	-1.05	12	0.003
KC DS	0.74	0.42	KC US	0.59	0.42	Fluoride	t-test	0.0482	2.2	12	0.003
PC DS	0.52	0.33	PC US	0.57	0.41	Fluoride	t-test	0.3283	-1.02	12	0.003
PC DS	0.52	0.33	KC DS	0.74	0.42	Fluoride	t-test	0.4109	-1.3	12	0.003
PC US	0.57	0.41	KC US	0.59	0.42	Fluoride	t-test	0.68	-0.09	12	0.003
KC DS	0.74	0.42	Well A	0.64	0.38	Fluoride	t-test	0.4681	-0.75	12	0.003
KC DS	0.74	0.42	Well B	0.68	0.38	Fluoride	t-test	0.652	-0.46	12	0.003
KC DS	0.74	0.42	Well C	0.6	0.39	Fluoride	t-test	0.3695	-0.93	12	0.003
Well A	0.64	0.38	Well B	0.68	0.38	Fluoride	t-test	0.555	0.61	12	0.003
Well B	0.68	0.38	Well C	0.6	0.39	Fluoride	t-test	0.5949	-0.55	12	0.003
Well A	0.64	0.38	Well C	0.6	0.39	Fluoride	t-test	0.7887	-0.27	12	0.003

3.3 Oxygen-18 Isotopes

Oxygen ($\delta^{18}O$) isotopes reported in per mille (‰) of surface water at Plum Creek and Kelsey Creek had similar seasonal trends, while groundwater at Kelsey Creek behaved in different patterns at each well. Surface water at Kelsey Creek was slightly lighter than Plum Creek throughout the study period. The lightest surface water at Plum Creek was -10.8‰ on February 25, 2014 and the heaviest was -6.3‰ on June 23, 2014 (Figure 3.14). Similarly, the surface lightest water at Kelsey Creek was on February 25, 2014 at -11.1‰ and the heaviest was on June 23, 2014 at -7.1‰.

Groundwater at Kelsey Creek is interesting because each well seems to follow a pattern distinct from the other wells. Well A has a seasonal trend closely related to the stream, but with some damped responses. The overall change in $\delta^{18}O$ was 1.9‰, with the lightest $\delta^{18}O$ was -9.4‰ on January 5, 2014, while the heaviest was -7.5‰ on July 18, 2014 (Figure 3.14). There are times when the water in Well A is isotopically very similar to the stream, suggesting these may be times when the stream could be connected to the groundwater and recharging Well A. The water in well B tracks closely to well A, but has a more gradual variation in $\delta^{18}O$ over the study period. The overall change in $\delta^{18}O$ for well B is 1.4‰, with the lightest $\delta^{18}O$ was -9.0‰ on May 30 and July 18, 2014 and the heaviest was -7.6‰ on May 16, 2014. I collected the lightest and heaviest $\delta^{18}O$ values in the month of May, potentially due to the precipitation event that happened a few days before the May 16, 2014 collection date. Precipitation that fell in Kent on May 13, 2014 had $\delta^{18}O$ of -1.5‰ (Jefferson, pers. comm.). Well C acts altogether differently than the well and stream sites. The water starts out isotopically heavy at -6.6‰ on October 9, 2013 and then progressively decreases to -7.2‰ on January 5, 2014, before abruptly decreasing $\delta^{18}O$ to -12.1‰ on May 16, 2014. Over the next three months the $\delta^{18}O$ gradually increased back to -6.6‰ on August 26, 2014. The overall range in $\delta^{18}O$ in well C is 5.5‰, with an apparent 64-day lag time from stream $\delta^{18}O$ minimum to the $\delta^{18}O$ minimum in well C. The exact lag is uncertain because of the low frequency of the sampling during this period. The maximum $\delta^{18}O$ lag time is at least 64 days, but sampling stopped on August 26, 2014 while the maximum $\delta^{18}O$ in well C could have still been rising, so the lag time may be longer than 64 days. In both surface and groundwater, the seasonal cycle of $\delta^{18}O$ is apparent, since the values from August 26, 2014 are similar to those on October 9, 2013.

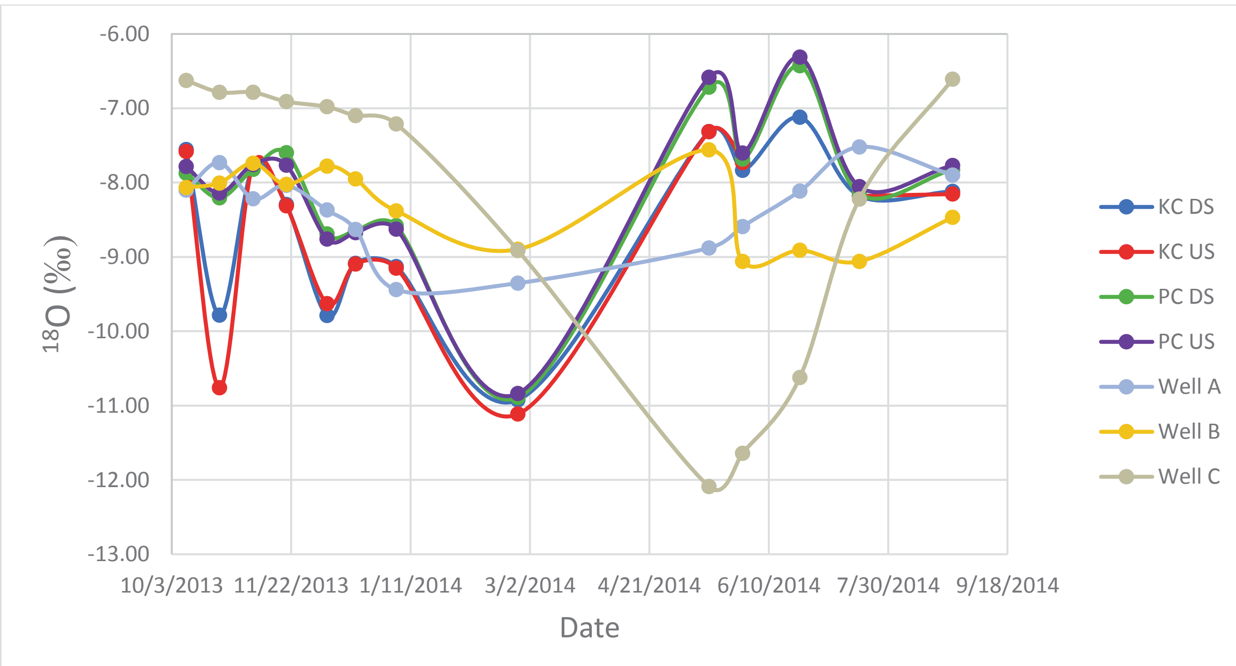

Figure 3.14. Oxygen isotopes for Plum Creek, Kelsey Creek, and Kelsey Creek wells, with location abbreviation on Table 3.1. Equipment error (0.08‰) is smaller than symbol size.

3.4 Modeling

3.4.1 Topography Map

Topographic maps created in AutoCAD and Surfer 10 are shown in this section. Figure 3.15 is the topographic map created in AutoCAD with cross sections A-G labeled. The x-axis coordinates are given in easting (feet) and the y-axis coordinates are given in northings (feet), using the Ohio State Plane coordinate system. The contour intervals are 1 foot. The boundaries for the map created in AutoCAD were Munroe Falls Ave. to the north, piezometer transect 5 to the south, a paved walking trail to the west, and the boundary of former reservoir to the east, adjacent to the City of Cuyahoga Falls Water Treatment Plant. The highest elevation is 1007 feet above sea level (306.9 m) to the west and the lowest elevation is ~990 feet (301.8 m) in the former reservoir area. Water at the time of surveying is depicted by dashed lines with the stream running down the middle. A natural levee was formed to the west of the stream.

Figures 3.16 and 3.17 display the topographic map created in Surfer, which was created using only the land surface elevations at the piezometers and wells. Unfortunately, the channel bottom (or thalweg) was not surveyed, for this topography map. Again, the x-axis coordinates are given in easting (feet) and the y-axis coordinates are given in northings (feet) in the Ohio State Plane coordinate system. The contour interval is 0.05 meters. The topographic map created in Surfer used the wells and piezometers as the boundaries of the map. Figure 3.16 is used to reference the topography relative to the photo of Kelsey Creek, while Figure 3.17 shows topography of the study area. In both Figures 3.16 and 3.17, the highest elevation is at 305.5 m above sea level and lowest elevation is at 304.3 meters. The two lower elevations to the west at well B and piezometer 3E represent low-lying wetland areas, while the three lower elevations to the east at piezometers 2C, 3C, and 5B represent in-stream piezometers. Since the map was created using land surface elevation, the lack of a continuously defined stream channel might result from in-stream piezometer locations occurring in a mix of pools and riffles. The high elevation area in the center of the map, at 304.85 m, is the natural levee that has formed to the west of the stream.

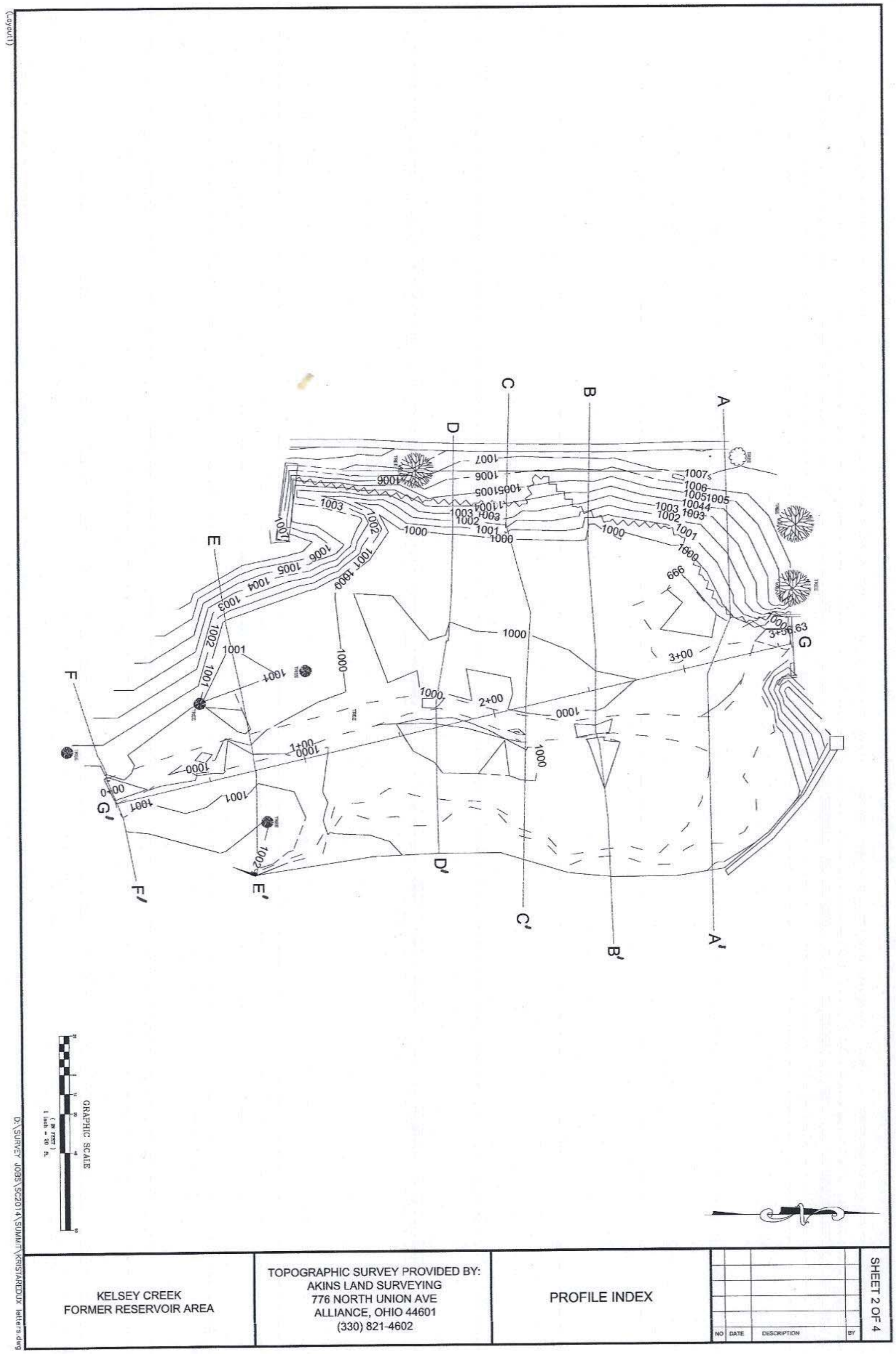

Figure 3.15. Topographic map created in AutoCAD using Ohio state plane coordinate system with contour intervals in 1-foot increments.

Figure 3.16. Topographic map created in Surfer using Ohio state plane coordinate system in feet with contour interval of 0.05 meters. Note: Kelsey Creek reach is referenced in the background and the black crosses represent well and piezometer locations.

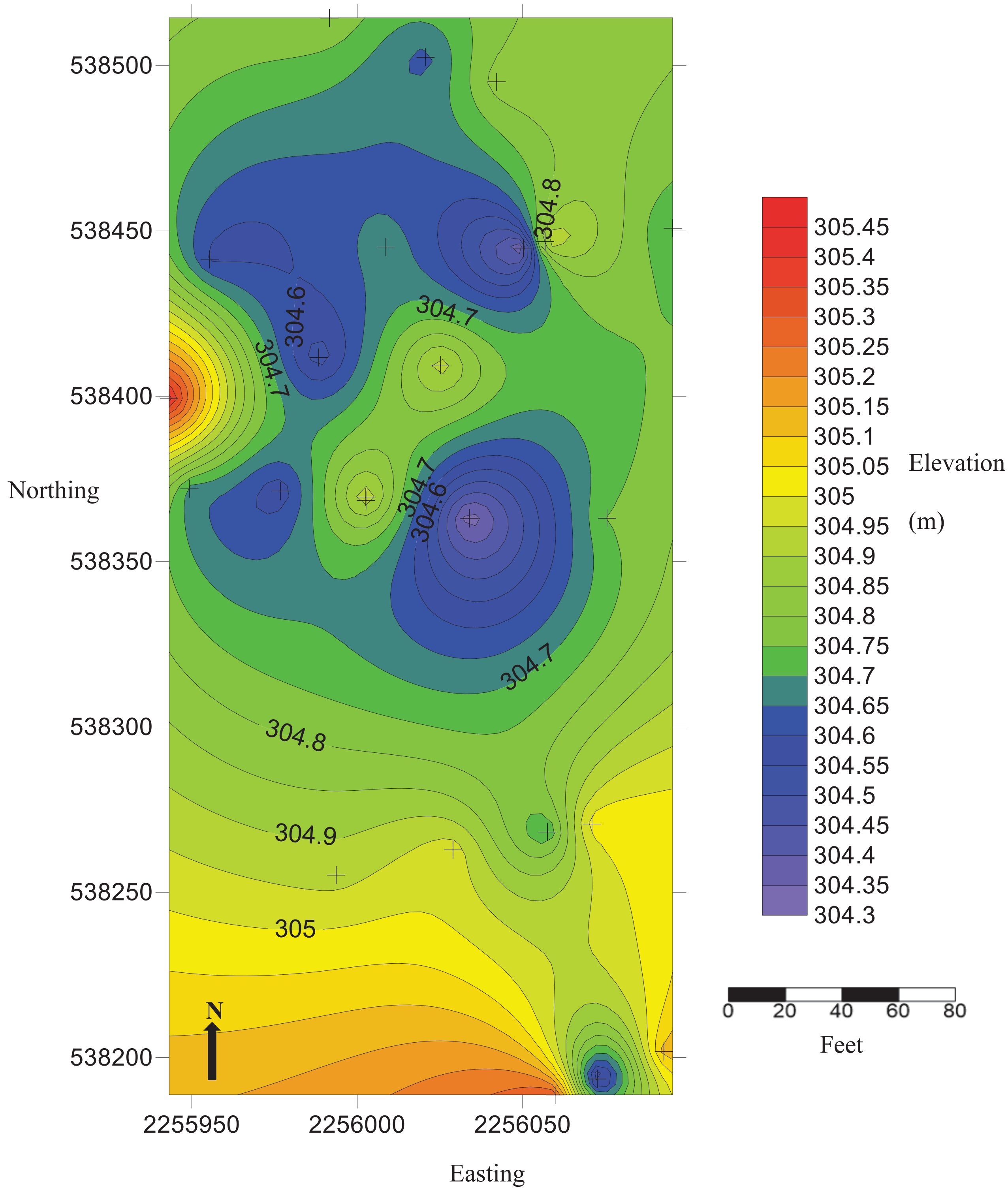

Figure 3.17. Topographic map created in Surfer using well and piezometer locations and elevations on the Ohio state plane coordinate system in feet with contour interval of 0.05 meters. Note: warm colors are higher elevations, while cool colors are low elevations and black crosses represent well and piezometer locations.

Topographical cross-sections through six east-west transects and through one north-south transect were also created in AutoCAD (Figures 3.18 and 3.19). These topographical cross-sections loosely correspond to the piezometer transects. The x-axis coordinates are instrument stationing (feet) and the y-axis coordinates are given in the elevation (feet). The contour interval is 1 foot, so fine detail is not represented. Cross sections A-D (Figure 3.18) have a steeply sloping bank in the west and a moderately even elevation of 1000 feet across the former reservoir, with the stream appearing 1 ft lower in cross-sections B and D. Cross section E (Figure 3.19) is similar to those in cross-sections A-D, with a small bank on the east side of the reach. Cross section F (Figure 3.19) is a shorter transect with steep bank on both sides of the stream, which has an elevation of 999 ft. Cross-section G (Figure 3.19) runs north to south through the reach, is relatively flat at 1000 feet and tappers off to 999 feet at the northern downstream section of the reach.

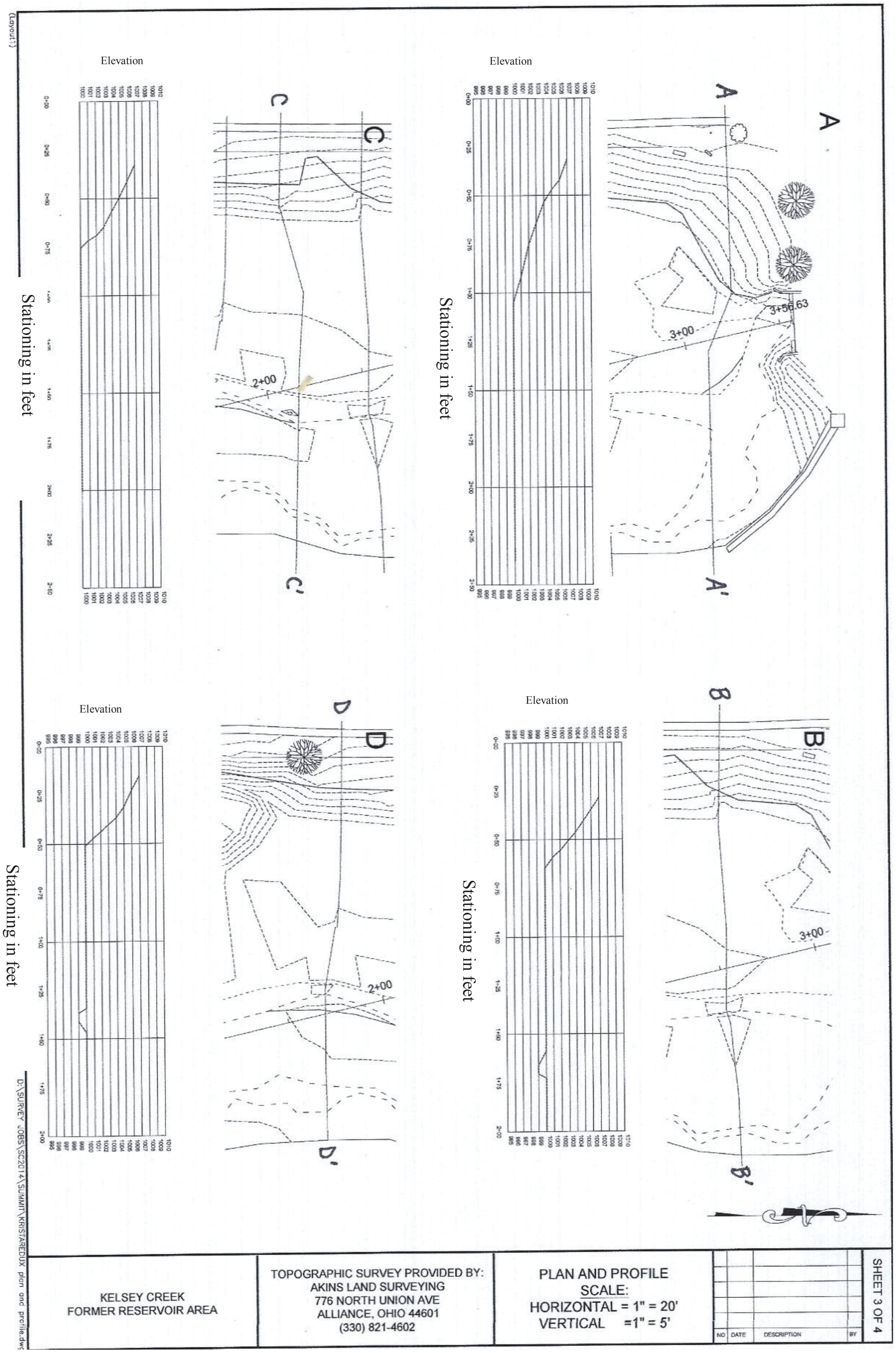

Figure 3.18. West to east cross-sectional profiles (A-D) from topographic map of Kelsey Creek from figure 3.15 created in AutoCAD using Ohio state plane coordinate system.

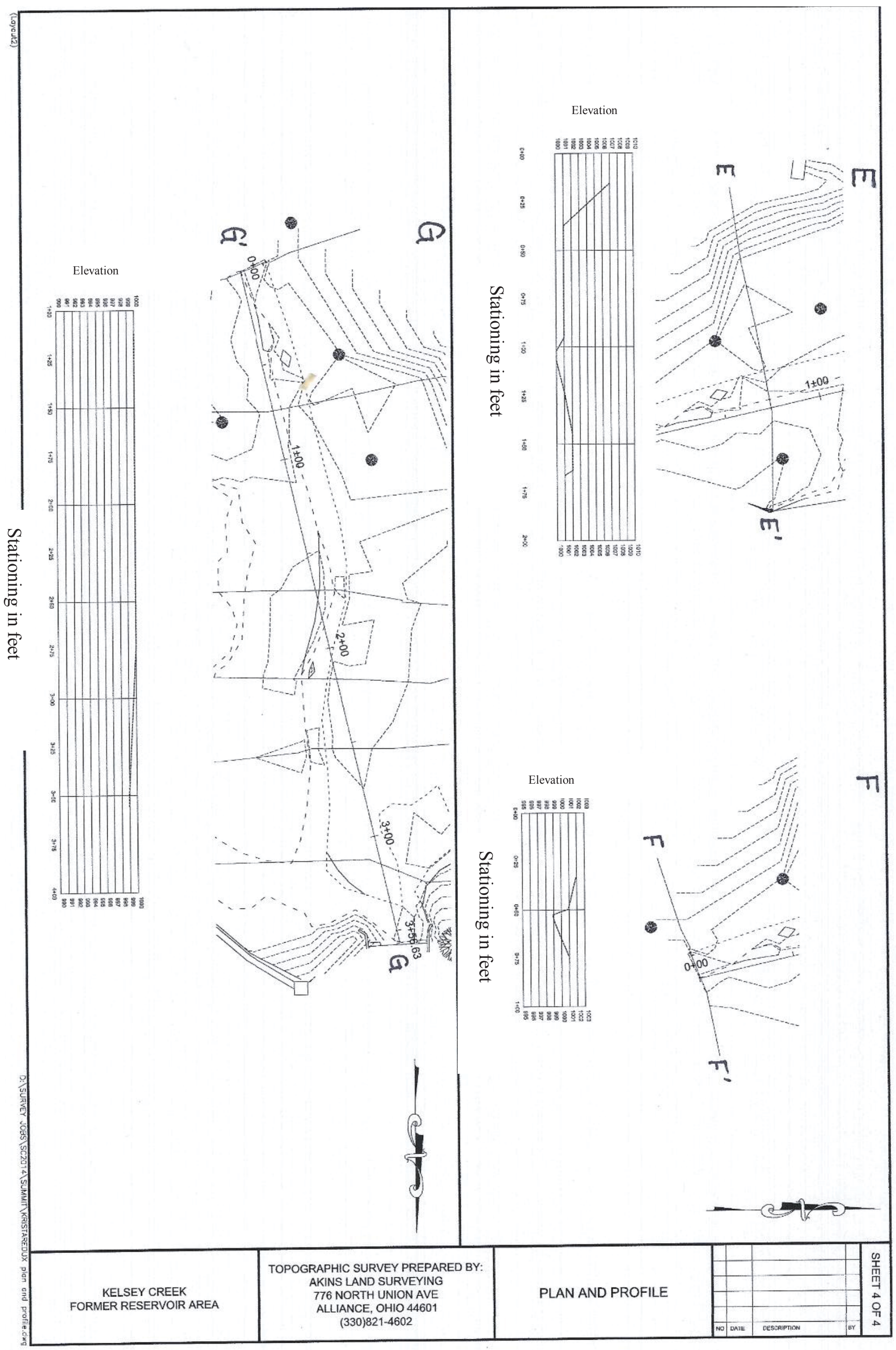

Figure 3.19. West to east cross-sectional profiles of E and F and north (G) to south (G') cross sectional profile of G from topographic map of Kelsey Creek (Figure 3.15) created in AutoCAD using Ohio state plane coordinate system.

3.4.2 Potentiometric Surface Maps

A total of 14 potentiometric surface maps were created. Figures 3.20-3.23 show representative conditions from each season, with the other 10 maps found in Appendix 1. The contour interval is 0.05 m. The x-axis coordinates are given in easting (feet) and the y-axis coordinates are given in northings (feet). The principal groundwater flow directions were determined by identifying areas of localized head maxima.

The potentiometric surface map for September 19, 2013 (Figure 3.20) has two different principal groundwater flow directions, with the southern part of the reach flowing WSW (261°) from piezometer 4B to 4D and the northern part of the reach flowing NW (315°) from 2D toward the west corner boundary. Groundwater flow on December 19, 2013 (Figure 3.21) flows NNW (330°) from 4B to 3D and SW (~235°) from 2B to well C and then toward the western edge of the map. During the spring (March 27, 2014) groundwater flowed WNW (277°) from 3C to well C (Figure 3.22). Groundwater flow on June 23, 2014 (Figure 3.23) was bidirectional, with the southern part of the reach flowing WSW (260°) from piezometer 4A to 4D and the northern part of the reach flowing WNW (324°) from 3C to the west corner boundary.

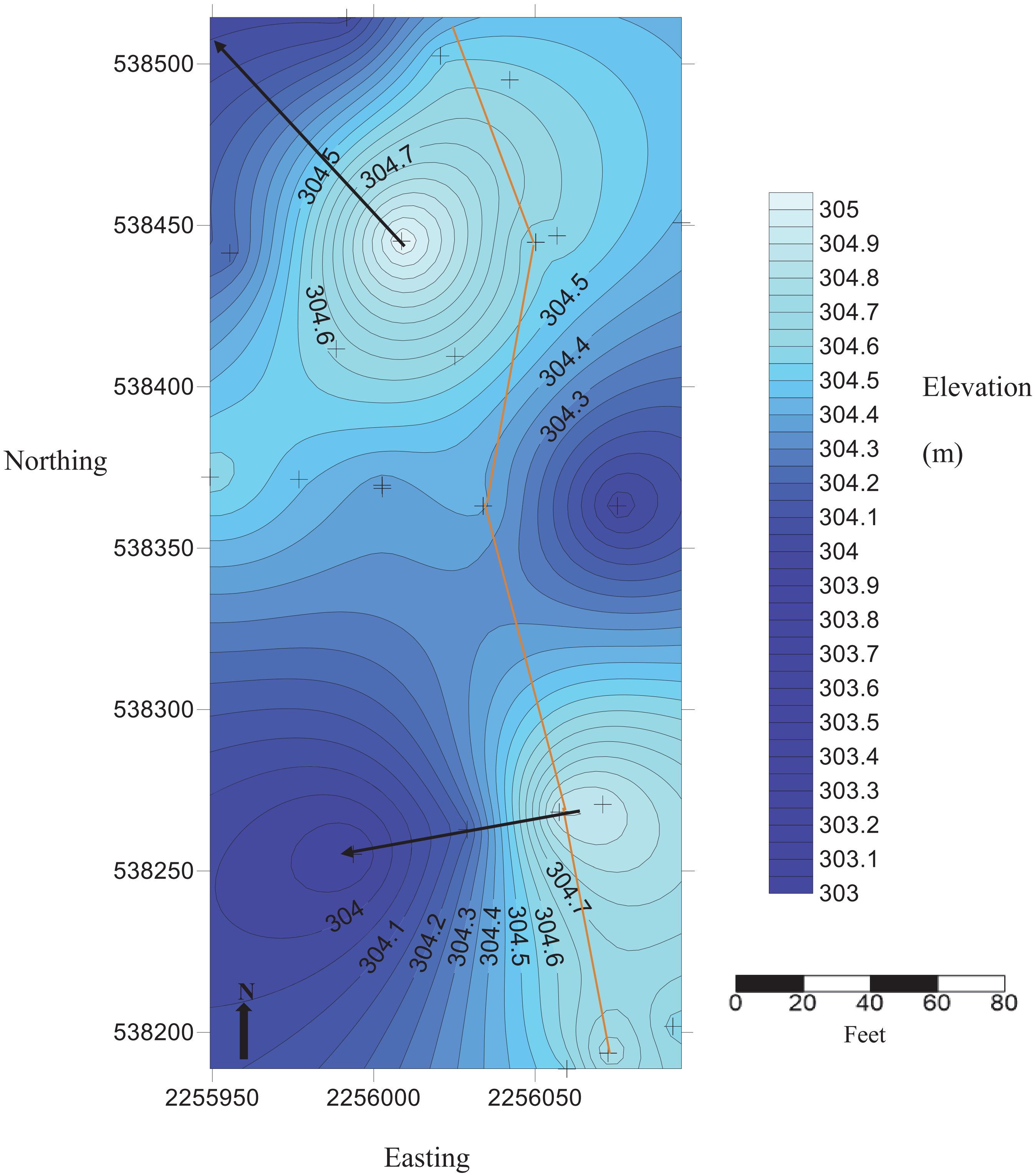

Figure 3.20. Potentiometric map created in Surfer from 9/19/13 collection data.
Note: Black crosses represent well and piezometer locations with the measurements of 1 piezometer and the 3 wells missing. Black arrows represent groundwater flow and red line represents the general stream location through Kelsey Creek.

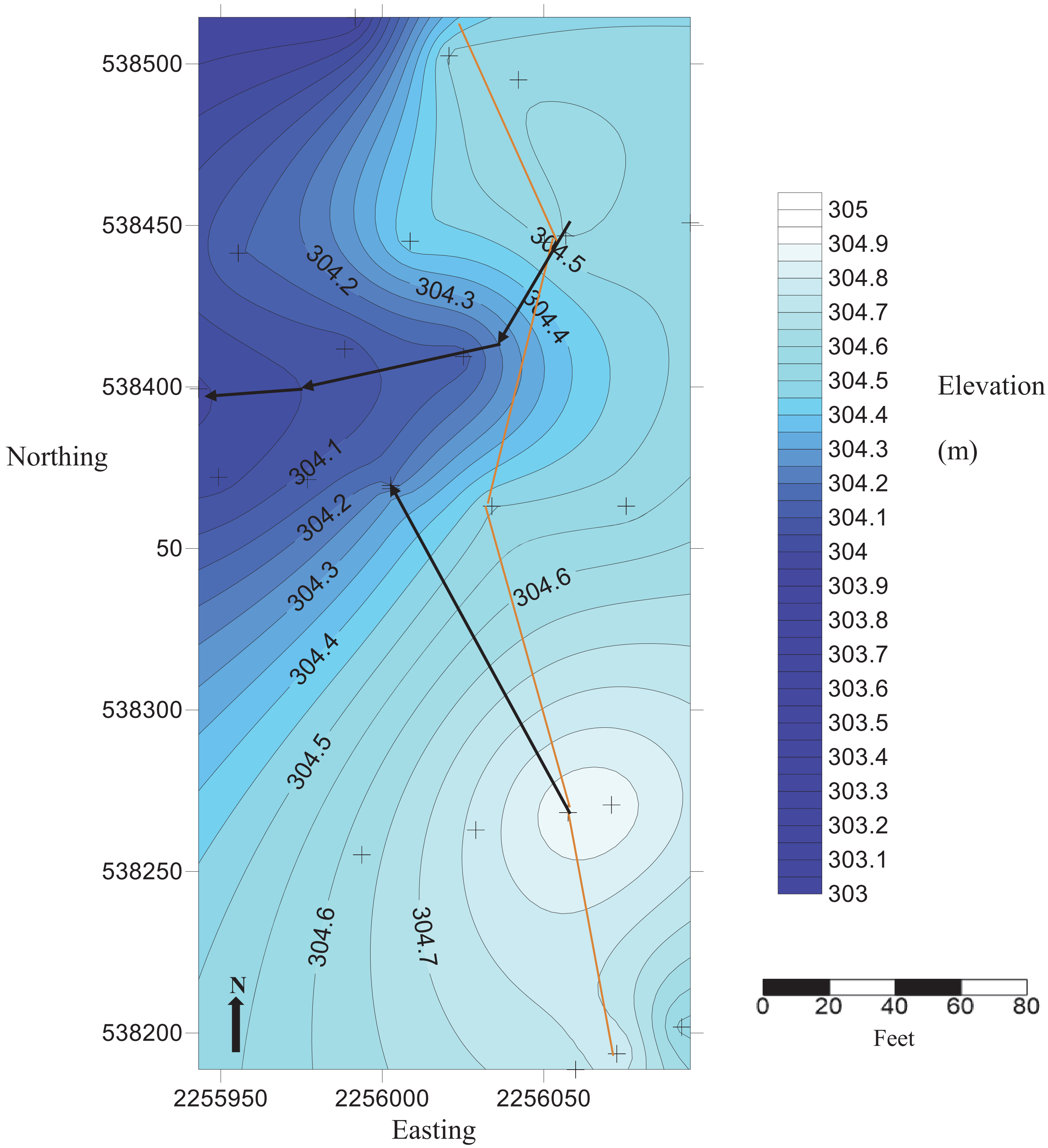

Figure 3.21. Potentiometric map created in Surfer from 12/19/13 collection data. Note: Black crosses represent well and piezometer locations with the measurements of 3 piezometers missing. Black arrows represent groundwater flow and red line represents the general stream location through Kelsey Creek.

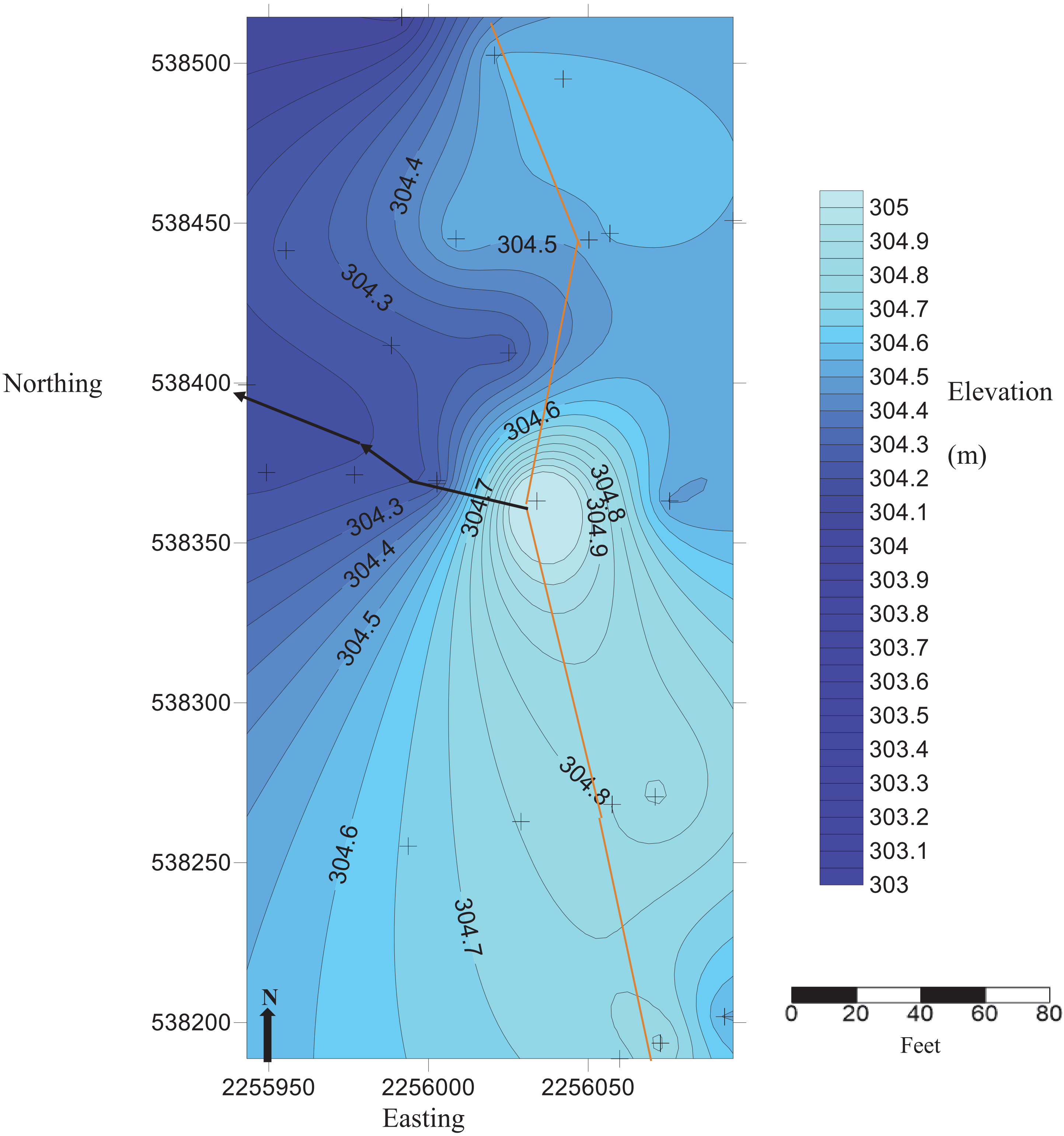

Figure 3.22. Potentiometric map created in Surfer from 3/27/14 collection data. Note: Black crosses represent well and piezometer locations with the measurements of 3 piezometer missing. Black arrows represent groundwater flow and red line represents the general stream location through Kelsey Creek.

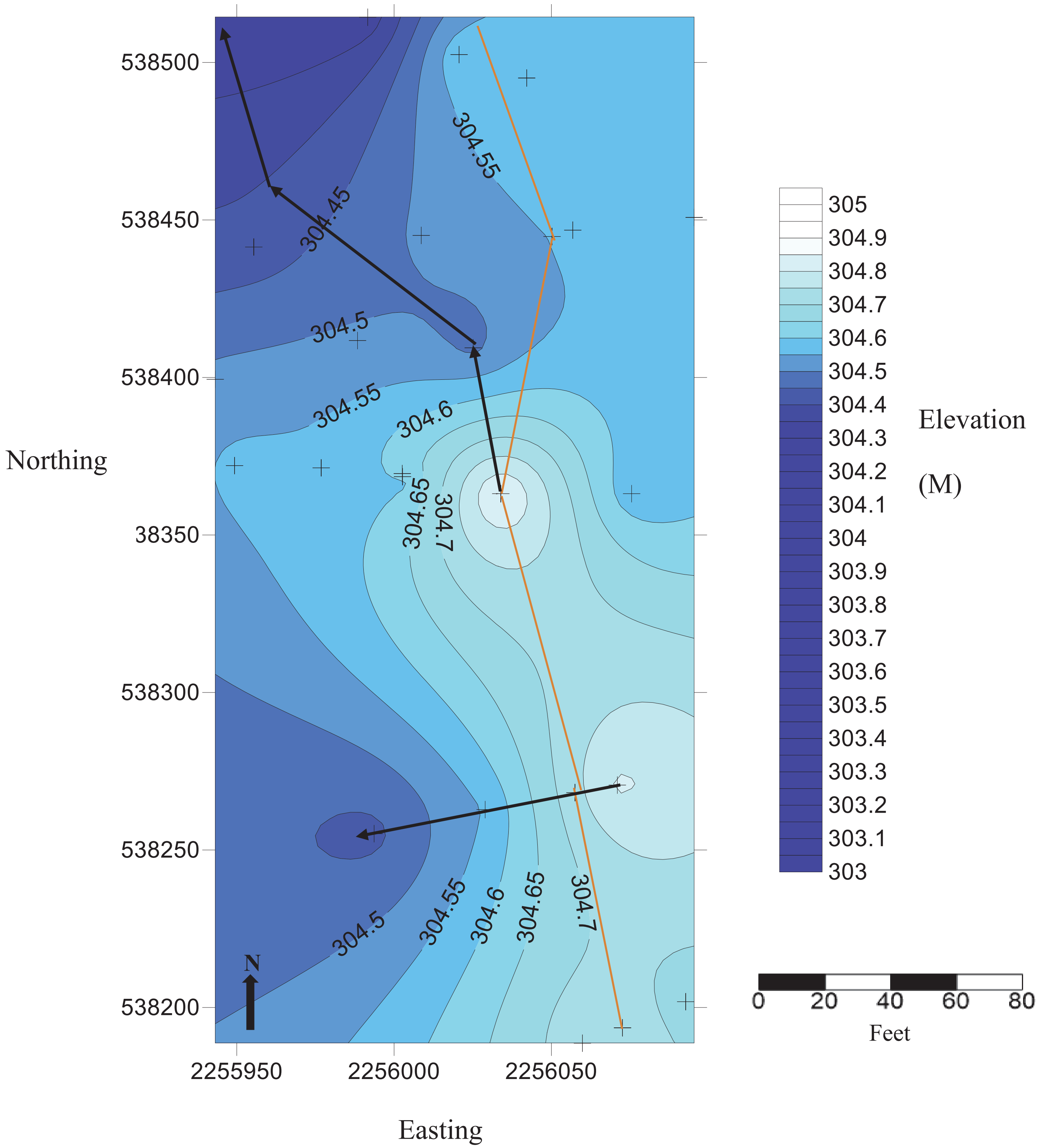

Figure 3.23. Potentiometric map created in Surfer from 6/23/14 collection data. Note: Black crosses represent well and piezometer locations with the measurements of 1 piezometer missing. Black arrows represent groundwater flow and red line represents the general stream location through Kelsey Creek.

The main direction of groundwater flow changes across the seasons, but seems to show a general northwest trend, away from the stream. This is most likely due to the consistently high head in the southeast region, while the area of minimal head is less fixed in the area. The direction of groundwater flow for all collection dates can be found in Table 3.7 of the groundwater flux section 3.4.2.

3.4.3 Hydraulic Conductivity (K)

Hydraulic conductivity (K) measurements made from the five transects of 21 piezometers and the one transect of 3 wells at Kelsey Creek revealed values of 10^{-4} m/s to 10^{-6} m/s, with a single lower outlier of 10^{-8} m/s (Table 3.6). In the heterogeneous study area of Kelsey Creek, the arithmetic mean was 7.0×10^{-5} m/s, the harmonic mean was 1.46×10^{-6} m/s, and the geometric mean was 2.35×10^{-5} m/s with a geometric standard deviation of 4.83. This harmonic mean was later used in calculations of groundwater flux.

Although K values at the three wells were calculated using the Bouwer-Rice method, their results were very similar to the 21 piezometers on which calculations were done using the Hvorslev method. The majority of K values are 10^{-4} m/s and 10^{-5} m/s and fall in the expected range of clean sand and silty sand (Figure 3.24) (Freeze, 1979). The lower K values ranging from 10^{-6} m/s to 10^{-8} m/s, are typical of unconsolidated silty sands, silt, and glacial till deposits. Field observations of sediment samples obtained near piezometer locations indicated that sediments at Kelsey Creek ranged from gravelly sand to clean clay lenses. At many of the sites we found core samples that were very heterogeneous with a range of layers, from 70% silt, 25% sand and 5% gravel, to layers with 90% coarse sand with 10% fine gravel, and layers of very hard and cohesive light gray clay. Thus, K values obtained in this study were generally comparable with those of similar material in the literature (Freeze, 1979).

Repeat slug test were conducted on six piezometers (1C, 2D, 2E, 3B, 4D, and 5A), on September 29, 2014 (Table 3.6). The repeated slug test yielded lower K values in 4 piezometers, and higher K values in 2 piezometers. The geometric mean of this subset of piezometers decreased from $3.2x10^{-5}$ m/s to $1.1x10^{-5}$ m/s upon repeat testing. Increases in the rate of recovery from the first slug test to the second slug test may indicate that the development of the piezometer was unsatisfactory (Surridge, 2005). For piezometers 2D and 3B that maybe the case since their values increase by one order of magnitude during the repeat slug test.

Some literature (Song et, al 2009, Chen, 2010) suggests that K decreases with depth, so I examined the relationship between K and the depth of sediment to the top of the screened interval. Of the five transects at Kelsey Creek, only Transect 4 showed a clear pattern of decreasing K with increasing depths (Figure 3.25). From Figure 3.25, the opposite is true for Transect 5, where K actually increased with depth. These data suggest that Kelsey Creek does not exhibit elevation-dependence of K, based on the small range of depths I examined.

Hydraulic conductivity in the subsurface at Kelsey Creek does not show any clear patterns when compared to the median grain size (d_{50}) and percent organic matter from the loss on ignition (LOI) method (Figures 3.26-3.27) However, Transect 3, does show some pattern toward increasing K as the median grain size increases, which could be due to smaller grain sizes (d_{10}) clogging the sediment pores (Figure 3.28). Transect 4 shows a pattern in lower K as the percent of organics increases. This is similar to the Nemes et al., (2005) paper that described with increased organic matter there is a decrease in K. That paper describes in more detail that the distribution of clay that directly correlates with the organic matter is really the driver of K.

The hydraulic conductivities through-out Kelsey Creek shows no real spatial patterns as a whole. But Transects 1-3 exhibit similar K values, while transect 4 has decreasing K towards the east and transects 4 and 5 show K decreasing to the west (Figure 3.29). The hydraulic conductivity in piezometers 3D versus 3D2 is interesting, because they are only 30 cm apart and 3D is only 34cm deeper than 3D2. Only 1 sediment core was retrieved between the two piezometers, and only to a depth of 0.90m. Therefore, the screened interval sediment at 1.20 to 1.34 m in 3D was not observed and no clear explanation of the low K in 3D can be given. However, it is likely that the low K reflects a deeper clay layer or lens within the sediments, as such lenses were observed in other parts of the study area.

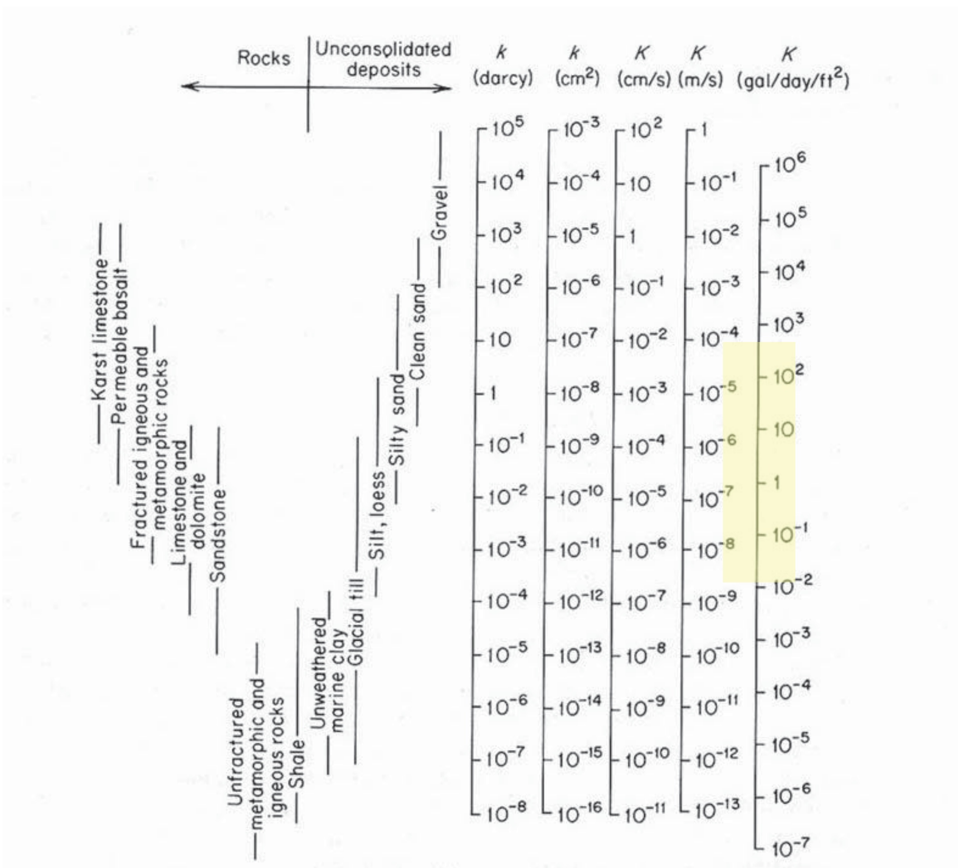

Figure 3.24. Range of values of Hydraulic conductivity from Freeze, 1979. See yellow highlighted area for Kelsey Creek specific measured K.

Table 3.6. Hydraulic conductivity (K) for all piezometers and wells at Kelsey Creek.

Site	Depth below surface (m)	Date of slug test	K (m/s)	Repeated K (m/s) (9/29/14)	Method
1A	1.30-1.46	10/10/2013	4.09×10^{-6}	n/a	Hvorslev
1B	0.50-0.66	10/10/2013	1.56×10^{-4}	n/a	Hvorslev
1C	0.93-1.09	10/10/2013	8.18×10^{-5}	1.05×10^{-6}	Hvorslev
2A	0.47-0.63	10/10/2013	2.02×10^{-5}	n/a	Hvorslev
2B	0.63-0.79	10/10/2013	2.84×10^{-4}	n/a	Hvorslev
2C	0.21-0.37	10/10/2013	1.24×10^{-4}	n/a	Hvorslev
2D	0.57-0.73	10/10/2013	1.07×10^{-4}	1.30×10^{-5}	Hvorslev
2E	0.67-0.83	10/10/2013	7.21×10^{-5}	2.37×10^{-4}	Hvorslev
3B	0.77-0.92	7/9/2014	1.08×10^{-6}	2.67×10^{-7}	Hvorslev
3C	0.14-0.30	7/9/2014	2.37×10^{-6}	n/a	Hvorslev
3D	1.10-1.26	7/9/2014	7.38×10^{-8}	n/a	Hvorslev
3D2	0.76-0.92	3/27/2014	1.11×10^{-5}	n/a	Hvorslev
3E	0.76-0.92	10/10/2013	5.75×10^{-5}	n/a	Hvorslev
3F	0.72-0.88	10/10/2013	1.18×10^{-4}	n/a	Hvorslev
4A	0.49-0.65	3/27/2014	1.49×10^{-4}	n/a	Hvorslev
4B	0.24-0.40	7/9/2014	8.05×10^{-5}	n/a	Hvorslev
4C	0.73-0.89	7/9/2014	2.30×10^{-5}	n/a	Hvorslev
4D	1.20-1.36	7/9/2014	8.94×10^{-6}	1.44×10^{-5}	Hvorslev
5A	0.73-0.89	3/27/2014	1.86×10^{-4}	1.15×10^{-4}	Hvorslev
5B	0.40-0.66	3/27/2014	1.07×10^{-4}	n/a	Hvorslev
5C	0.86-1.02	10/10/2013	6.40×10^{-5}	n/a	Hvorslev
Well A	1.12-2.64	7/9/2014	3.46×10^{-5}	n/a	Bouwer -Rice
Well B	0.14-1.66	7/9/2014	1.79×10^{-5}	n/a	Bouwer -Rice
Well C	1.43-2.95	7/9/2014	1.17×10^{-5}	n/a	Bouwer -Rice

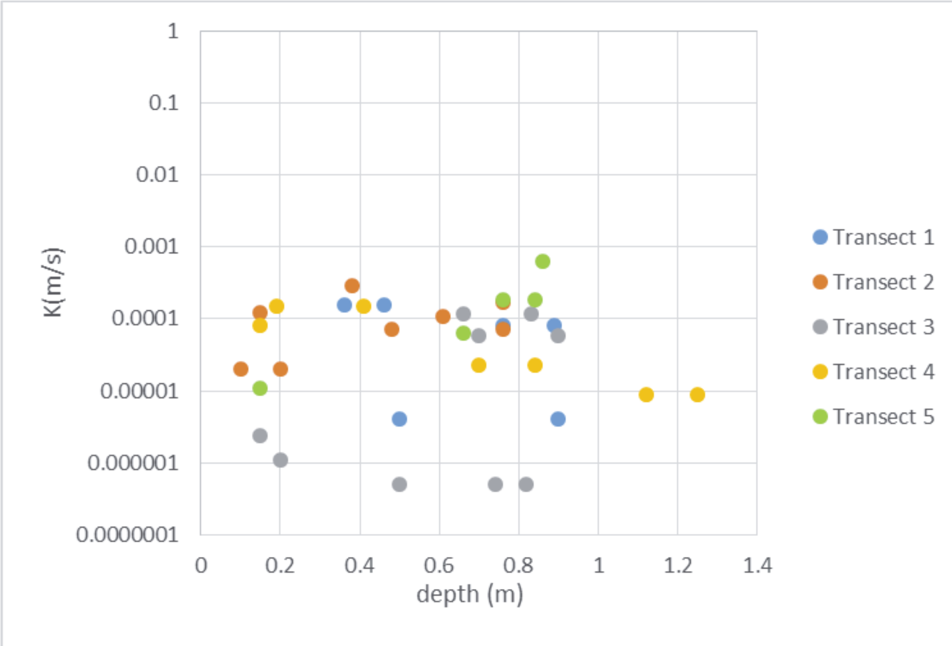

Figure 3.25. The distribution of K at the depth corresponding to the screened interval of sediments from the piezometers of all 5 transects at Kelsey Creek.

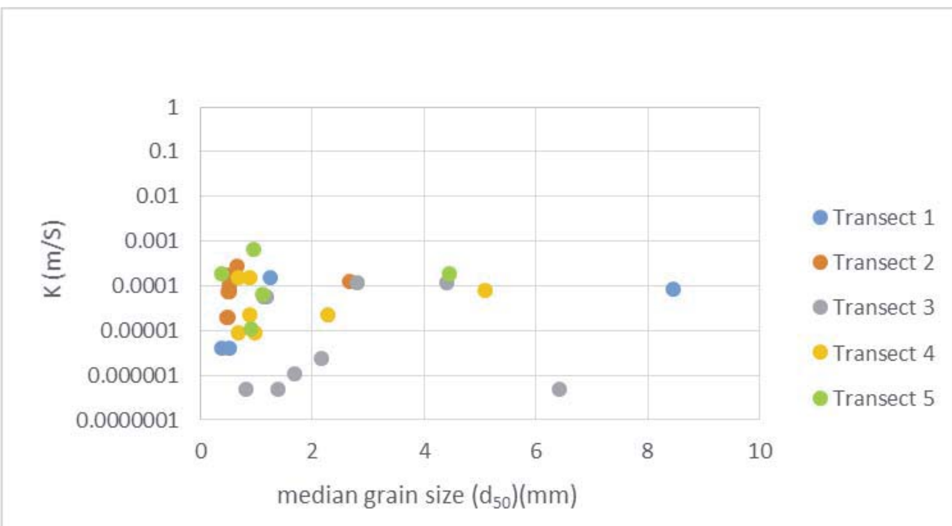

Figure 3.26. The distribution of K at varying the median grain size (d_{50}) from each piezometer within the 5 transects at Kelsey Creek.

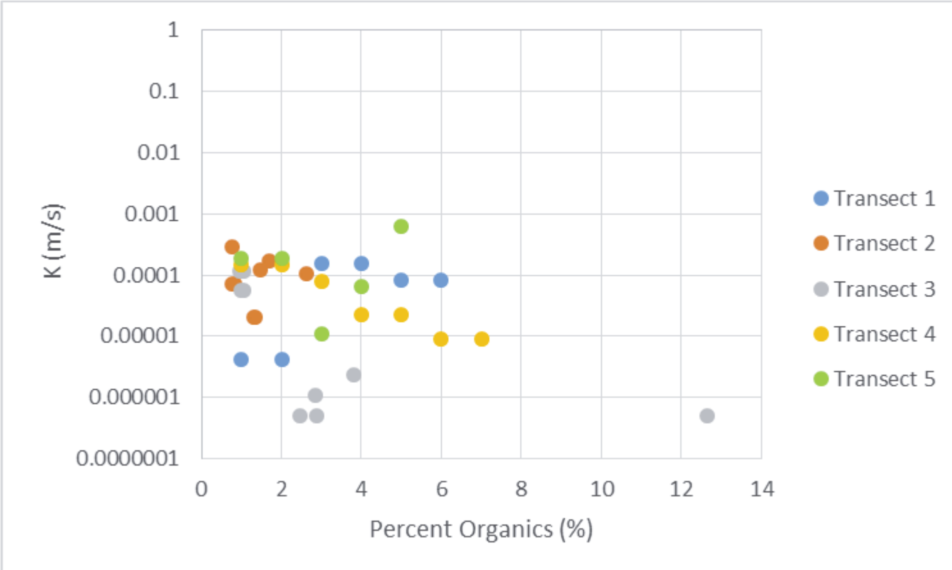

Figure 3.27. The distribution of K with varying organic matter found from loss on ignition (LOI) method determined for each piezometer within the 5 transects at Kelsey Creek.

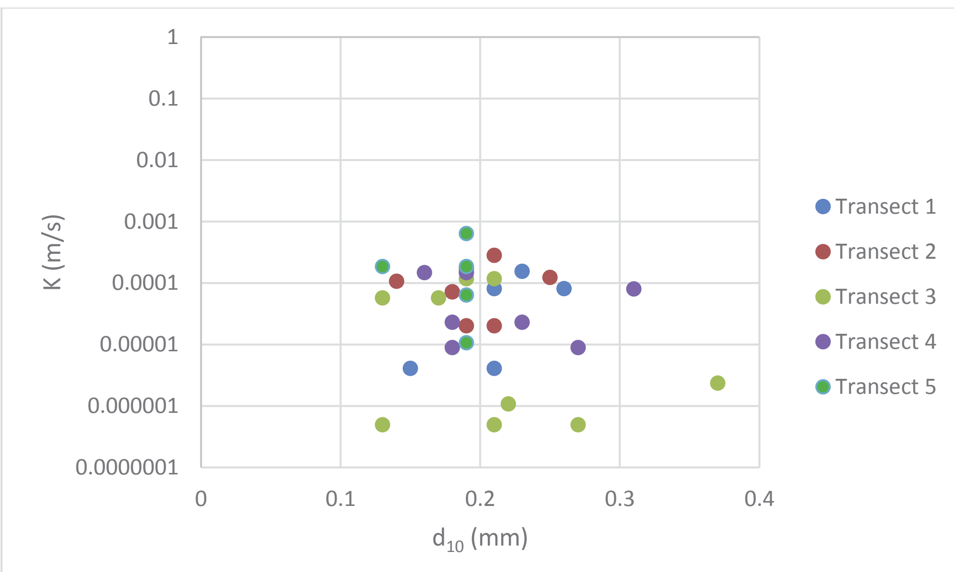

Figure 3.28. The distribution of K at d_{10} from each piezometer within the 5 transects at Kelsey Creek.

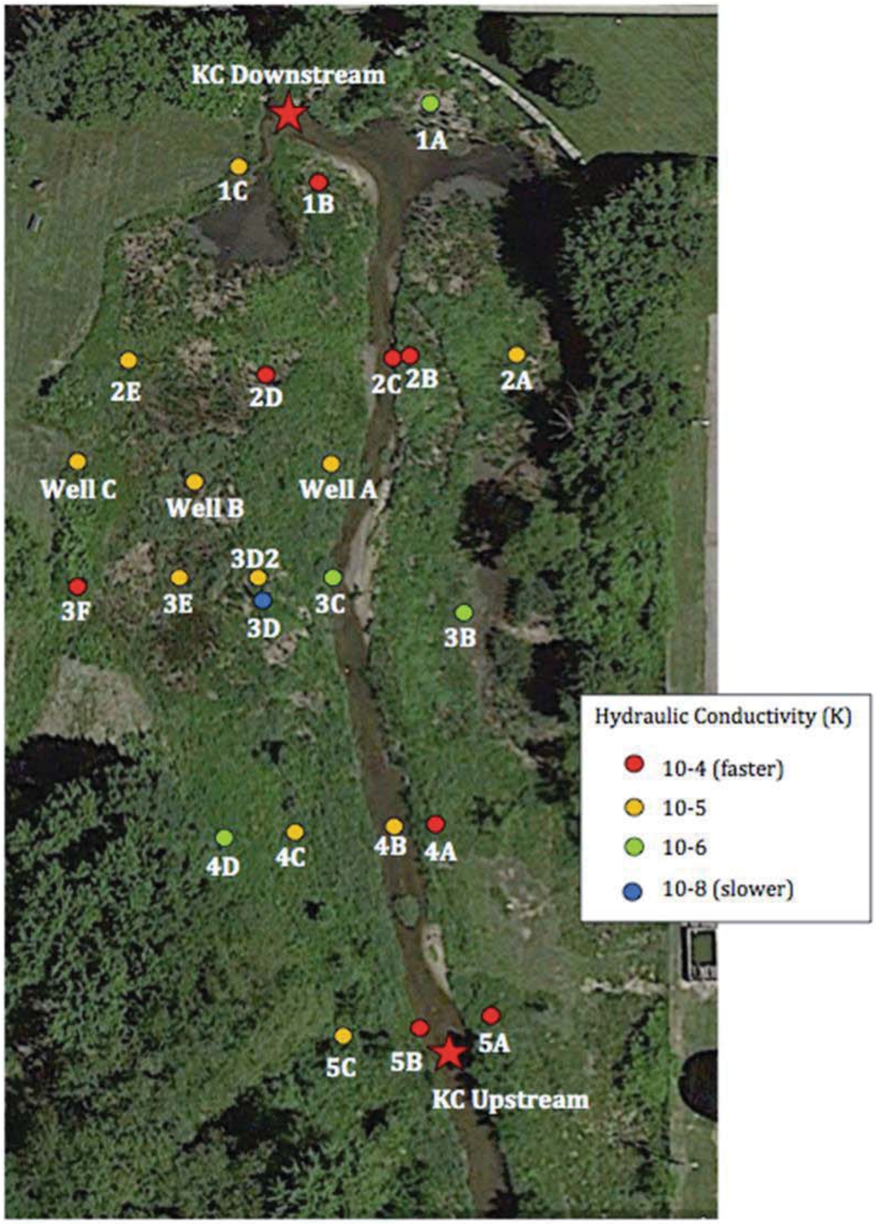

Figure 3.29. Hydraulic Conductivity site map for all 21 piezometers through the Kelsey Creek study area.

3.4.4 Groundwater Flux

The Darcy flux or groundwater flux per unit cross-sectional area (q), calculated from head measurements from 14 different dates and 19 flowlines, revealed values between 1.07^{-06} m/s to 9.23^{-08} m/s (Table 3.7). Groundwater flow directions can be found in Table 3.7 and in Figures 3.20-3.23 and Appendix A. As the minimum head increases within the piezometers and wells the flux decreases across Kelsey Creek. During the fall, the flux tends to be at the highest and gradually decreases until the summer when the groundwater flux is at the lowest value of the study period. The groundwater flux may be related to seasonality, or the decreasing flux may represent some longer-term trend, but more data would be required to differentiate the two.

Table 3.7. Darcy flux of cross-sectional area of 14 select dates and piezometers

Date	Maximum Head (m)	Maximum Head ID	Minimum Head (m)	Minimum Head ID	Change in Head (m)	Distance (m)	Flow Direction	K (m/s)	Hydraulic Gradient (*i*)	Darcy Flux (*q*) (m/s)
9/19/2013	305	2D	304.05	boundary	0.95	26.3	WNW 270°	2.35E-05	3.61E-02	8.49E-07
9/19/2013	304.9	4B	303.5	4D	1.4	23	WSW 261°	2.35E-05	6.09E-02	1.43E-06
10/4/2013	304.9	4A	304	4D	0.9	22.7	WSW 261°	2.35E-05	3.96E-02	9.32E-07
10/10/2013	304.9	4A	304	4D	0.9	25.6	WSW 260°	2.35E-05	3.52E-02	8.26E-07
11/6/2013	304.9	4B	303.5	4D	1.4	22.6	WSW 260°	2.35E-05	6.19E-02	1.46E-06
11/20/2013	304.9	4A	303.85	4D	1.05	25.2	WSW 260°	2.35E-05	4.17E-02	9.79E-07
11/20/2013	304.5	1B	304.1	1C	0.4	9.6	WNW 288°	2.35E-05	4.17E-02	9.79E-07
12/7/2013	305.9	4A	304.75	4D	1.15	25.2	WSW 262°	2.35E-05	4.56E-02	1.07E-06
12/19/2003	304.5	2B	304	boundary	0.5	43.6	WSW ~235°	2.35E-05	1.15E-02	2.69E-07
12/19/2013	304.9	4B	304.2	3D	0.7	35.7	NNW 330°	2.35E-05	1.96E-02	4.61E-07
1/5/2014	304.9	4B	303.8	4D	1.1	23.6	WSW 262°	2.35E-05	4.66E-02	1.10E-06
2/25/2014	304.85	4A	303.95	4D	0.9	26.2	WSW 261°	2.35E-05	3.44E-02	8.07E-07
3/27/2014	305	3C	304.25	Well C	0.75	30.3	WNW ~277	2.35E-05	2.48E-02	5.82E-07
4/17/2014	304.9	4B	303.95	4D	0.95	22.6	WSW 259°	2.35E-05	4.20E-02	9.88E-07
5/15/2014	304.85	Well B	304.7	Mid	0.15	29.4	ESE 122°	2.35E-05	5.10E-03	1.20E-07
5/15/2014	304.85	5A	304.7	4D	0.15	38.2	NWN 294°	2.35E-05	3.93E-03	9.23E-08
5/30/2014	304.9	4B	304.5	4D	0.4	20.6	WSW 260°	2.35E-05	1.94E-02	4.56E-07
6/23/2014	304.8	3C	304.3	boundary	0.5	55.2	WNW ~324	2.35E-05	9.06E-03	2.13E-07
6/23/2014	304.8	4A	304.45	4D	0.35	26.1	WSW 260°	2.35E-05	1.34E-02	3.15E-07

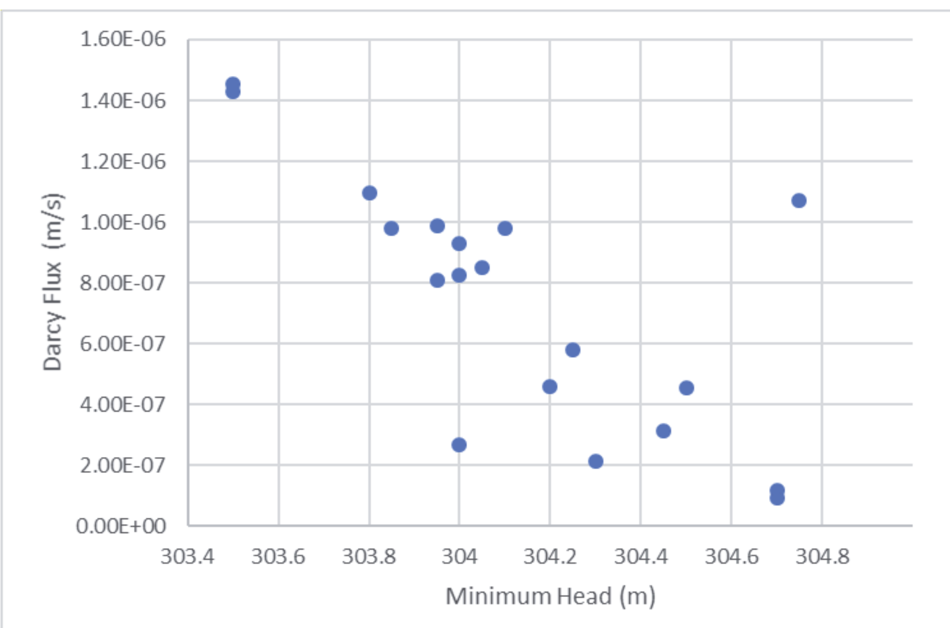

Figure 3.30: Darcy flux (q) decreases as minimum head in piezometers increases

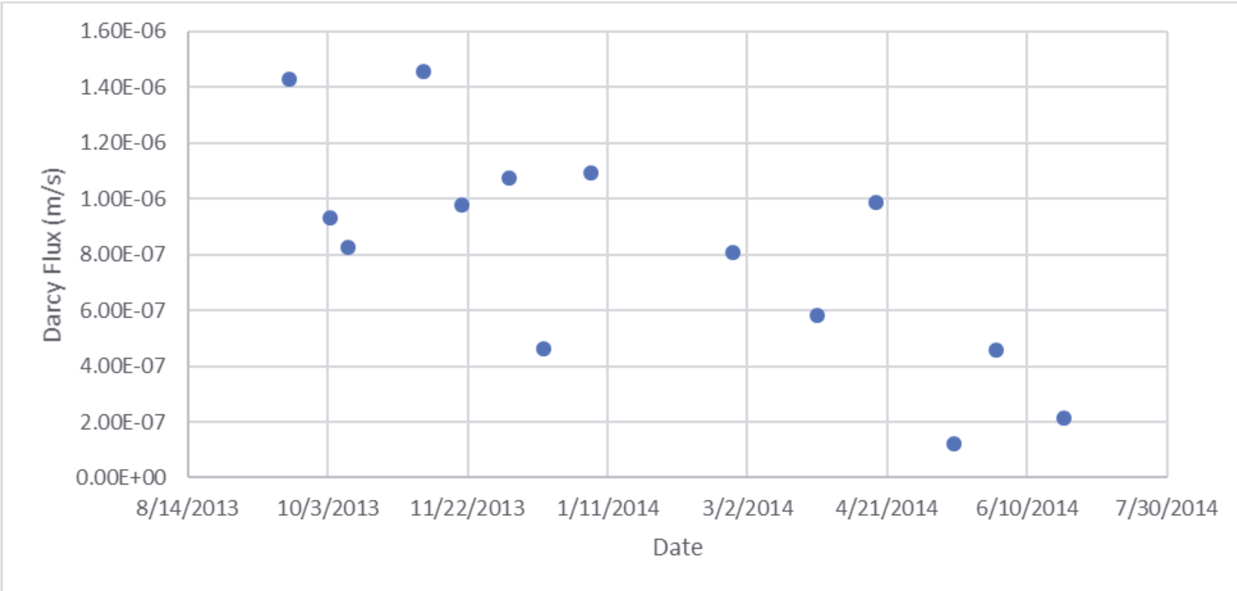

Figure 3.31: Darcy flux (q) for different dates of the study period

3.4.5 Groundwater-Stream Interaction

From selected dates of dry (lower head), wet (higher head) and average (average head) the groundwater-stream interactions were determined using the installed transects of wells and piezometers. Note that these transects may or may correspond to flowlines.

The head measurements in the wells tended to change minimally during different water level conditions (Figure 3.31). The stream was losing water to the closest well A during wet (5/30/14) and dry (2/25/13) conditions. During wet conditions, all the wells had similar head measurements, but in dry and average (10/10/13) conditions, well B and C were similar and had higher head than well A (Figure 3.32).

Piezometer Transect 2 shows the groundwater-stream interaction between 1 in-stream and 4 in-ground piezometers (Figure 3.33). During the driest water level (12/19/13), the stream is losing water toward the west into piezometers 2D and 2E and gaining water from piezometer

2B, which is also losing water toward the east piezometer 2A. During average water level dates like 10/10/13, the water movement was similar to the dry conditions but with less head difference. During the wet conditions (5/30/14), the water movement behaved much differently. The water in the stream tended to gain from both the east from (piezometer 2B and 2A), and very little from piezometer 2D to the west. Piezometer 2D also contributed water to the west and piezometer 2E.

Piezometer Transect 3 showed an interesting interaction between 1 in-stream piezometer and 5 in-ground piezometers (Figure 3.34). On the dry date (12/19/13), head measurements show a flow through system including the stream, gradually gaining from the eastern piezometer 3B and steeply losing to the western piezometers 3D/3D2 and beyond. During average conditions, the stream is similarly flow through with respect to the surrounding piezometers, but piezometers 3D and 3D2 tend to gain water from the west. The wet water level (5/30/14) data showed the stream piezometer 3C gradually losing to both the eastern piezometer 3B and the western piezometer 3D2.

In piezometer Transect 4, the stream was losing water to both piezometer 4A to the east and 4C to the west during wet (5/30/14) and average (10/10/13) conditions (Figure 3.35), with a steeper gradient toward the western side of the former reservoir. On the dry condition (12/19/13) date, empty piezometers were observed at locations 4C and 4D, results are indeterminate about the groundwater-stream interaction to the west of the stream, due to the steep hydraulic gradient created by these empty piezometers. Piezometer 4A shows that at that time, water was moving east out of the stream, as well.

At Transect 5 (Figure 3.36), all water level conditions showed water leaving the stream to both the east and west. It appeared that the water was moving toward piezometer 4A to the east of the stream at a steeper gradient than exhibited to the west.

Overall, the results present a bidirectional groundwater-stream exchange, with predominantly losing conditions and the majority of flow going toward the western side of the former Kelsey Creek reservoir.

Continuous water level fluctuations were recorded from 11/22/13 until 12/19/13 at a downstream site at Kelsey Creek and in wells A, B and C in order to assess the responsiveness of the groundwater system to stream water level fluctuations. During the recorded time period, surface water remained almost constant at around 304.75 m, with a few fluctuations most likely due to precipitation (Figure 3.37). All of the wells exhibited the same patterns during the collection time with similar reactions to water fluctuations. Well A had the highest groundwater head, with well B having just slightly lower head. The groundwater head in well C was 0.1 to 0.15m lower than well A and the lowest of all the wells. These are the results expected based on the results of groundwater movement towards the west. With the stream showing only slight fluctuations and almost constant water levels, the wells exhibit a gradual lowering of head over time. During the continuous water level data collection, manual head measurements were made on two dates (12/7/13 and 12/19/13) and showed similar water level readings.

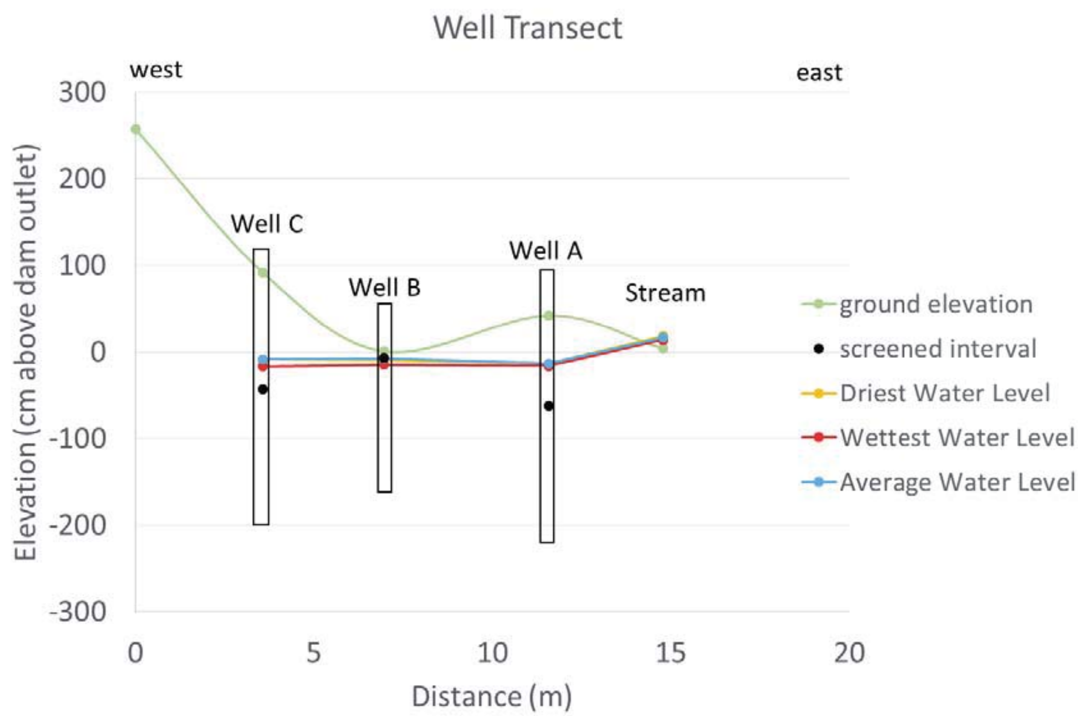

Figure 3.32. Cross section of well transect with a dry water level date of 2/25/13, an average water level date of 10/10/2013 and a wet water level date of 5/30/14. Notice x-axis is in meters and y-axis is in centimeters. Note: Black dot represents top of screened interval and driest water level is plotted under average water level.

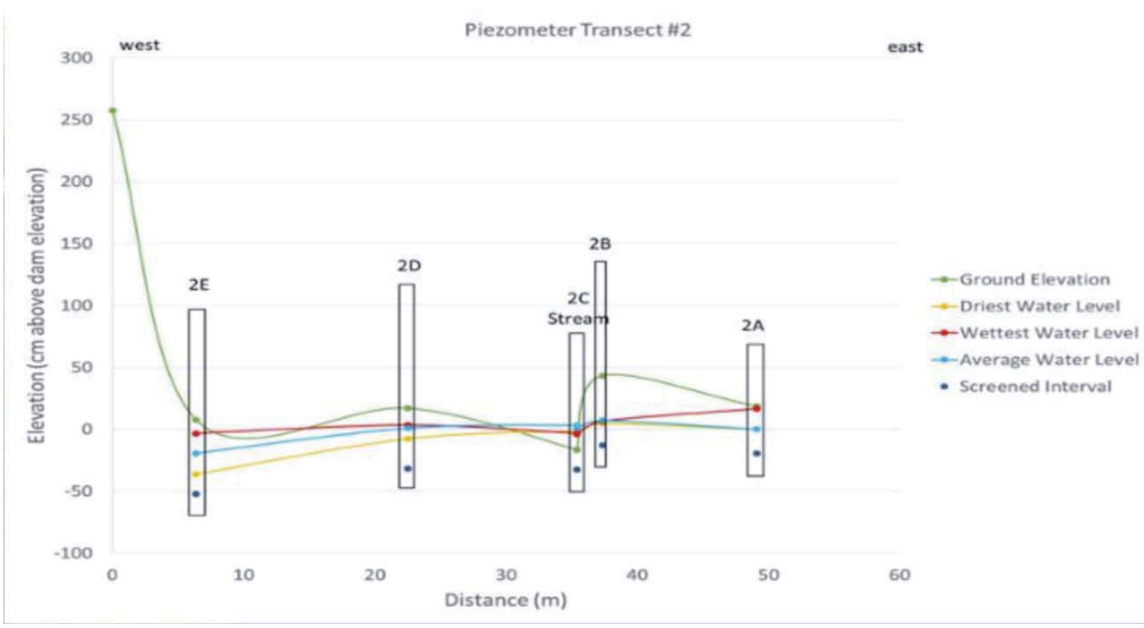

Figure 3.33. Cross section of piezometer transects 2 with a dry water level date of 12/19/13, an average water level date of 10/10/2013 and a wet water level date of 5/30/14. Notice x-axis is in meters and y-axis is in centimeters. Note: Black dot represents top of screened interval.

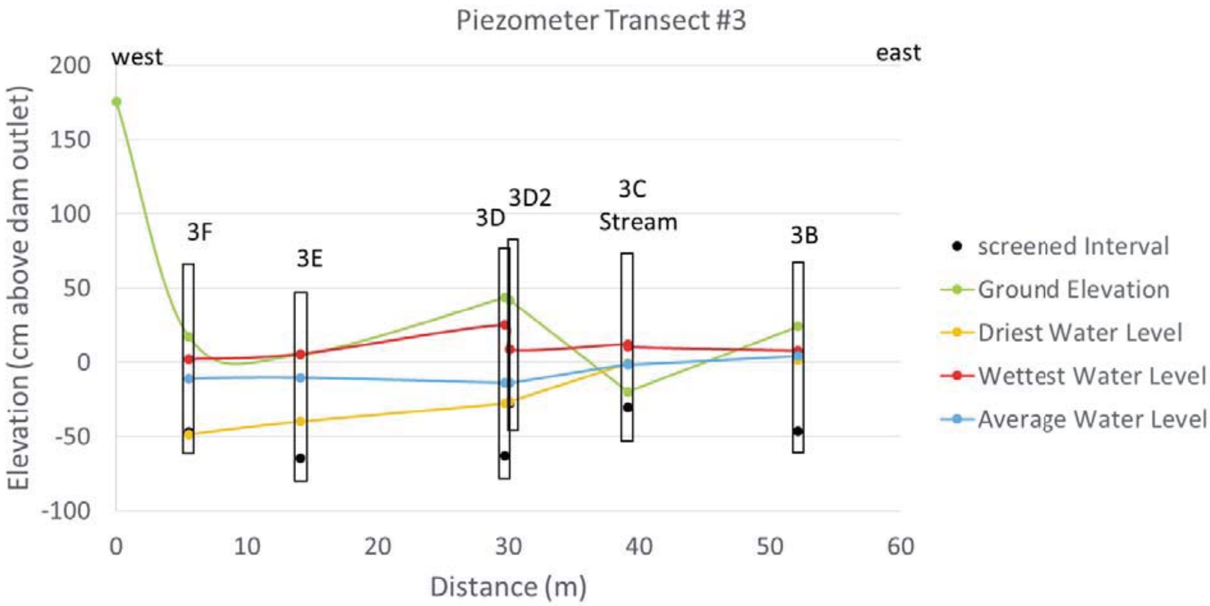

Figure 3.34. Cross section of piezometer transect 3 with a dry water level date of 12/19/13, an average water level date of 10/10/2013 and a wet water level date of 5/30/14. Notice x-axis is in meters and y-axis is in centimeters. Note 3D is 60cm south of 3D2 and black dot represents top of screened interval.

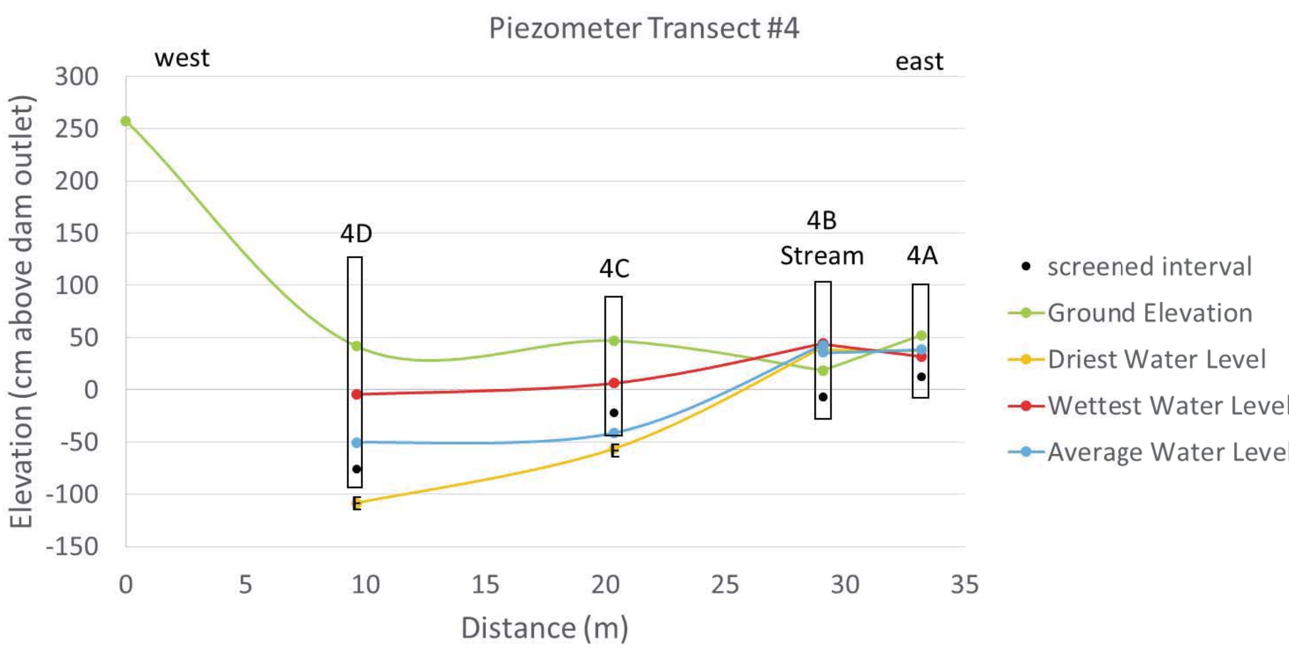

Figure 3.35. Cross section of piezometer transect 4 with a dry water level date of 12/19/13, an average water level date of 10/10/2013 and a wet water level date of 5/30/14. Notice x-axis is in meters and y-axis is in centimeters. Note: E= empty piezometers and black dot represents top of screened interval.

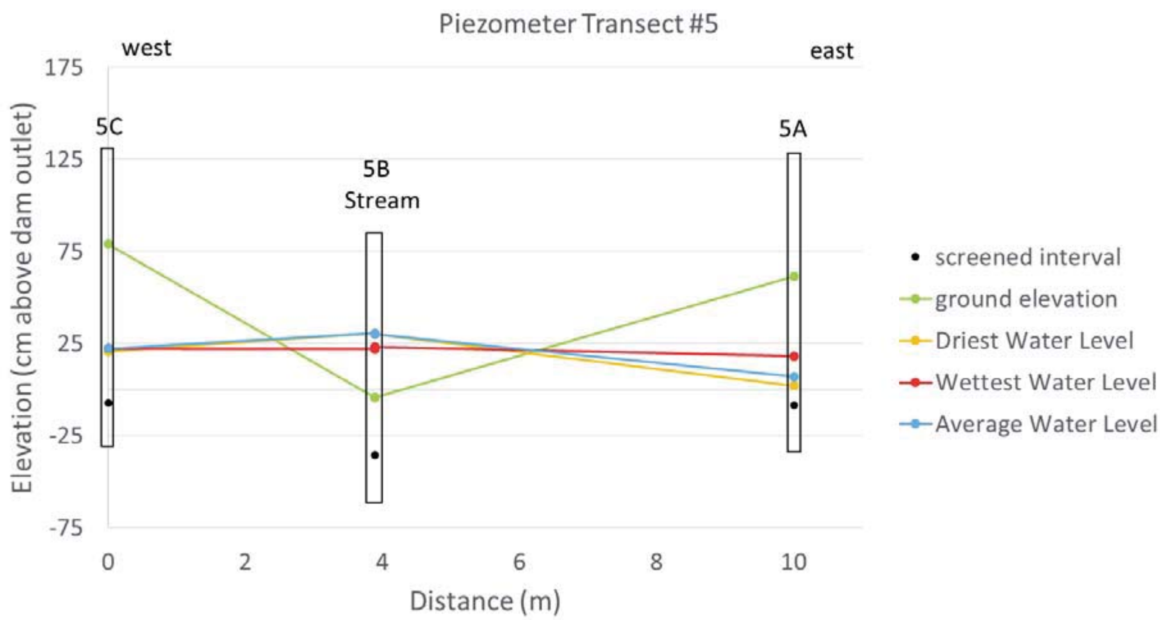

Figure 3.36. Cross section of piezometer transect 5 with a dry water level date of 12/19/13, an average water level date of 10/10/2013 and a wet water level date of 5/30/14. Notice x-axis is in meters and y-axis is in centimeters. Note: Black dot represents top of screened interval.

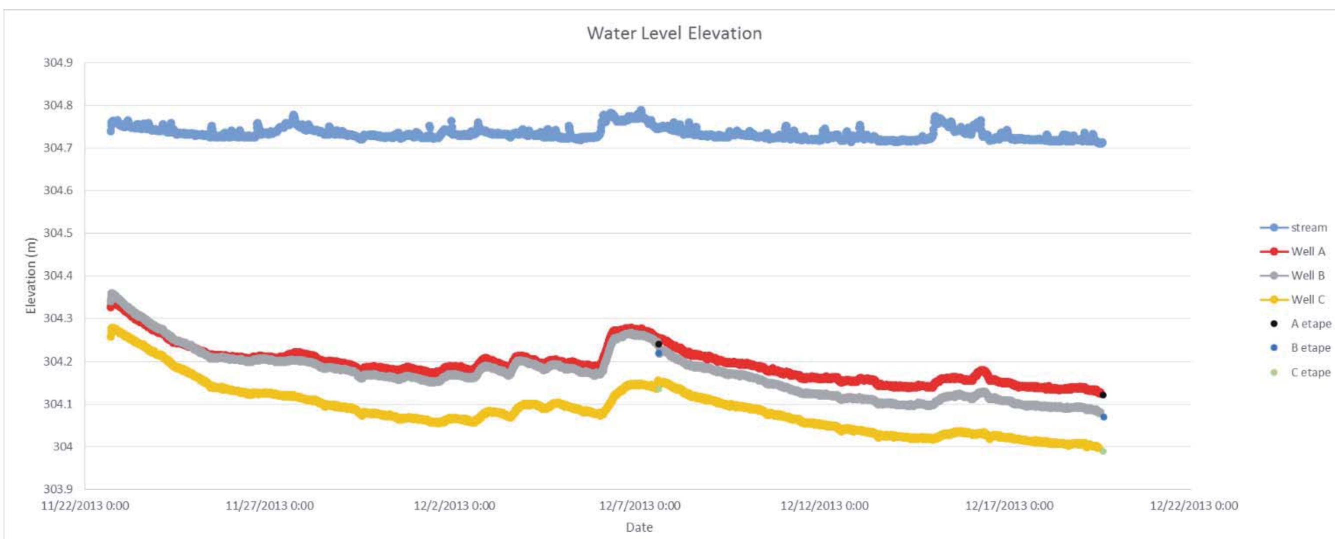

Figure 3.37. Water level measurements from continuous HOBO loggers in the stream and wells A, B and C from 11/22/13 to 12/19/13. Notice two discrete collection dates from in situ electrical tape measurements on 12/7/13 and 12/19/13.

3.4.6 Sediment Measurements

Using the laser particle-size Camsizer, grain size distribution, median grain size (d_{50}), and sorting coefficients from the 35 sediments samples that corresponded to the screened interval of all 21 piezometers was determined. The grain size distribution for each transect can be located on Figures 3.28-3.42. In Transect 1, the grain sizes of 1A is of uniform size throughout the whole depth of the borehole, while in 1B an 1C the grain size tends to be finer with depth and have a bimodal distribution (Figure 3.38). In Transect 2, grain size distribution is uniform and tracks the same for each piezometer, regardless of depth. 2A, 2B, and 2E have similar distributions, 2D has a somewhat coarser sediment distribution, and the stream piezometer 2C has even coarser sediment that has a different distribution from the rest (Figure 3.39). Transect 3 is interesting because the stream piezometer 3C has finer sediments compared to the rest of the sites within that transect. Piezometer site 3E has similar grain size distribution in both deep and shallow sediment, but in 3F grain size coarsens downwards. The same is true for 3D-3D2, but we see a layering of sediments, as it gets coarser from a depth of 0.74-0.82m, it then gets finer from a deeper depth of 0.82-0.90m (Figure 3.40). Transect 4, 4A and 4C have uniform grain size distributions that fine upwards. The stream piezometer at 3C has a more coarse, bimodal distribution, while 4D has a more uniform distribution that fines downward (Figure 3.41). In transect 5, the distribution for 5A is similar to what we have seen in other transects, with coursing of grains with depth with the addition of more bimodal distribution with depth, in 5C grains are similar to each other in both deep and shallow sediments and have a similar distribution as the stream piezometer site, 5B (Figure 3.42).

The median grain size (d_{50}) ranged from 0.41mm to 9.23mm (Table 3.8), with an average of 1.72 mm and the sorting coefficient ranged from 1.58 to 4.78 (Table 3.8), with an average of

2.93 throughout the whole study area. The relatively high sorting coefficient value indicate that the sediment was poorly sorted. In 1B, the median grain size and sorting coefficient was undetermined due to the amount of leaf litter in the sample. Depth of the sediment below the surface had no effect on the d_{50} observed (Figure 3.43) or on the sorting coefficient, but the largest median grain sizes are observed between a depth of 0.4 and 0.5m below the surface.

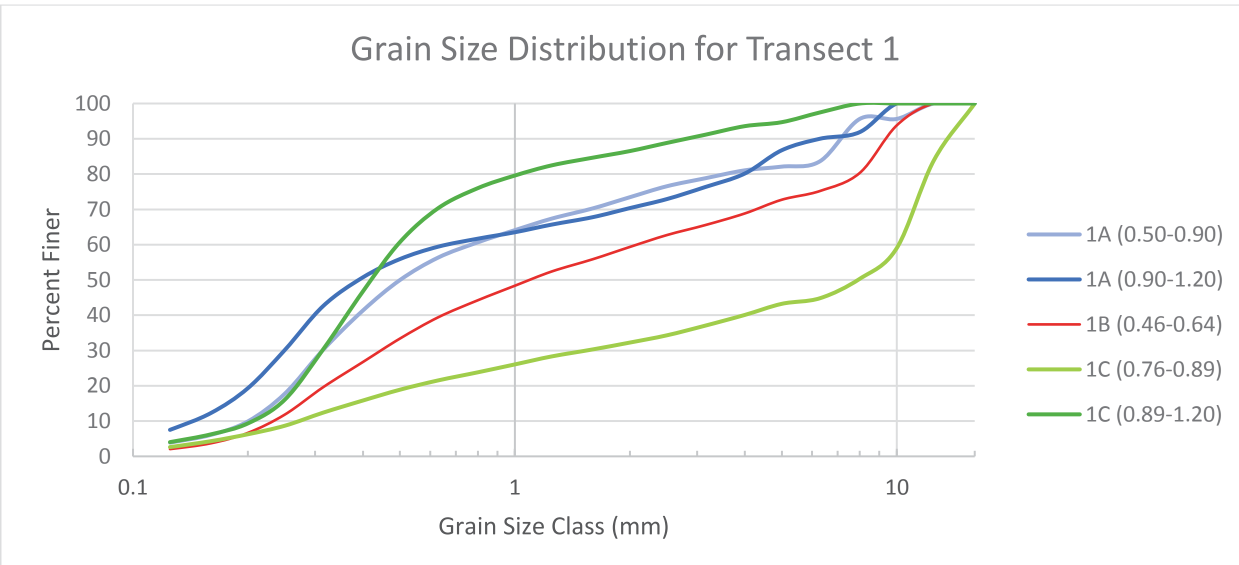

Figure 3.38. Grain size distribution of the 3 piezometer locations of transect 1 at Kelsey Creek. Transect 1 is the northern most transect in this reach and location A starts in the east and runs west. Note parentheses are depths in meters below surface.

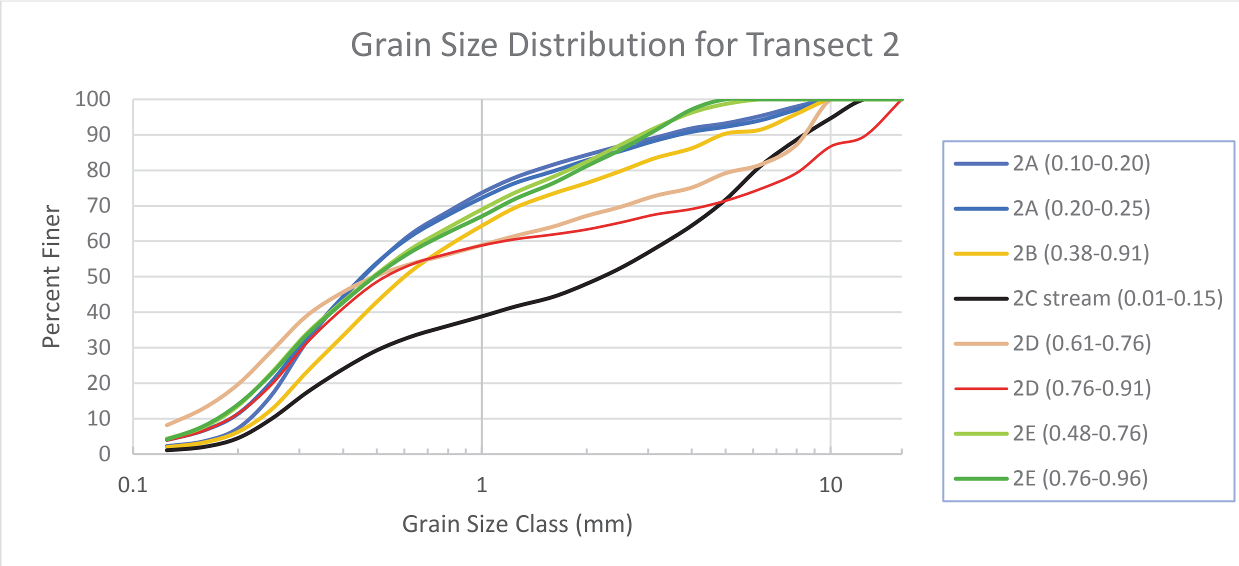

Figure 3.39. Grain size distribution of the 5 piezometer locations of transect 2 at Kelsey Creek. Location A starts in the east and runs west. Note parentheses are depths in meters below surface.

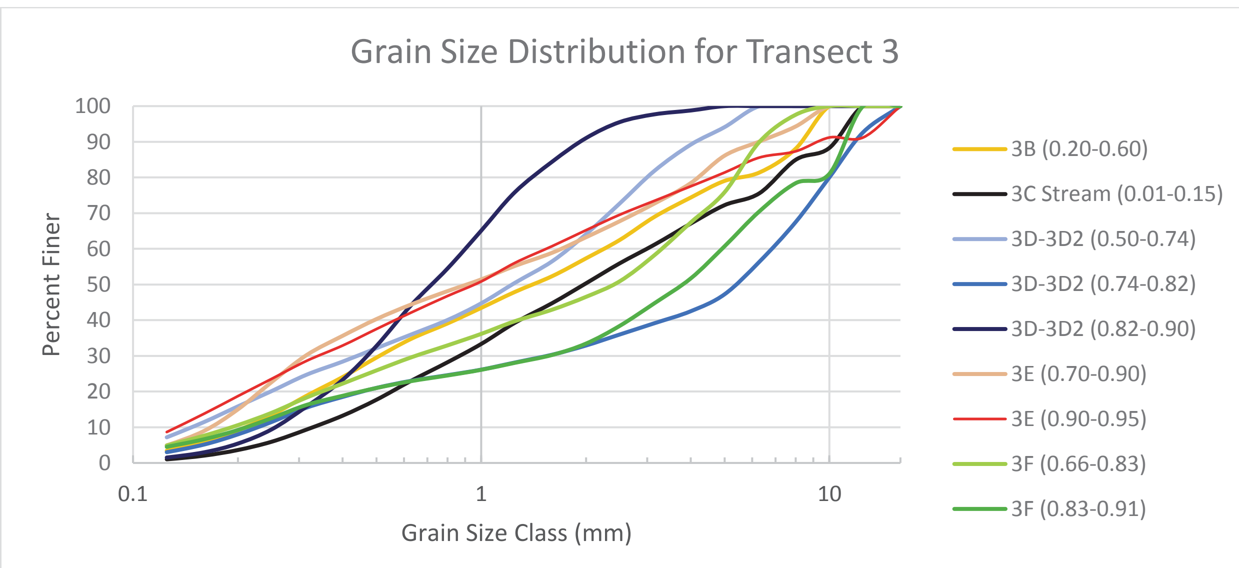

Figure 3.40. Grain size distribution of the 5 piezometer locations of transect 3 at Kelsey Creek. Location B starts in the east and runs west. Note parentheses are depths in meters below surface.

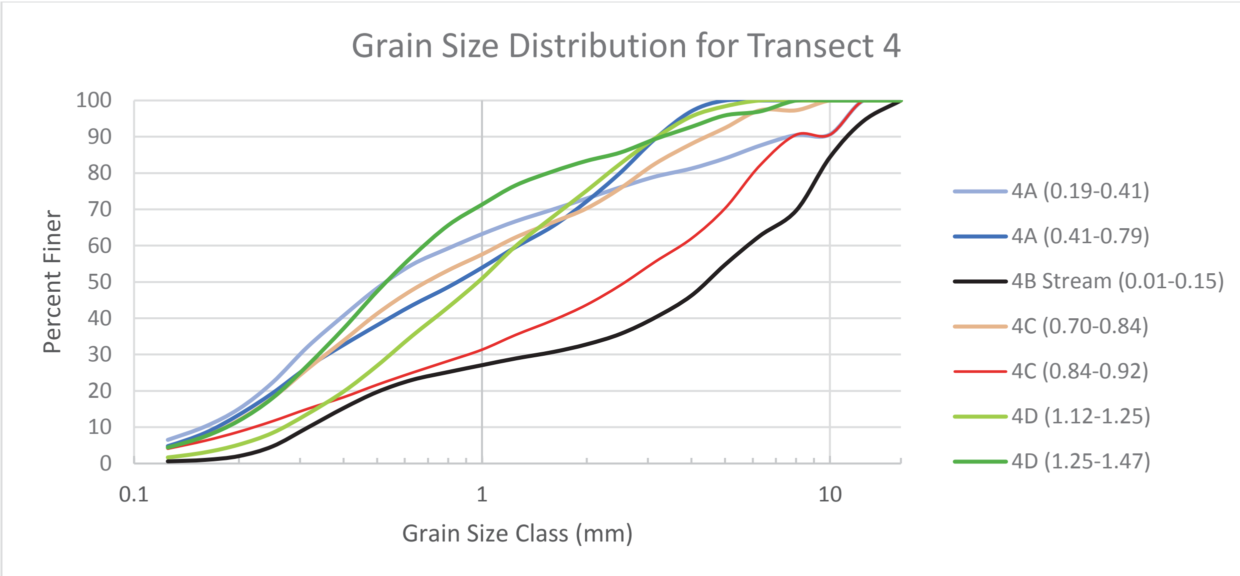

Figure 3.41. Grain size distribution of the 4 piezometer locations of transect 4 at Kelsey Creek. Location A starts to east of the stream and runs west. Note parentheses are depths in meters below surface.

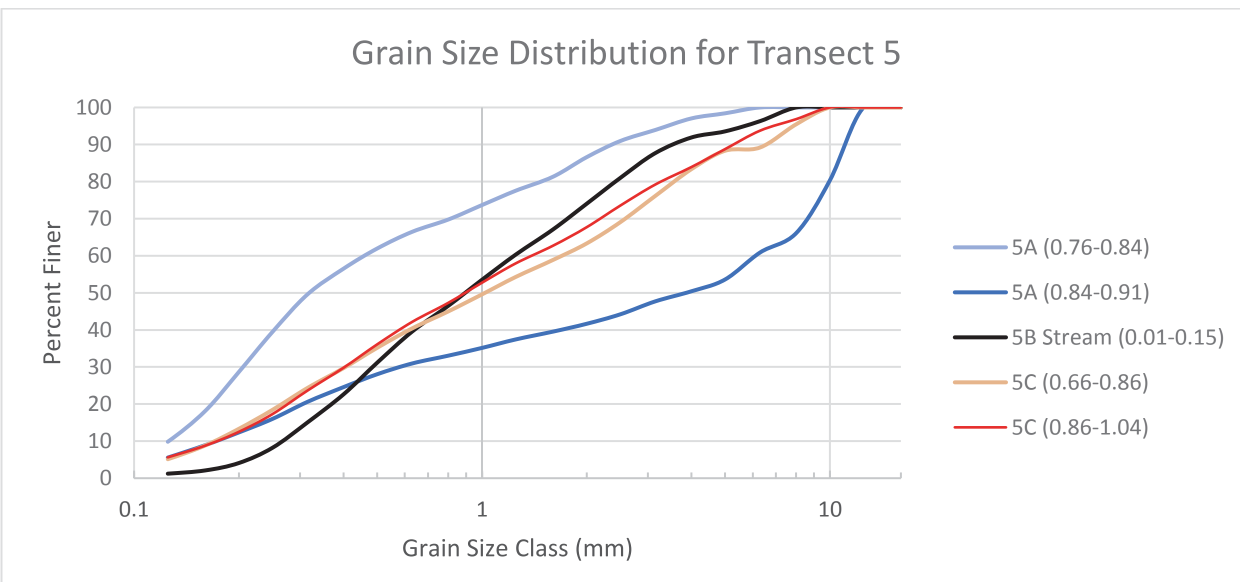

Figure 3.42. Grain size distribution of the 3 piezometer locations of transect 5 at Kelsey Creek. Transect 5 is the southernmost transect in this reach and location A starts in the east of the stream and runs west. Note parentheses are depths in meters below surface.

Table 3.8. Grain size values (d_{50} and sorting coefficient) for sediment samples selected adjacent to piezometer-screened intervals at Kelsey Creek.

Sample ID (cm)	Depth below surface (cm)	Surface Elevation (m)	Median Grain Size d_{50} (mm)	Sorting Coefficient	Sediment Type
1A	0.50-0.90	305	0.52	2.92	Med. Sand
1A	0.90-1.20	305	0.37	3.59	Med. Sand
1B	0.36-0.46	305.25	leaf litter	leaf litter	Organic
1B	0.46-0.64	305.25	1.25	4.04	Coarse Sand
1C	0.76-0.89	305.36	8.45	3.42	Med. Pebble
1C	0.89-1.20	305.36	0.52	1.58	Med. Sand
2A	0.10-0.20	305.17	0.47	1.89	Med. Sand
2A	0.20-0.25	305.17	0.48	2.06	Med. Sand
2B	0.38-0.91	304.94	0.65	2.34	Coarse Sand
2C	stream (0.01-0.15)	305.24	2.67	3.5	V. Fine Pebble
2D	0.61-0.76	305.66	0.51	4.08	Coarse Sand
2D	0.76-0.91	305.66	0.5	4.78	Coarse Sand
2E	0.48-0.76	305.45	0.49	2.26	Coarse Sand
2E	0.76-0.96	305.45	0.51	2.39	Coarse Sand
3B	0.20-0.60	305.11	1.67	3.16	V. Coarse Sand
3C	stream (0.01-0.15)	305.11	2.15	2.98	V. Fine Pebble
3D-3D2	0.50-0.74	305.26	1.38	2.82	V. Coarse Sand
3D-3D2	0.74-0.82	305.26	6.42	3.3	Fine Pebble
3D-3D2	0.82-0.90	305.26	0.82	1.65	Coarse Sand
3E	0.70-0.90	304.92	1.14	3.83	V. Coarse Sand
3E	0.90-0.95	304.92	1.17	3.63	V. Coarse Sand
3F	0.66-0.83	304.1	2.8	3.18	V. Fine Pebble
3F	0.83-0.91	304.1	4.4	2.89	Fine Pebble
4A	0.19-0.41	305.49	0.67	3	Coarse Sand
4A	0.41-0.79	305.49	0.89	2.7	V. Coarse Sand
4B	stream (0.01-0.15)	305.5	5.1	3.32	Fine Pebble
4C	0.70-0.84	305.35	0.87	2.84	Coarse Sand
4C	0.84-0.92	305.35	2.27	2.85	V. Fine Pebble
4D	1.12-1.25	305.73	0.98	2.04	V. Coarse Sand
4D	1.25-1.47	305.73	0.67	2.09	Coarse Sand
5A	0.76-0.84	305.91	0.37	2.61	Med. Sand
5A	0.84-0.91	305.91	4.44	4.64	Fine Pebble
5B	stream (0.01-0.15)	305.16	0.91	2.1	V. Coarse Sand
5C	0.66-0.86	305.78	1.11	2.82	V. Coarse Sand
5C	0.86-1.04	305.78	0.95	2.98	V. Coarse Sand

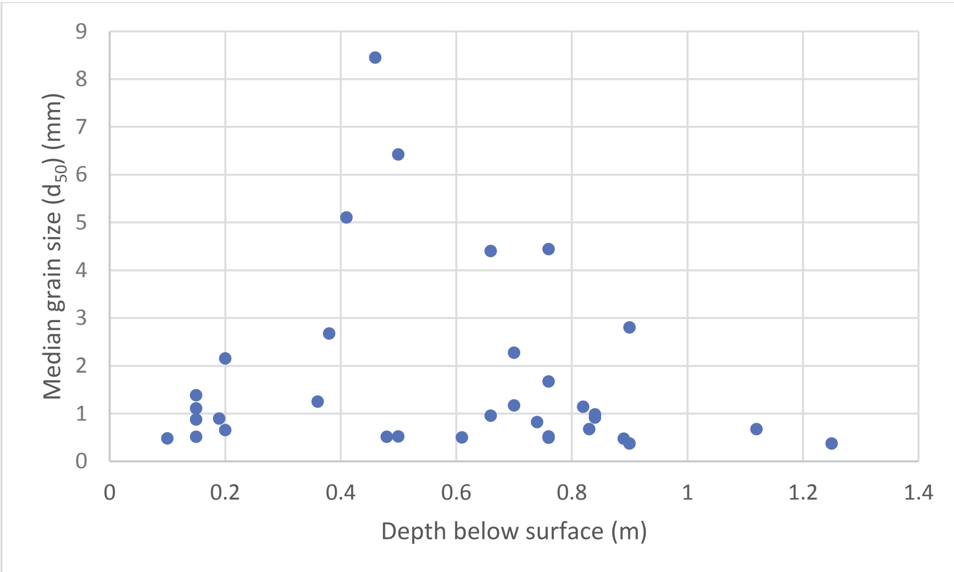

Figure 3.43. The distribution of d_{50} at the depth of the sediments corresponding 30 cm south of each piezometers from all 5 transects at Kelsey Creek.

CHAPTER 4 – DISCUSSION

The overall goal of this study was to increase understanding of how former reservoirs can impact water quality and groundwater-stream interactions several years after a dam removal. This research expanded the way stream restorations by dam removal are assessed, by considering persistent effects on water quality and hydrogeology, rather than focusing changes relative to conditions prior to dam removal.

It was hypothesized that there would be no change in water quality as water flows through each former reservoir. This hypothesis is supported. The surface water that flowed through both Plum Creek and Kelsey Creek was relatively unchanged over the range of different parameters for each upstream site to the downstream site. Due to the water collection of the upstream water and downstream water being within minutes of each other, I was only able to retrieve the water moving directly through the stream at one given time. Had water samples been collected continuously, maybe a lag in water quality improvement may have been detected.

It was also hypothesized that there would be no distinguishable water quality effects seen between restored versus unrestored sites, in terms of the changes to water quality as the streams flowed through the former reservoirs. For the water quality parameters measured, neither the restored site, Plum Creek, or the unrestored site, Kelsey Creek, revealed evidence of water quality improvements at the restored sites, so there was no apparent effect of restoration. This supports the hypothesis that restoration status will have no effect on water quality improvement in former reservoirs. Both the upstream and downstream surface water at Plum Creek compared to Kelsey Creek was generally the same, but Plum Creek did have overall slightly better water quality results. This is most likely due to the larger, less urbanized watershed contributing to Plum Creek relative to the watershed of Kelsey Creek. Overall, these results suggest that water quality issues within urban stream systems will continue to persist, even after dam removals and restoration.

The unrestored Kelsey Creek site exhibited interesting hydrogeologic flowpaths, sediment characteristics, and groundwater quality that suggest that former reservoirs may create opportunities for groundwater-stream interactions. I hypothesized that local groundwater contributed to the stream from both the east and west sides of the former reservoir at Kelsey Creek. However, potentiometric surface maps created in Surfer 10® show the groundwater movement differs in the northern and southern ends of the study site, moving more northwesterly in the north area and more southwesterly in the south area. These potentiometric maps also help determine that the groundwater is moving overall in westerly direction, while the surface water is moving north. Over the study period, the maximum head remained fairly constant, while the minimum head is what actually changed over time, leading to the variation of hydraulic gradient seen in the potentiometric surface. The stream tends to lose water to surrounding groundwater during lower water level conditions and gain water during wetter water level conditions, which can be seen better in some transects that have steeper gradients. From these finding we find the original hypothesis not supported.

Hydraulic conductivity was very important in this study because high heterogeneity of the site (ranging from gravelly sands to clean clay lenses) made determining the geometric mean essential to other factors, such as groundwater flux. The site had a large range of sediment sizes which are poorly sorted, with no clear correlation between depth and sediment size or loss on ignition. Overall, the poorly sorted sediments and low loss on ignition for the kind of wetland like setting found at the former reservoir at Kelsey Creek is unusual, which may reflect the site's history as a reservoir that was fluvially reworked into its current wetland state.

Water quality associated with the groundwater-stream interactions at Kelsey Creek turned out to be very interesting. Specific conductance was very high and exhibited strong seasonal patterns in both surface and groundwater. An inverse relationship emerged between specific conductance and stream discharge. These relationships may be explained by the residence time of water in the system. Water that remained trapped within the ground longer resulted in a higher specific conductance than water that moved through the system quickly. These results could be due to groundwater contributing to the stream during low flows and losing water from the stream to the local groundwater during high flows.

At Kelsey Creek, stream and groundwater show some differences. The results are not always seen in the statistical analyses but can be clearly observed within seasonal patterns of the different parameters measured. In general, water in well A is most similar to the stream, while well C is the most different. Well B displays variability that might be related to its location in the former reservoir, where it is sometimes submerged, similar to anaerobic conditions seen in wetland areas. The oxygen (δO^{18}) isotopes support evidence that water within well A is closely related to the surface water, with well B more dampened in the results. It also revealed an approximately 64-day lag time between the stream and well C, which also helps explains some of the anion and water quality lags also seen within well C.

Within the near-stream groundwater, chloride is significantly different overall between wells B and C and each well exhibited different seasonal patterns. While groundwater concentrations did not show the same range of seasonal variability as surface water, groundwater concentrations ranged from 96-451mg/L, which often exceeded the 250 mg/L secondary maximum contaminant level recommendations for the US EPA. Chloride was most likely present in such high concentrations due to the application and runoff of road salt near and around this urban area.

Other anions also exhibited elevated concentrations in Kelsey Creek surface water and groundwater. Sulfate had the second highest concentration of the measured anions, with well C having the greatest concentrations. Nitrate was at or around the US EPA maximum contaminant level of 10 mg/L for drinking water. Sulfate and nitrate are most likely elevated from fertilizers used on golf course and lawns, leaky sewer pipes, and atmospheric deposition within the Kelsey Creek watershed.

CHAPTER 5 – CONCLUSION AND RECOMMENDATION

5.1 Conclusion

At the two former reservoirs studied here, water quality concerns were part of the justification for removal of the dams, and relative to pre-removal conditions, dissolved oxygen may have increased, and stagnant water decreased, as have been documented in other studies. However, regardless of restoration status of the former reservoir reaches, they now have little effect on stream water quality when considered on an upstream to downstream basis. Instead, overall water quality may be affected by the urban stream settings.

In terms of groundwater-stream interactions, shallow, local hydrogeologic flowpaths within the former reservoirs may not be consistent with broader regional groundwater flow directions. This may be because of the high heterogeneity of reworked reservoir sediments or because of other local influences just outside of the former reservoir site. Therefore, groundwater may have no significant influence on the overall stream water quality, and stream water entering the shallow groundwater in a former reservoir may degrade local groundwater quality. Without previous hydrogeologic knowledge of the areas, we have a limited understanding of how reservoir and sediment characteristics may influence the flowpaths that develop post-dam removal. Via, sediment removal or compaction. However, knowing the post-dam removal shallow flowpaths in former reservoirs may help determine what type, if any of stream stability to use or if additional water quality Best Management Practice's (BMPs) need to be added.

While dam removal is considered a great start for improving stream ecosystems, I have found that, regardless if a system is unrestored or restored, the post-removal water quality will depend on the overall watershed area and quality. Left unaltered, the former Kelsey Creek reservoir provides some flood control and shallow groundwater recharge in a wetland area, while the design of the restoration at Plum Creek will control the extent of those functions at that site.

Overall, dam removal can be good for lots of the reasons, but former reservoir reaches, restored or unrestored, have no practical means to mitigate the watershed-level influences on water quality. This suggests that there are many variables associated with the success of dam removals and only looking at a few cannot be a single solution to all the water quality problems within a watershed.

5.2 Recommendation for Future Research

Continual research and monitoring of dam reservoirs prior to removal and post removal to ensure all variables of these removals are properly identified and studied. Continual water quality sampling versus the grab water quality sampling used in this study, could provide more data and potential information into flow pathways once waterways are affected from dam removals. Future dam removal studies can also be cataloged and used to build upon as more dams near or pass their life expectancy and need to be torn down.

This study was limited in scope, but it is recommended that future research expand to include biology, geomorphology and urban hydrology, which could strengthen how we decommission dams in the future.

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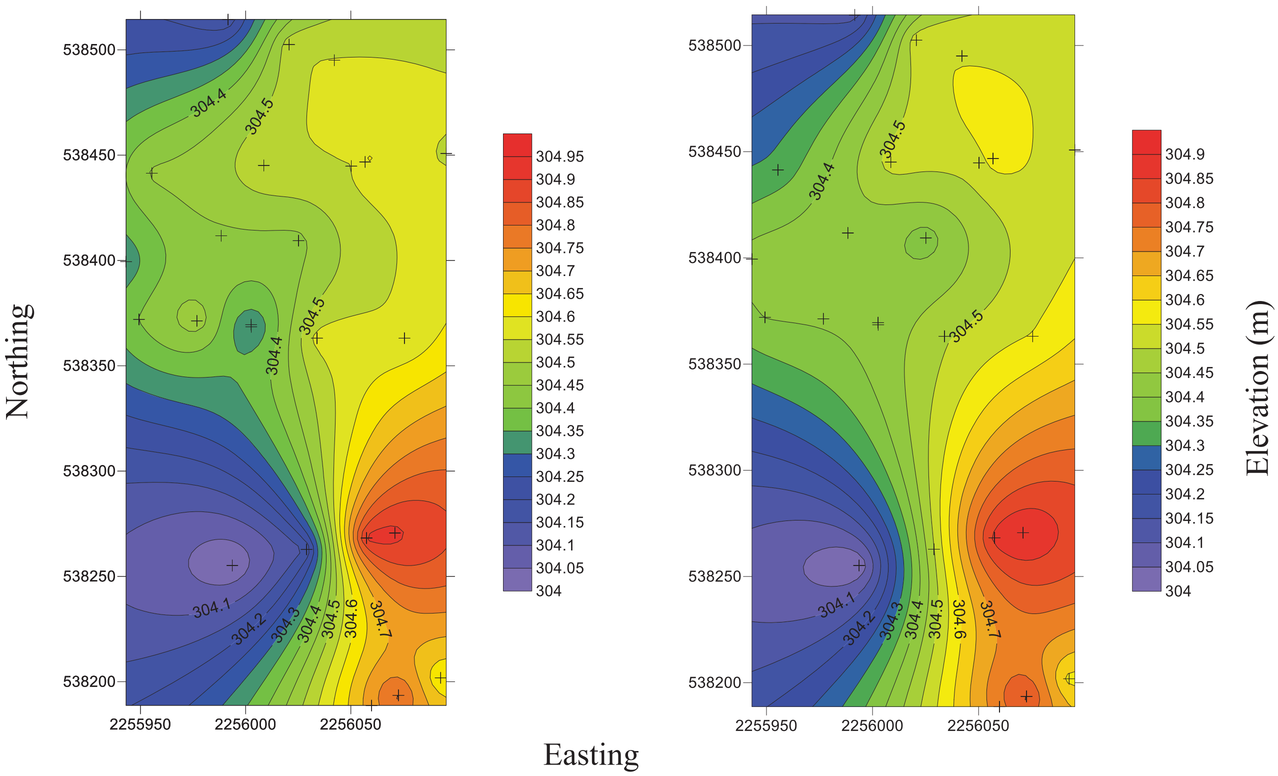
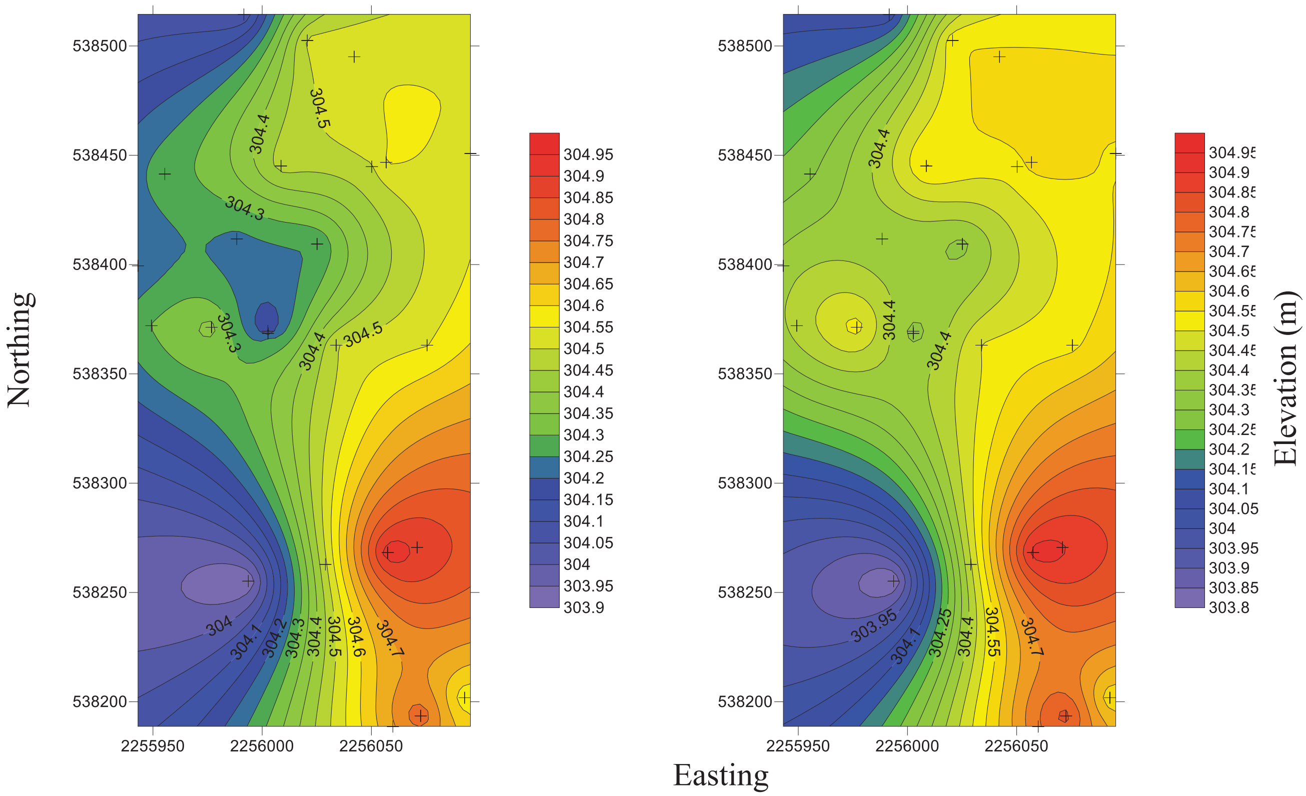
APPENDICES

APPENDIX A: Potentiometric maps created in Surfer from 10 additional data collection dates

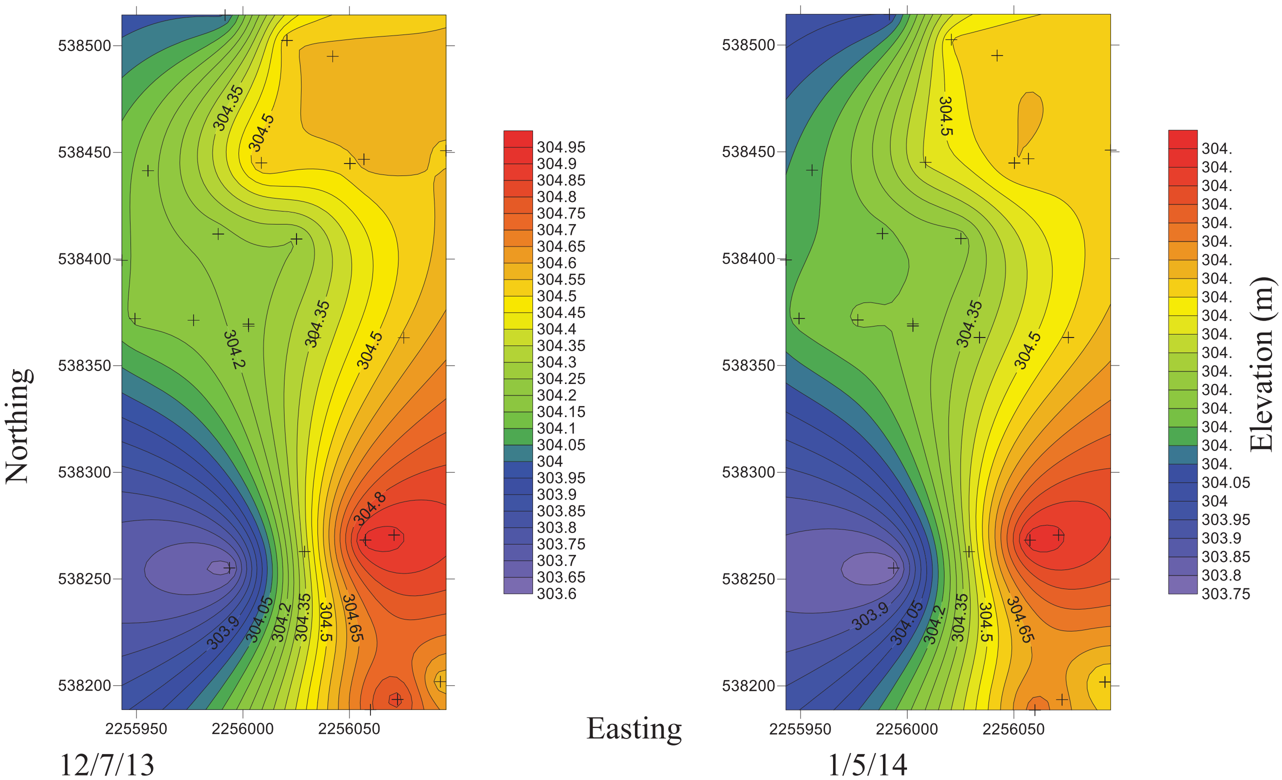


10/4/13 10/10/13



11/6/13

11/20/13


Northing
Easting
Elevation (m)
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538300
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538200
2255950
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304.35
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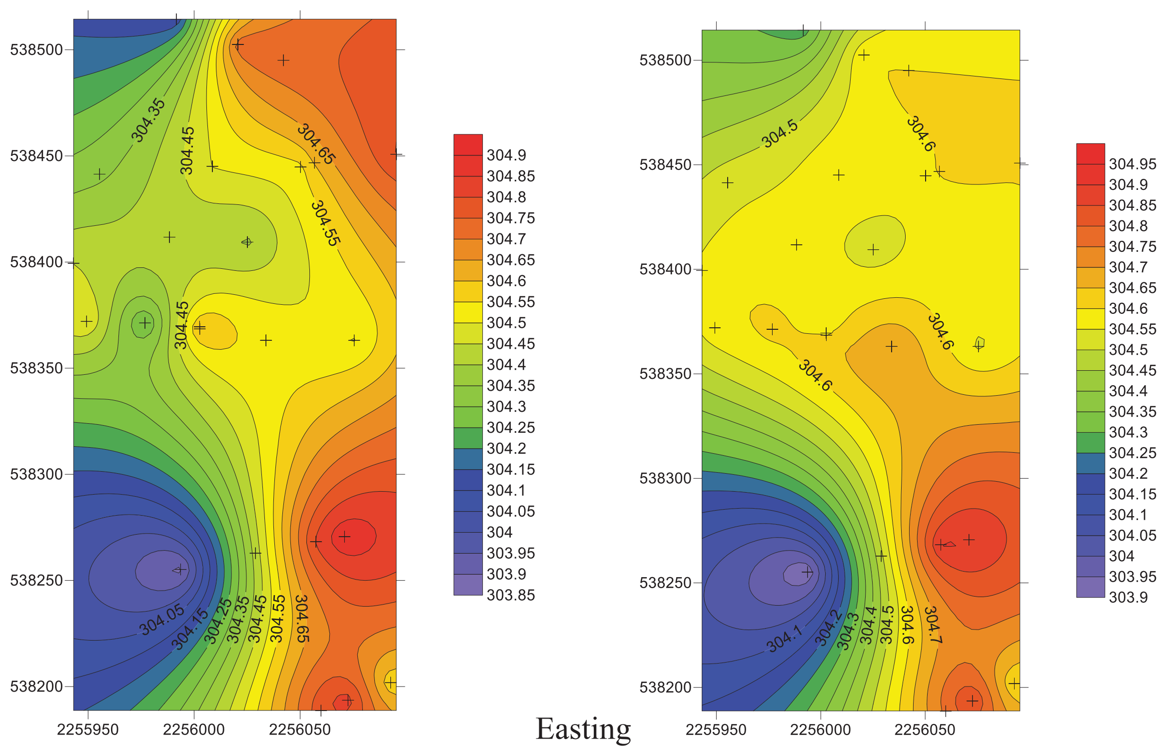
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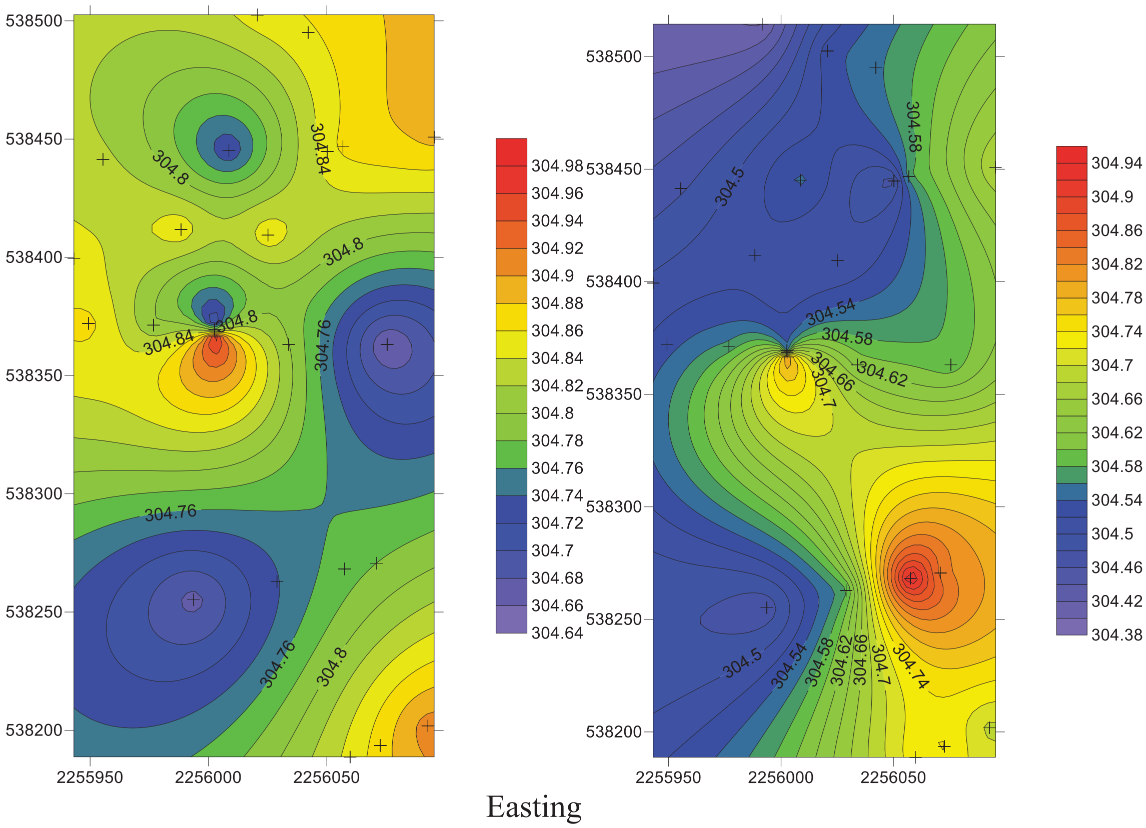
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