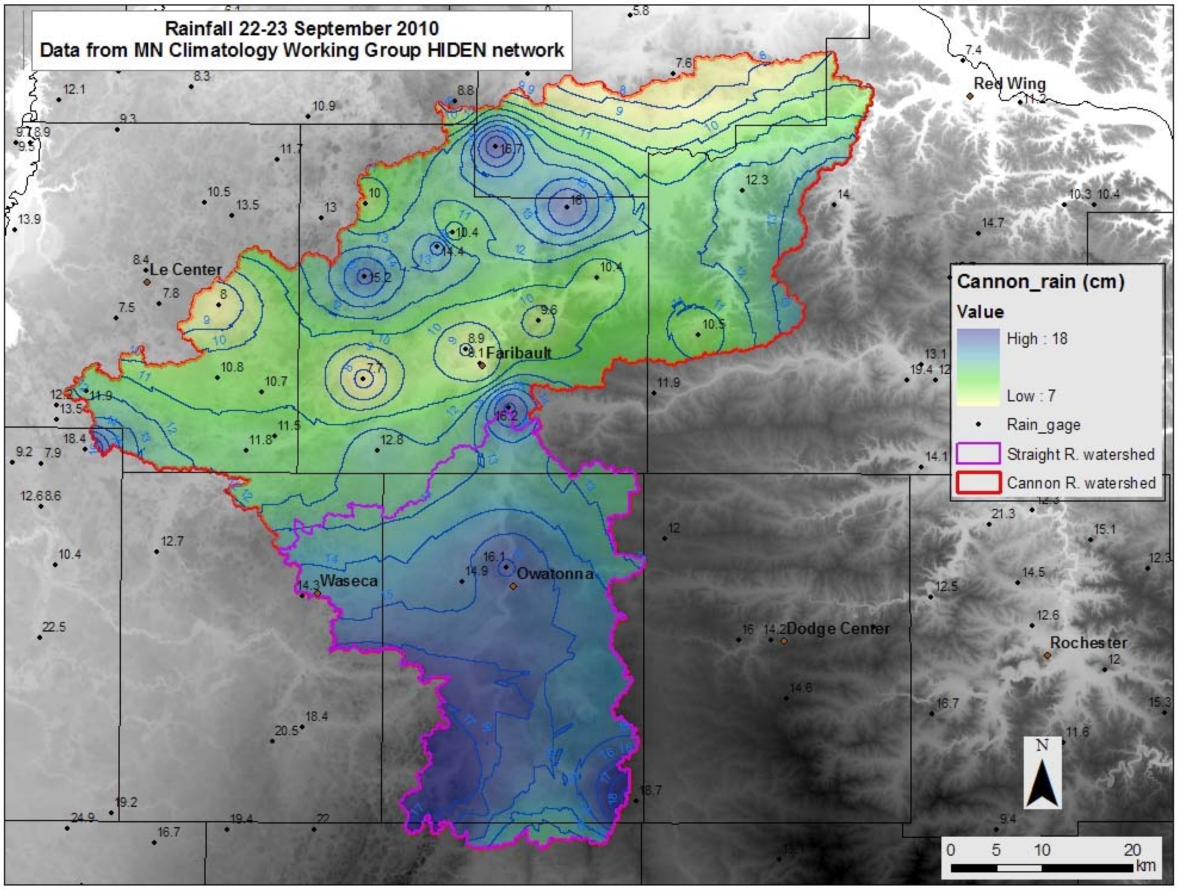
Introduction to Geology

Final Projects

Volume 2: Flood Fall 2010



Instructor
Professor Bereket Haileab
Carleton College Northfield, Minnesota
Fall, 2010

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Introduction

In the fall of 2010 Southern Minnesota received 10 inches of precipitation over two days, causing a flood event later characterized by the USGS as having an 800 year periodicity. In order to understand and document the event, students in my introduction to geology course were broken into small groups that conducted studies on different aspects of the flood, including: the history of rainfall in the county; land cover in the county, tile drainages and their impact during flooding; frequency of floods in Southern Minnesota, and the fall 2010 flood. Also, at the request of the people who deal with water and water quality of the county, we started monitoring the headwaters of Spring Creek, located near the city wells.

The students did a great job and their preliminary findings are discussed in the following pages.

Bereket Haileab

Fall 2010

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Rainfall
In Rice County

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Fall 2010

Introduction to Geology
Carleton College, Northfield, MN
Bereket Haileab

Introduction:

This study will look at rainfall patterns in Northfield, MN, and the surrounding area. Northfield is a small town located Rice County in southern Minnesota with a population of 19,872. This means that it falls into the eighth climate division of Minnesota, which gets a variety of precipitation, from rain in the spring, summer and fall, to heavy snow in the winter months.

Figure 1: Location map of Northfield, MN, photo courtesy of bestplaces.net

On September 22-24, 2010, Northfield, MN, experienced almost constant rainfall in a forty-eight hour downpour resulting in its worst case of flooding in recorded history. The Cannon River rose by 7.29 feet, flooding multiple buildings, parks and fields in the town. Many people, from students at the local colleges to residents of town, gathered in a joint sandbagging effort to protect the town, but damage was still sustained in a number of areas. In the weeks that followed, the community continued to work together to bring the town back into balance.

This study will seek to analyze the rainfall patterns for the eighth climate district in Minnesota, including where its rain originates from, what patterns occur over the course of the year, and whether these general patterns have shifted over the past one hundred and fifteen years. We will use data gathered over the years at various neighboring sites, which are held in the public records, to discover whether rainfall has increased on a larger scale, and whether we can expect more flooding in the future. In so doing, we are conducting the first close study of long term precipitation in southern Minnesota.

In a 2009 study on rainfall as the main driver of runoff under future $C0_2$ concentrations in deciduous forests, Sebastian Leuzinger and Christian Korner (2009) found that transpiration levels were reduced under elevated CO_2 emissions. Furthermore, they showed that transpiration is always drawn from the second soil layer rather than the topsoil layer. Their findings are pertinent to our research topic because the underlying bedrock of Rice County consists of sandstone and limestone, which have a high porosity and permeability. However, the majority of the glacial sediment in the County is graying calcareous loam-textured till, which is relatively impermeable to water due to limited pore space. $C0_2$ emissions in Northfield, like everywhere else in the world, have increased (Leuzinger et. al. 2009). This means that the passage of water through plant roots through the vascular system to the atmosphere has been less frequent. This has allowed water to build up in the underlying bedrock, creating a greater intake of water than is being discharged. Furthermore, since runoff occurs at topsoil, rainwater still flows from the soil into nearby streams. This combined information means that an increase in rain, will ultimately lead to a flood.

In a 2006 study on vernal pool hydrology, R. B. Boone et. al. demonstrated that it is generally not possible to extrapolate hydroperiod modeling to overarching regions because each area has different infiltration rates (588). Thus, it is difficult for us to generalize about what caused the flooding in our region overall, since individual areas have different contributing factors. Among these factors can be ground-water inflows, which R. B. Boone et. al. found to be significant in at least one-fourth of the vernal pools in 2002. Ground-water inflows, or seepage from elevated water tables, can increase significantly if there has been an accumulation of rain over the previous season.

They also noted that evapotranspiration, or the combined loss of water due to both evaporation and moisture taken up by surrounding plants, can cause less accumulation (R.B. Boone et. al. 2006). Thus we can conclude that in the fall, when there is less evaporation due to a general decrease in temperature, water is more likely to accumulate and stay longer in the case of a flood.

J. Llovet et. al., 2008, demonstrated that, while burning the soil before a simulated rainfall did not significantly change the hydraulic conductivity of the soil, extensive rainfall itself could be the cause of decreased hydraulic conductivity. In other words, significant rainfall over the course of a season can cause the soil surface to seal and crust through structural degradation, preventing normal water seepage. This was in part due to the impact of raindrops when they hit the soil surface.

D. P. Malinowski et. al., 2009, demonstrated how, from a myriad of cool-season perennial grasses, the summer dormant grasses of the Mediterranean Basin are becoming more suited to the southern Great Plains in the United States than the traditionally recommended summer active types. Summer active grasses avoid drought and come back after short periods dormancy during drought, but have the tendency to die off when subjected to simulated longer periods of drought, whereas the summer dormant species produce dormant regenerating buds at their tiller bases, and resume growth the next season from there. The latter survive better in the increased patterns of drought between the March and September rainy seasons in the bimodal precipitation system in the Great Plains. Minnesota, in the northern Great Plains, has a similar pattern of heavy rains in the spring and fall. Furthermore, the longer droughts in recent years may indicate a shift in the overall patterns of precipitation that could help explain the heavier rains here in previous decades.

James A. Smith et. al., 2010, conducted an analysis of three floods in the Delaware river system entitled “The Hydrology of Flooding”. The study investigated the origins of the three consecutive floods from 2004-06 concluding the various sources as landfalling tropical cyclones (September 2004), winter/spring extratropical cyclones (april 2005), and warm-season convective systems (June 2006). Furthermore they investigated the impacts these sources of water would cause on a given region by looking at the role mixtures of flood causing factors such as dams, soil composition, forests, etc. Also the researchers investigated the origins of the various floods and attributed volumes of flooding with each, giving landfalling tropical cyclone credit for 10% of flooding, mesoscale convective systems associated with the stationary trough over the upper Ohio

River basin with 30% and 40-50% to winter-spring melt water. Included in the article was an inspection of how factors of nature (terrain, forest cover, soil properties, drainage network structures) and human-influences (urbanization, agricultural practices, regulation through dams and reservoirs) influence flooding characteristics.

In relation to the Cannon River flooding of September 2010, the idea of Orographic precipitation mechanisms mentioned in the article likely played a key role in the final accumulation of water in Rice County, considering the presence of the mountainous composition of western North America, important to note when thinking the flood was solely brought by the tropical systems of the Gulf of Mexico. The winter-spring melt, shown to possess a large amount of influence with regards to flooding, is likely also responsible for saturating the ground and creating a shallow enough water table for high summer rain to overload the soil. Finally the influences considered and explained in the article such as dams and land use would allow for more in-depth understanding of the flooding factors given more time and resources.

Methods of Research:

We were able to collect the information we needed regarding past rainfall for this study through a number of excellent resource sites, including the National Climatic Data Center online, which has records dating back to 1895. These sites allowed us to collect information based in southern Minnesota, in particular the eighth climate division of Minnesota, where Northfield resides. This data was then entered into Excel and subsequently used to create the line graphs we used for this study. Other data was collected from the Community Collaborative Rain, Hail & Snow Network.

Results:

Figure 2 shows how the annual rainfall from March through September over the past one hundred and fifteen years has gradually increased. Recent years have seen greater variation. This past year saw one of the greatest annual rainfalls in recorded history, second only to 1993, although 1903, 1951, 1965, 1986, 1991, 2004 and 2005 all had an annual precipitation of greater than the thirty inches. Of these nine seasons with the greatest amount of precipitation, seven of them occurred in the last fifty years.

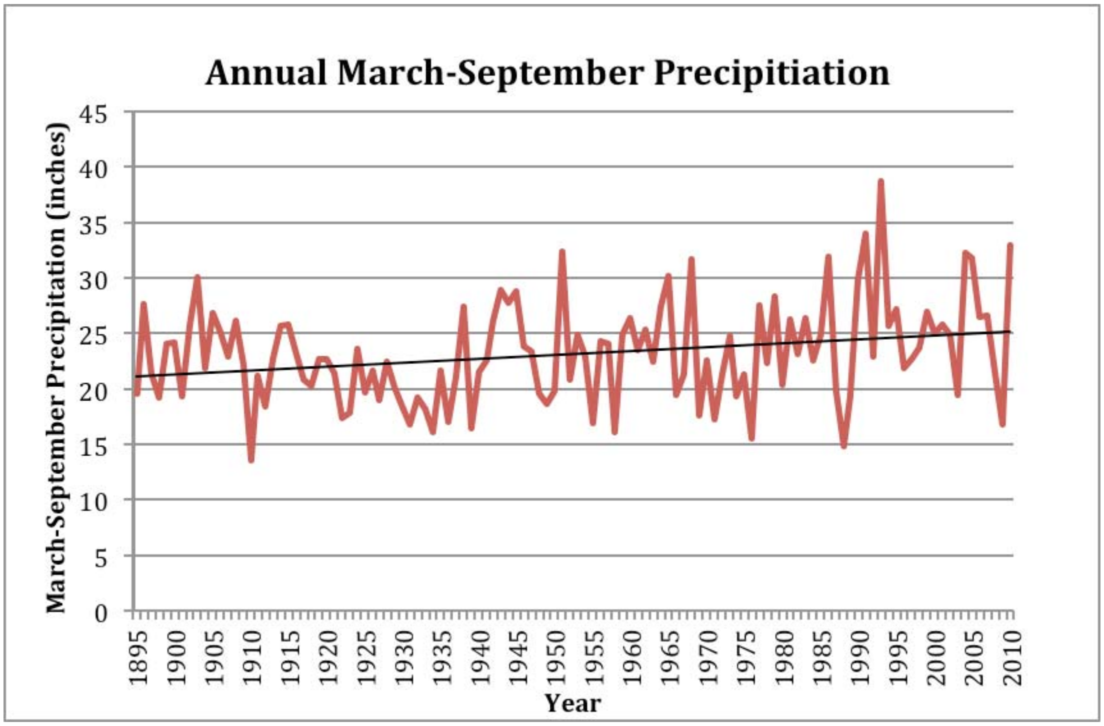

Figure 2: Annual precipitation for March through September in Minnesota's eighth climate division

As can be seen in Figure 3, the precipitation for September this year surpassed all other figures available for September rainfall in Minnesota's eighth climate division. The closest previous years have come is 7.89 inches in 2005. 2004 and 2005 were exceptionally high years for rainfall in both the March through September accumulation and September rainfall itself. A much lower precipitation has been the norm in the past, however. In fact, in the past one hundred and fifteen years, nine seasons saw less than an inch of rainfall during September.

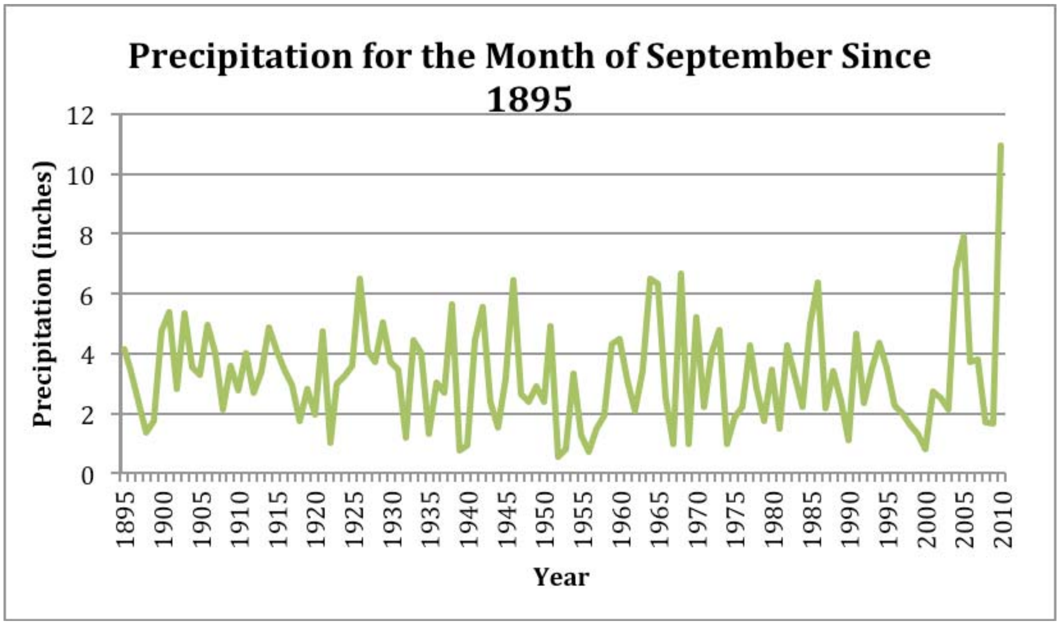

Figure 3: Precipitation for September in Minnesota's eighth climate division since 1895

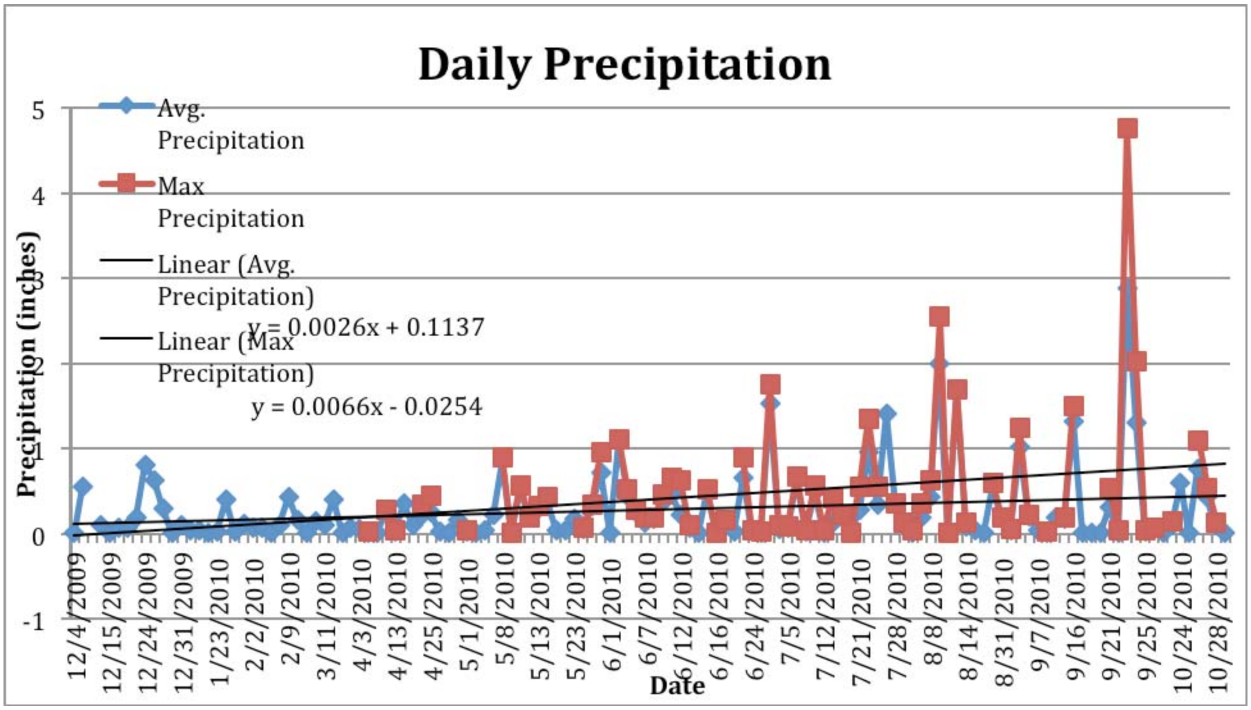

Figure 4: Average and maximum daily precipitation 4 December 2009 and 28 October 2010

Using data taken from the Community Collaborative Rain, Hail & Snow Network we created a graph measuring the average precipitation and the maximum precipitation for almost over the course of a year in Rice County. The dates on the graph range from December 4, 2009 until October 28, 2010. The x-axis represents the dates, and the y-axis represents the amount of rainfall in inches that occurred for any given day. Dates not shown on the graph are done so deliberately, because there was no precipitation (at least recorded) on that day. The blue markers represent the average precipitation for any given day, while the red markers represent the max precipitation for any given day. The days that do not show the max precipitation, had the same average precipitation.

Origin of storm:

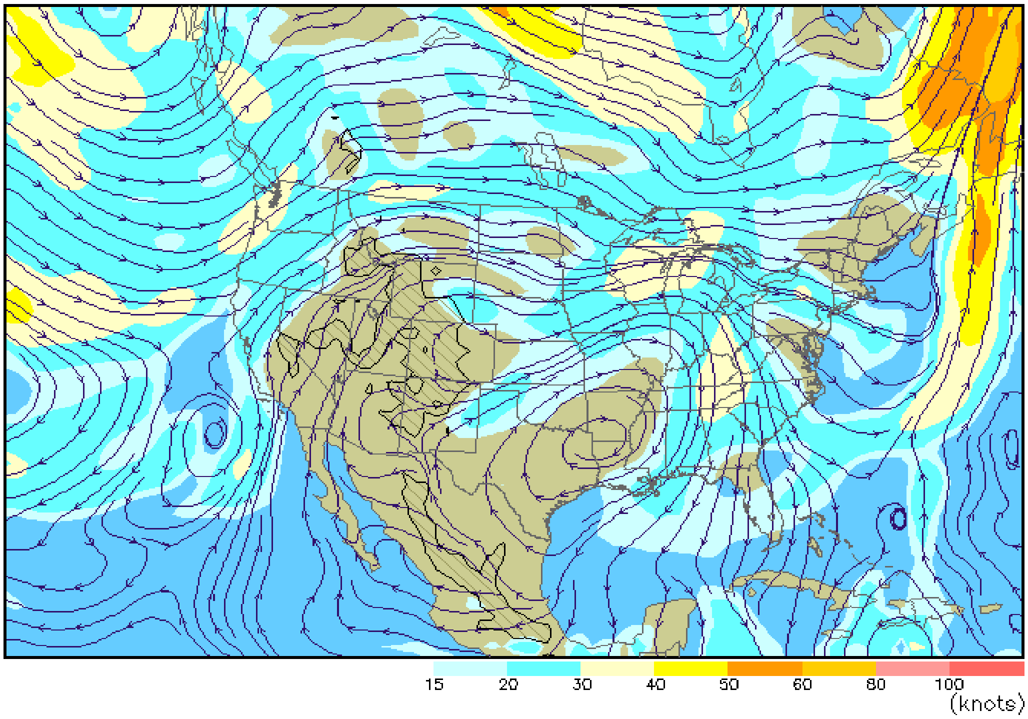

Figure 5: Direction and speed of streamline winds at 6000 feet over the United States

During the week preceding September 23, the then current setting of high and low pressure systems was setup so that the three jet streams coming from over Washington, northwestern Mexico, and the Gulf of Mexico converged over Minnesota. The previous image is of wind speed and directions at 6,000 ft MSL (800 mb) taken on September 23.

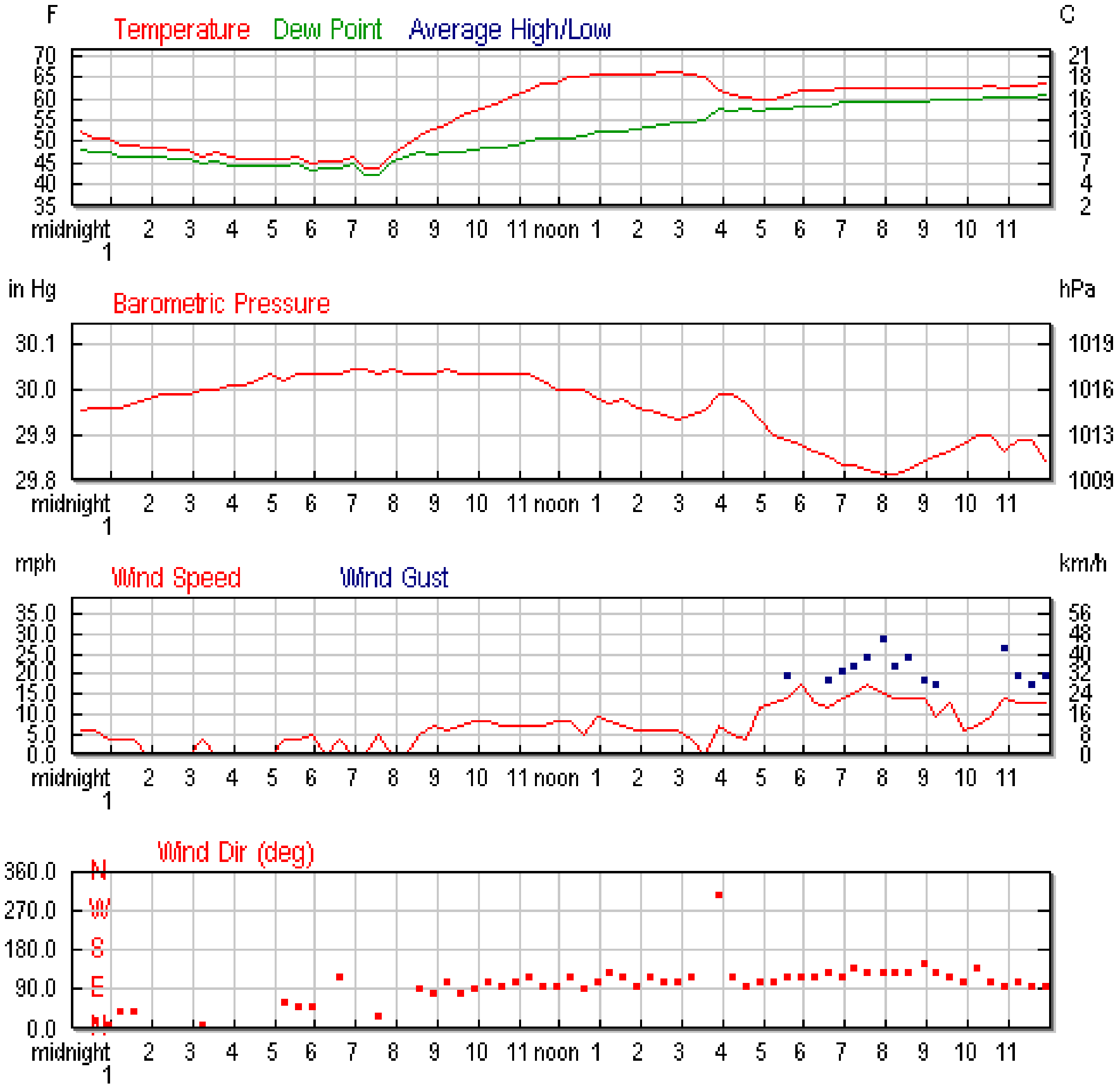

Figure 6: Data taken for Rice County on September 23, courtesy of NOAA

The velocity of the wind currents varied, but showed that dominantly the motion of the air was strongly west to east over the Canadian border, a fact supported in the graphs in Figure 7.

The wind had been moving for days before the heavy rain similar to the bottom graph, where the wind showed distinctive signs of being easterly-directed, with slight fluctuation to the south.

Preceding the arrival of the heavy rains, we can see the Barometric Pressure began to drop dramatically, from its peak of about 30.05 Hg to 29.8 Hg, right at the same time that the wind speed picked up to the max of 20 mph. Finally we can see that the day warmed up as usual but steadied out at about 60 degrees Fahrenheit.

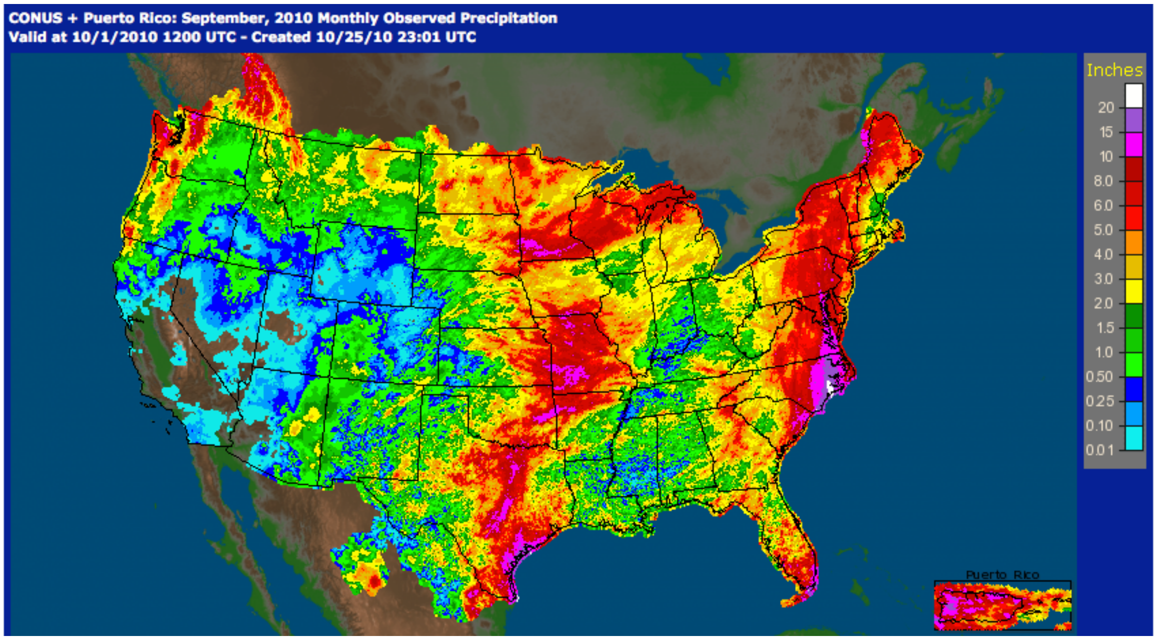

Figure 7: Total precipitation for September 2010 over the US, courtesy of NOAA

In Figure 7 we can see the rain for the month of September as captured by the National Oceanic and Atmospheric Administration (NOAA). The areas with the most rainfall are colored with the darker reds and form lines along the jet stream paths shown above.

The most recent factor that caused the flash flood of the Canon River was moisture from the remnants of tropical storm Georgette in the eastern Pacific Ocean and

Hurricane Karl in the Gulf of Mexico. The storms first moved through Kansas, progressed into northwest Iowa, and then went into Southern Minnesota before moving in to Northern Minnesota. Along the way the storms were picking up moisture, and water vapor mixed with current rainclouds already above Northfield, causing the precipitation rate to lie between 10 millimeters and 50 millimeters per hour, classifying the rainwater as heavy rainfall. This rainfall not only fell into the Canon, but creeks and streams that lead into it, thus adding to the volume of the river.

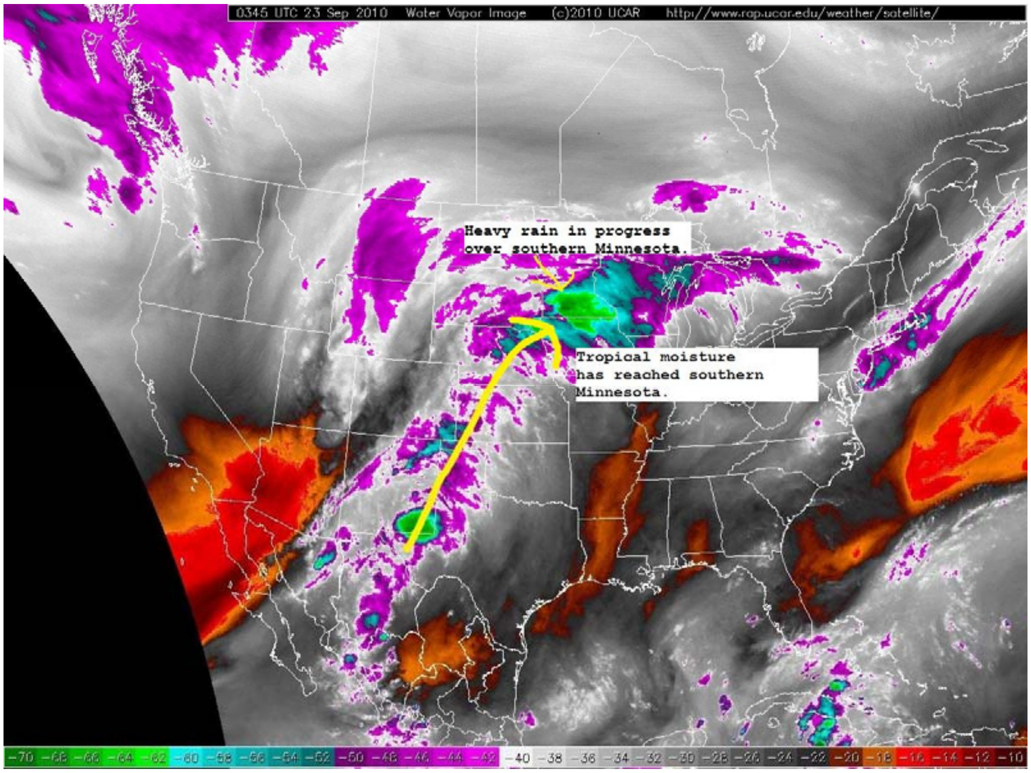

Figure 8: Tropical storm path for Tropical Storm Georgette and Hurricane Karl, courtesy of National Weather Service Weather Forecast Office

A large reason why the flood was so devastating on September 23 was due to the consistent heavy rain southern Minnesota experienced from June onwards. In contrast to the heavy rainfall in September, Figure 9, below, shows a typical amount of precipitation, around 1 inch of rain over the entire month of January. This would not cause the ground’s water table to rise greatly because the plant absorption and drainage rates would easily drain this amount. However, this is not the case for the rainfall over the course of the images in Figure 10.

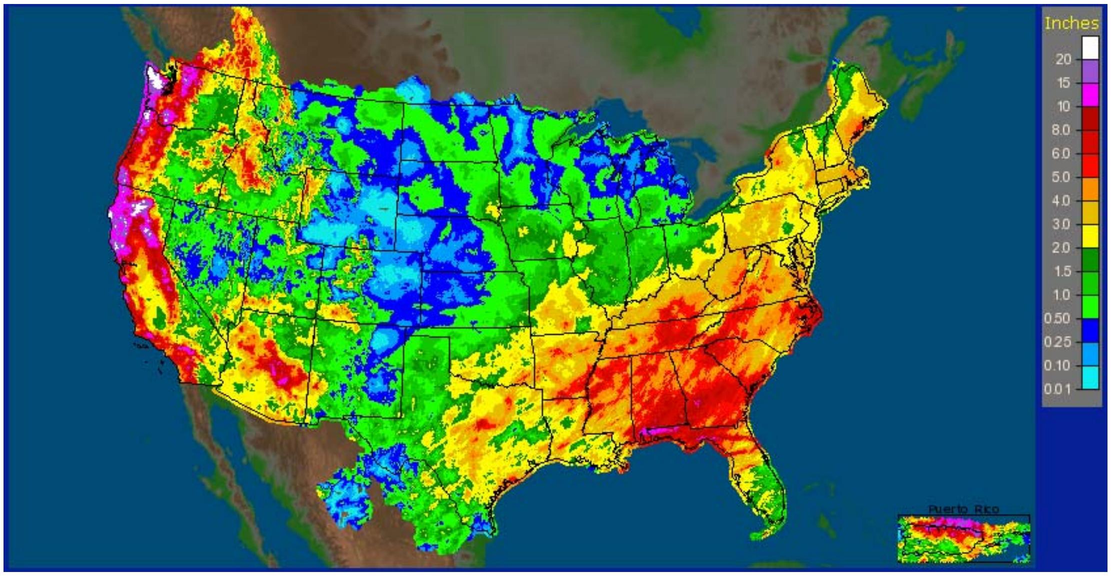

Figure 9: Cumulative precipitation for January 2010 over the US, courtesy of NOAA

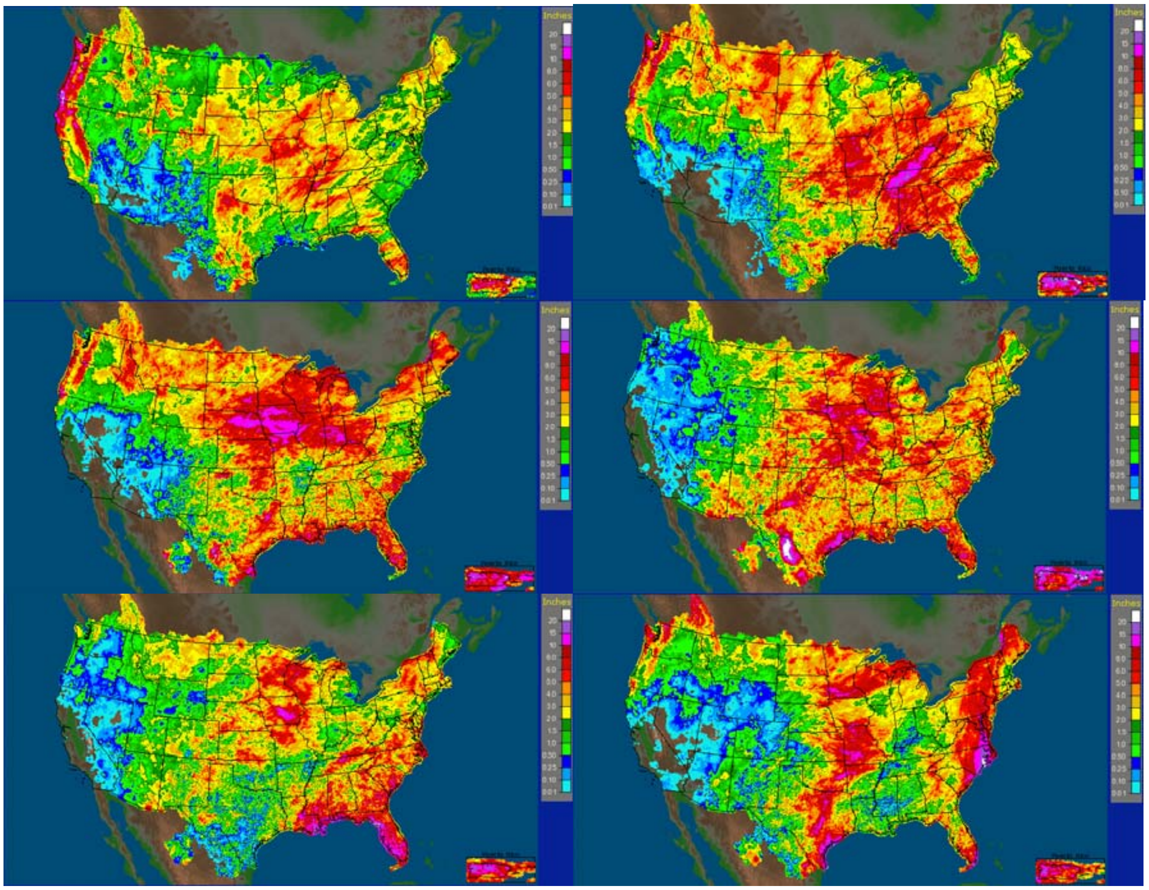

Figure 10: Cumulative precipitation April through September, left to right, from NOAA

The following images should be read from left to right, top to bottom, and are the images of the amount of rain in the months of April to September. The rainfalls of these months for Rice County Minnesota were approximately 2, 3, 6, 5, 5, and 11 inches respectively, creating an average rainfall in the last four months of over 7 inches of rain per month – much more than the soil of Minnesota can drain. This fact that the ground was already saturated of course aided the flooding on September 23, as did the speed at which the month of September received the majority of its rain, over the course of a few days, nearly nonstop.

Discussion:

The data we reviewed regarding coastal storms allows us to see the origin of the rainclouds which passed over the continent of North America preceding the week of September 23. First we looked at the jet streams at an elevation of 6,000 feet, the height that the travel of the very tall cumulonimbus clouds is dictated at. Cumulonimbus is the familiar storm cloud formed in warmer settings of summers and early falls. The speculation that the rainclouds were cumulonimbus is supported by the way the temperature remained steadily high for the rest of the day, as though the heavy, moist clouds, trapping the reflected heat, blanketed the site. The significance of the barometric pressure is simply a sign of the coming rainstorm, as the pressure drops when storms and windy weather arrive which accompany cumulonimbus.

Knowing this we can deduce that the rain clouds were carried from three origins and formed over southern Minnesota – the majority came from northern Washington State and the Gulf of Mexico, while some came from the Mexican western peninsula.

From Figure 2 we can see that there has been a gradual increase in the average rainfall for Minnesota’s eighth climate division over the past one hundred and fifteen years. The average has moved from twenty-one inches at the beginning of the century to today’s average of just over twenty-five inches annually between March and September. Thus we can infer that the climate patterns passing through southern Minnesota, where both Pacific and Atlantic storms ultimately cross, have in fact shifted. We can observe that the storms which eventually reach southern Minnesota do in fact coincide with storms over the ocean; for example, the years 2004 and 2005, which saw such devastation on the coast lines, coincides with the highest rainfalls on record for the eighth division. That seven out of the nine annual rainfalls to exceed thirty inches fell within the past fifty years indicates that not only is overall precipitation increasing, so is the frequency of exceptionally high precipitation years.

In Figure 3, we can see that this past year, we saw the greatest amount of precipitation on record in the eighth division for the month of September. This year’s 10.95 inches was a full three inches higher than the next highest precipitation recorded, in 2005. Once again we see that high rainfall corresponds to the high degrees of activity of the coastal storms.

In Figure 3 we can see evidence to support Figure 2. The greatest amount of precipitation for any given day this year in Rice County was 4.76 inches of rain on September 23, 2010 while the greatest amount of rainfall in any other month (in this case October), was only 2.55 inches of rain. From graph 3, we can infer that there is a positive trend, despite the different levels of precipitation each month. The line of best fit is positioned in increasing motion, indicating that over the course of the year, the precipitation rate has been increasing in Rice County. The equation $y = 0.0026 + 0.1137$ (from the equation $y = mx + b$) shows the numerical average rate at which precipitation has been increasing this given year.

Conclusion:

In this study, we were able to track the origin of the storms from their coastal counterparts and also saw how the average rainfall has been increasing in Minnesota over the past one hundred and fifteen years. In future studies, it would be beneficial to look closely at the water table levels in southern Minnesota over the course of the year. This would help determine whether further flooding is likely to occur in the near future, and whether the excessive flooding this past September might be repeated. It would also be helpful to do further work on the rate of soil absorption for the same reasons.

While it is evident that the average rainfall has been increasing, it would be helpful to look further into which specific areas are contributing to this phenomenon. Future studies could also look into rainfall patterns in adjacent climate divisions to see which costal storms are contributing the most to recent increases in precipitation.

Acknowledgements:

We would like to thank the National Climatic Data Center, the Community Collaborative Rain, Hail & Snow Network, and the National Oceanic and Atmospheric Administration for the information they have made available to the public, and the Carleton College Geology Department for its support. We would also like to thank our professor Bereket Haileab, and our lab TAs Adam Denny and Sarah Marks for their support and their help when we had questions.

Appendix:

Table 1

Year	March-September Precipitation	September Precipitation
1895	19.55	4.13
1896	27.61	3.4

1897	21.44	2.38
1898	19.25	1.34
1899	24.06	1.71
1900	24.14	4.74
1901	19.3	5.38
1902	25.73	2.8
1903	30.1	5.31
1904	21.87	3.53
1905	26.86	3.26
1906	25.14	4.94
1907	22.96	4.01
1908	26.15	2.1
1909	22.28	3.59
1910	13.62	2.75
1911	21.13	4
1912	18.38	2.65
1913	22.7	3.34
1914	25.64	4.84
1915	25.85	4.1
1916	23.29	3.45
1917	20.89	2.92
1918	20.28	1.73
1919	22.69	2.81
1920	22.7	1.94
1921	21.45	4.72
1922	17.34	1.01
1923	17.82	2.96
1924	23.59	3.22
1925	19.68	3.58
1926	21.65	6.46
1927	18.95	4.09
1928	22.4	3.71
1929	20.2	5.02
1930	18.42	3.68
1931	16.84	3.42
1932	19.24	1.16
1933	18.14	4.43
1934	16.14	3.99
1935	21.63	1.29
1936	17.04	3.01
1937	21.12	2.66
1938	27.37	5.61
1939	16.42	0.73
1940	21.51	0.93
1941	22.52	4.42
1942	26.2	5.52

1943	28.86	2.37
1944	27.77	1.5
1945	28.85	3.14
1946	23.84	6.43
1947	23.35	2.64
1948	19.54	2.39
1949	18.6	2.87
1950	19.83	2.39
1951	32.37	4.88
1952	20.86	0.54
1953	24.87	0.77
1954	22.96	3.31
1955	16.87	1.25
1956	24.3	0.69
1957	24.07	1.46
1958	16.1	1.89
1959	24.84	4.31
1960	26.33	4.48
1961	23.51	3.1
1962	25.33	2.05
1963	22.44	3.39
1964	27.36	6.48
1965	30.21	6.31
1966	19.47	2.48
1967	21.31	0.94
1968	31.71	6.66
1969	17.65	0.96
1970	22.62	5.18
1971	17.21	2.19
1972	21.32	4.01
1973	24.74	4.77
1974	19.35	0.94
1975	21.28	1.84
1976	15.54	2.19
1977	27.58	4.27
1978	22.39	2.84
1979	28.37	1.73
1980	20.37	3.43
1981	26.29	1.48
1982	23.16	4.24
1983	26.39	3.24
1984	22.53	2.21
1985	24.86	4.96
1986	31.86	6.34
1987	19.8	2.17
1988	14.85	3.4
1989	19.31	2.43

1990	29.82	1.09
1991	34.03	4.64
1992	22.97	2.32
1993	38.78	3.46
1994	25.7	4.34
1995	27.21	3.5
1996	21.92	2.24
1997	22.67	2
1998	23.77	1.62
1999	26.96	1.3
2000	25	0.8
2001	25.78	2.71
2002	24.93	2.52
2003	19.43	2.12
2004	32.22	6.76
2005	31.8	7.89
2006	26.51	3.71
2007	26.64	3.77
2008	21.54	1.7
2009	16.76	1.66
2010	32.99	10.95

Table 1: Data from the National Climatic Data Centre (Online), pertaining to the eighth climate division of Minnesota

Table 2

Date	Average Precipitation	Max Precipitation
12/4/2009	0.02	0.02
12/9/2009	0.55	0.55
12/10/2009	0.1	0.1
12/15/2009	0.01	0.01
12/20/2009	0.07	0.07
12/21/2009	0.07	0.07
12/22/2009	0.2	0.2
12/24/2009	0.82	0.82
12/25/2009	0.64	0.64
12/26/2009	0.3	0.3
12/27/2009	0.01	0.01
12/31/2009	0.11	0.11
1/7/2010	0.05	0.05
1/8/2010	0.05	0.05
1/22/2010	0.01	0.01
1/23/2010	0.03	0.03
1/24/2010	0.4	0.4
1/25/2010	0.03	0.03
1/26/2010	0.12	0.12
2/2/2010	0.08	0.08
2/5/2010	0.08	0.08

2/6/2010	0.01	0.01
2/8/2010	0.11	0.11
2/9/2010	0.44	0.44
2/15/2010	0.16	0.16
2/24/2010	0.01	0.01
3/10/2010	0.15	0.15
3/11/2010	0.1	0.1
3/12/2010	0.41	0.41
3/13/2010	0.01	0.01
3/17/2010	0.07	0.07
4/3/2010	0.06	0.06
4/4/2010	0.02	0.03
4/6/2010	0.01	0.01
4/7/2010	0.27	0.29
4/13/2010	0.03	0.04
4/15/2010	0.36	0.36
4/16/2010	0.11	0.11
4/24/2010	0.23	0.35
4/25/2010	0.25	0.45
4/26/2010	0.03	0.03
4/27/2010	0.01	0.01
4/30/2010	0.16	0.16
5/1/2010	0.03	0.04
5/4/2010	0.01	0.01
5/5/2010	0.04	0.04
5/7/2010	0.22	0.22
5/8/2010	0.86	0.9
5/9/2010	0.01	0.02
5/11/2010	0.53	0.57
5/12/2010	0.19	0.2
5/13/2010	0.3	0.33
5/14/2010	0.38	0.43
5/21/2010	0.05	0.05
5/22/2010	0.05	0.05
5/23/2010	0.18	0.18
5/25/2010	0.06	0.08
5/26/2010	0.33	0.35
5/31/2010	0.73	0.97
6/1/2010	0.01	0.01
6/2/2010	1.09	1.11
6/4/2010	0.45	0.52
6/6/2010	0.26	0.29
6/7/2010	0.13	0.19
6/8/2010	0.18	0.19
6/9/2010	0.37	0.47
6/11/2010	0.47	0.66
6/12/2010	0.23	0.63
6/13/2010	0.08	0.11

6/14/2010	0.01	0.01
6/15/2010	0.5	0.52
6/16/2010	0.01	0.02
6/18/2010	0.13	0.16
6/22/2010	0.03	0.03
6/23/2010	0.67	0.9
6/24/2010	0.03	0.05
6/26/2010	0.02	0.03
6/27/2010	1.53	1.76
6/28/2010	0.06	0.1
7/5/2010	0.07	0.09
7/6/2010	0.64	0.68
7/8/2010	0.03	0.04
7/11/2010	0.49	0.57
7/12/2010	0.02	0.04
7/15/2010	0.14	0.42
7/18/2010	0.22	0.23
7/20/2010	0.01	0.02
7/21/2010	0.28	0.55
7/22/2010	0.96	1.35
7/23/2010	0.34	0.56
7/24/2010	1.42	1.42
7/28/2010	0.35	0.36
7/30/2010	0.1	0.13
7/31/2010	0.02	0.04
8/5/2010	0.19	0.36
8/8/2010	0.43	0.64
8/11/2010	2	2.55
8/12/2010	0.01	0.02
8/13/2010	1.68	1.7
8/14/2010	0.09	0.13
8/15/2010	0.05	0.05
8/21/2010	0.01	0.01
8/24/2010	0.57	0.61
8/31/2010	0.18	0.19
9/1/2010	0.04	0.06
9/2/2010	1.02	1.25
9/3/2010	0.21	0.22
9/7/2010	0.05	0.05
9/10/2010	0.02	0.03
9/11/2010	0.2	0.2
9/15/2010	0.18	0.19
9/16/2010	1.33	1.5
9/17/2010	0.02	0.02
9/19/2010	0.01	0.01
9/20/2010	0.01	0.01
9/21/2010	0.31	0.54
9/22/2010	0.02	0.04

9/23/2010	2.89	4.76
9/24/2010	1.31	2.03
9/25/2010	0.03	0.05
9/26/2010	0.07	0.08
10/10/2010	0.02	0.02
10/18/2010	0.11	0.15
10/24/2010	0.61	0.61
10/25/2010	0.01	0.01
10/26/2010	0.77	1.1
10/27/201	0.44	0.54
10/28/2010	0.1	0.13
10/29/2010	0.01	0.01

Table 2: Data from the Community Collaborative Rain, Hail & Snow Network (Online), pertaining to Rice County

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<http://waterdata.usgs.gov/nwis/dv/?site_no=05355200&agency_cd=USGS&referred_module=sw>.

Land Practice in Rice County:

A Historical Overview and Geospatial Analysis

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Land Practice and Flooding in Rice County

1. Introduciton

The impact of the flood on Northfield, MN in September of 2010 demonstrated how vulnerable the area is and thus it has become a priority to examine flood risk.

Many factors contribute to the occurrence of hydrologic flood events. Of course, natural events such as extreme precipitation play a role, but a human factor must also be considered. While failure of structural flood defenses, lack of information and low awareness of flood risk are all human factors, land use and population trends play an even larger role. Although flood risk is a complex thing, in this paper we chose to focus on land use.

Hazard, exposure and vulnerability are the three factors typically used to assess flood risk (Kron, 2002). If one of these factors increases, so does flood risk. In this context, hazard is the occurrence of a flood and its probability, and vulnerability is the susceptibility to the damaging and destructive forces. By studying land use, we are focusing on the exposure component, which is composed of factors like the population, assets, environmental resources and biological resources located in the hazardous zone.

Recent studies across the globe have linked increased flood risk and damage to increased human development and urbanization. In Europe, increased damages caused by recent floods have been attributed to new urban developments on floodplains and the associated land use (Berz, 2000). In fact, according to Jose Barredo, author of *Normalised Flood Losses in Europe*, “the *main* driving force behind flood disaster damages and increasing exposure is extensive building in flood prone areas" (Barredo, 2009). In California, heavy flooding has also been linked to increased exposure of land, reflected by population growth and the forcing new development adjacent to flood prone areas (EQECAT). In Asia, where the pace of urbanization is highest among developing nations, flood risks continue to grow as populations are expanding into productive floodplains (Shaw et al, 2008). This global focus on land use, specifically urban development, as a major factor of flood risk indicates that changing land use could have implications on flood risk in Rice County.

This paper presents a historical overview of land practice in Rice County, MN and a geospatial comparison and analysis of the land from 1992 and from 2001. We have compiled this report to help us as well as other agencies, organizations and community members gain a better understanding of how Rice County's land use has changed over time and how recent development affects flood risk.

2. Methods

2.1 History

We began by reviewing land practice use in the last century and a half as a means of setting a background for our more current look at development in flood zones. To get a good idea of how the land has changed, we looked to a variety of sources. For the nineteenth century, we found a pre-settlement land cover map (Figure 1) and coupled it with several first-person accounts of the land. More concrete data becomes available starting in the mid twentieth century. Aerial photos taken in 1938 were compared to current satellite photos of Northfield, to visualize the residential growth (Figure 10). We also compared land use and flood plain maps created in 1972 with the present.

2.2 GIS

For the GIS (geographic information systems) portion of this project, we used the program ArcGIS to analyze the National Land Cover Database land cover data of the years 1992 and 2001. We simplified the land cover classes in these two datasets so they could be compared side by side. After that, the changes in land cover over those years were calculated using the tabulate area tool (Table 4, Figure 4). Once the land use over that time period was analyzed, FEMA Flood Zone data was used to analyze the type of land use change within flood risk zones. The 1992 (Table 2, Figure 2) and 2001 (Table 3, Figure 3) land use data were overlaid with a layer that represented the high flood risk areas (the 100 year flood plain—areas with a 1% annual chance of flood) (Figure 5). This was used to determine the land changes that took place in high risk flooding areas. The same thing was done with lower risk flooding areas (areas with a 0.2% annual chance of flooding) to determine the land cover changes in those areas.

3. Results

3.1 History

Historical land use maps and population data reveal steady urban growth and increasing cultivation of land. Before trying to map the changes in land use over time, it is necessary to understand its natural history and the processes that created the ideal spaces for settlement and agricultural cultivation. The hills, lakes, moraines and plains of

Rice County can be attributed to the series of glaciations that passed through about one million years ago. Pleistocene glaciers advanced through Rice County creating topographic highs, and filling depressions with sand, gravel and boulders with their retreat. Melt water carved channels through the Platteville limestone and St. Peter sandstone and drained to the north, creating the Cannon River Valley. Glacial and post-glacial erosion is responsible for creating the mesas of the northeastern part of the county (Sholes et al, 1972).

After the glaciers' retreat 11,000 years ago, a thick spruce forest sprung up, until tall-grass prairie replaced it about 7,500 years ago (Sholes et al, 1972). When the climate became wetter and cooler, the banks of the Cannon and Straight Rivers were entirely reforested as oak-hickory forests took over roughly one half to two thirds of the county, leaving the rest as prairie. Since then, the forest has slowly transformed into bottomland hardwoods in the river and stream valleys (elm, ash, oaks, basswood, maple) and the northern hardwoods (elm-ash, oak dominant, maple-basswood) (Sholes et al, 1972).

European American settlers began trapping furs and setting up trading posts in the early nineteenth century (Swanberg, 1976). Early accounts of the land cover were compiled to create a pre-settlement map (Figure 1) and roughly divided into 6 different categories of land practice (Table 1). In 1887, Professor L. B. Sperry noted that "[Rice County] is being cleared up rapidly and there are now many fine farms in every township of the timber regions of this country" (Sperry, 1878).

We did not find information in the same form spanning both centuries of land development, but by looking at a variety of aerial photos, first-person accounts, old land use maps, and census data, we conceived of a general concept of how the land has changed. Essentially, the population continued to grow steadily (Figure 7) and agricultural land practice increased and diversified.

By 1972, over 91% of Rice County's total area was classified as farmland. Three quarters of that agricultural land was cultivated, and the rest was used by dairy, hog, and poultry operations. Between 1940 and 1980, the urban population grew by 51% and the rural non-farm population grew by 377% (US Census Bureau, 1992). Currently, most land areas are being used for pastures and crops, mostly corn, soybeans, wheat, rye, oats, alfalfa, and barley.

Few detailed accounts of flooding were recorded before the 1940s, but we accessed FEMA records reporting significant flooding of the Cannon River during March 1949, July 1951, June 1954, April 1969, and March 1973. Major floods occurred in Faribault in 1965, 1969 and 1973 (FEMA). Most of these floods have been attributed to either rapid spring snowmelt, heavy rainfall in the upper reaches of the drainage basin, or a combination of the two. In the past, flood problems have included "siltation, debris, accumulation, ice jams, inundated structures, streambed erosion, wet basements, and disruption of business" (FEMA).

3.2. GIS

The first part of the data we calculated was the area and percentage of area of each land cover type in 1992 and 2001 (Tables 2,3). A side-by-side comparison of these two times is in Figure 7. In all of Rice County, between 1992 and 2001, developed, forested upland, herbaceous upland natural/semi-natural vegetation, and shrubland land cover types increased in area. Herbaceous planted/cultivated (agricultural land) and wetlands decreased in land area. Open water and barren land stayed about the same.

When analyzing the high-risk flood zone land use, the results were somewhat similar. We calculated the area and percentage of area of each land cover type in 1992 and 2001 that lie within the high-risk flood zones (Tables 4 and 5; Figure 8). Developed, forested upland, herbaceous upland natural/semi-natural vegetation, and shrubland land cover types increased in the high-risk zone over this time period. Herbaceous planted/cultivated, barren, and wetlands decreased, while water remained about the same. In high-risk zones, the largest gap was that the amount of wetlands decreased from 26,342,365 square meters to 19,935,878 square meters, which is a 24% change.

Since the medium-risk flood area is a much smaller area, there are less land cover types present in those areas. The results can be seen in tables 6 and 7 and figure 9. Developed and herbaceous upland natural/semi-nature vegetation land types increased by a significant margin. Herbaceous planted/cultivated decreased by a large margin, and the rest of the land types stayed about the same. The developed land in medium-risk zones increased from 306,112 square meters to 752,420 square meters, while the herbaceous planted/cultivated decreased from 1,099,656 square meters in 1992 to 573,696 square meters in 2001.

Discussion

Natural hazards have been a regularly occurring phenomena for thousands of years and complex natural systems are in place to help return the land to homeostasis. Thus, increase in regularity and magnitude can be attributed directly to human interference and the tendency to ignore problems due to infrequency. Assessing the landscape can help prevent and minimize future damages.

Our GIS comparison of 1992 and 2001 found that there was an increase in development in high and medium-risk flood areas, or floodplains. Floodplains are key elements in maintaining normal water balances. In Rice County, many floodplains (high-risk zones) have been converted to agriculture and residential areas. The land around many lakes has been extensively developed with vacation and 3-season homes (FEMA). Agricultural activity increases runoff potential because it often reduces ground cover and infiltration rates. Developing on floodplains, whether it be for agriculture or buildings, reduces flood-carrying capacity, increases flood heights and velocities, and increases flood hazards in areas beyond the natural flood zones (FEMA).

We also found that the total area of wetlands decreased in high-risk flood zones between 1992 and 2001. Three drainage land types commonly found in Rice County are marshes, lakeshores and misfit streams (Sholes et al, 1972). The storage provided by these land covers help mitigate flood peaks (FEMA). Thus developing wetlands could have increasing implications for flood risk in Rice County.

In the fall of 2010, many of Northfield’s streets were submerged in water. If rainwater and wastewater cannot infiltrate into the ground, then a large run-off is produced. Drainage networks often cannot accommodate this surge of water and thus flooding occurs. Paving portions of flood plains results in flash flooding when the rainfall runs directly into the stream, rather than becoming groundwater (Sholes et al, 1972). This is not to say that urbanization is bad. The progress and expansion of humanity is inevitable. However, it would be even more progressive if we learned to minimize current flood risk and take measures to prevent increasing it in the future.

We recognize the need to protect existing assets in flood-prone areas. However, developing new land in flood zones is neither sustainable nor reasonable. In fact, some geologists and lawmakers recommend the removal of high risk developments (Kundzewicz, 2006). However, many consider urbanization as an irreversible process and so urban vulnerability becomes an inescapable reality (Quarantelli, 2003). Currently, flood risk measurement and treatment focuses primarily on short-term economic losses, and insurance is used for compensation (Crichton, 2002). Looking to the future, it is necessary to factor sustainability into city planning in regard to flood prevention.

However, in the mean time, short term goals to decrease risk can be accomplished at a personal level. For example, awareness of being at-risk for flooding is vital for self-protective behavior. Recent exposure to flooding increases awareness and provides motivation for preparedness (Coulston, 1995).

Further studies could be done to increase our knowledge of how flooding risk relates to land practices. First, more recent land use data could determine if the increases and decreases found from 1992 to 2001 have continued to the present, which would help us predict urban and agricultural growth into the future. In the last ten years, Northfield has developed rapidly, paving large portions of flood plains, but we did not have access to this updated data. Also, the areas of high change could be examined closer for explanations. For example, the land within the high flood-risk zone that underwent change from agricultural to developed land could be compared with census data to see who lives there. This could determine what type of social or economic pressures would cause people to live in high risk zones. A closer look at underlying factors like that help create a better understanding of how to decrease flood risk and help the community. It would also be interesting to examine chemical composition change of the waterways attributed to development and to check the accuracy of FEMA’s flood zones.

Correlation is not causation. However, previous geological research indicates that the correlation between increased urbanization and increased flood risk is not just happenstance. Therefore, our findings of Rice County’s increasing development in floodplains and encroachment on wetlands may have future implications on flood risk.

Table 1: Pre European Settlement Land Cover Areas, This table corresponds with the below figure (figure 1) in the land use of Rice County pre-settlement. It displays the area of each land type in meters and the percentage of each land type. Because the land use types are very different than current land use, it is difficult to compare these figures with the more current land cover.

Pre-Settlement Land Cove, Rice County	Area (sq m)	Area Percent
Aspen-Oak Land	124669719	9.33775
Big Woods - Hardwoods (oak, maple, basswood, hickory)	495135563	37.085602
Lakes (open water)	37091480	2.77815
Oak openings and barrens	106957814	8.01113
Prairie	400372933	29.9879
Wet Prairie	170887113	12.7994

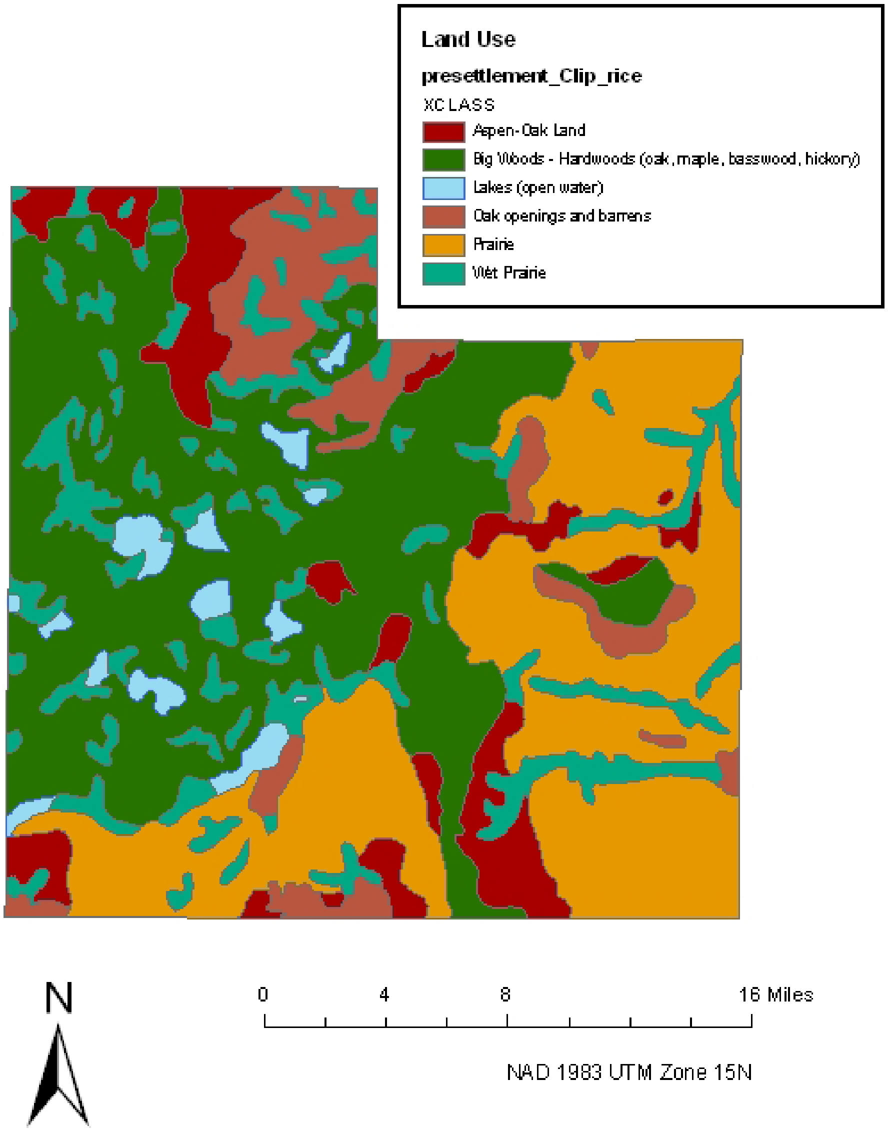


Figure 1: Land Use Pre-settlement, this figure corresponds with the areas shown in table 1. It displays the pre-European settlement land cover in Rice County.

Table 2: 1992 Land Cover Type in Rice County. This table corresponds to figure 2. It shows the area (in square meters) for each land cover type. The total percentage of each land type is also displayed.

1992 Land Cover, Rice County	Area (sq m)	Area Percentage
Barren	321905	0.024116
Developed	27747975	2.07877
Forested Upland	107896689	8.08322
Herbaceous Planted/Cultivated	1061472999	79.521599
Herbaceous Upland Natural/Semi-natural Vegetation	2450950	0.183616
Shrubland	24857	0.001862
Water	47904610	3.58883
Wetlands	87003701	6.51799

Table 3: 2001 Land Cover Type in Rice County. This table corresponds to figure 3. It shows the area (in square meters) for each land cover type. The total percentage of each land type is also displayed.

2001 Land Cover, Rice County	Area (sq m)	Area Percentage
Barren	361845	0.027109
Developed	114551704	8.58206
Forested Upland	124221689	9.30653
Herbaceous Planted/Cultivated	934364031	70.001297
Herbaceous Upland Natural/Semi-Natural Vegetation	54825418	4.10745
Shrubland	14858504	1.11318
Water	47948229	3.59222
Wetlands	43648948	3.27012

Table 4: 1992 Land Cover Type in High Risk Flood Zones, Rice County. High risk flood zones refer to areas within the 100 year floodplains (places with a 1% annual chance of flooding). This table displays the area (in square meters) and percentage of area of each of the land types present in 2001.

1992 Land Cover, High Risk Flood Zones	Area (sq m)	Area Percentage
Barren	3060	0.002655
Developed	1469620	1.27512
Forested Upland	8329674	7.22724
Herbaceous Planted/Cultivated	35283575	30.6138
Herbaceous Upland Natural/Semi-natural Vegetation	128193	0.111227
Shrubland	7943	0.006892
Water	43689381	37.907101
Wetlands	26342365	22.856001

Table 5: 2001 Land Cover Type in High Risk Flood Zones, Rice County. High risk flood zones refer to areas within the 100 year floodplains (places with a 1% annual chance of flooding). This table displays the area (in square meters) and percentage of area of each of the land types present in 2001.

2001 Land Cover, High Risk Flood Zones	Area (sq m)	Area Percentage
Developed	3934295	3.41329
Forested Upland	11843252	10.2749
Herbaceous Planted/Cultivated	30431884	26.401899
Herbaceous Upland Natural/Semi-natural Vegetation	4290890	3.72266
Shrubland	1219647	1.05813
Water	43608134	37.833302
Wetlands	19935878	17.295799

Table 6: 1992 Land Cover Type in Medium Risk Flood Zones, Rice County. Medium risk flood zones refer to areas with a 0.2% annual chance of flooding. This table displays the area (in square meters) and percentage of area of each of the land types present in 1992.

1992 Land Cover, Medium Risk Flood Zones	Area (sq m)	Area Percentage
Barren	533	0.033336
Developed	306112	19.145399
Forested Upland	103891	6.49775
Herbaceous Planted/Cultivated	1099656	68.776802
Herbaceous Upland Natural/Semi-natural Vegetation	2490	0.155734
Water	10033	0.627503
Wetlands	76162	4.76347

Table 7: 2001 Land Cover Type in Medium Risk Flood Zones, Rice County. Medium risk flood zones refer to areas with a 0.2% annual chance of flooding. This table displays the area (in square meters) and percentage of area of each of the land types present in 2001.

2001 Land Cover, Medium Risk Flood Zones	Area (sq m)	Area Percentage
Developed	751420	46.996799
Forested Upland	94451	5.90734
Herbaceous Planted/Cultivated	573696	35.881302
Herbaceous Upland Natural/Semi-Natural Vegetation	83586	5.2278
Shrubland	6778	0.423923
Water	7026	0.439434
Wetlands	81917	5.12342

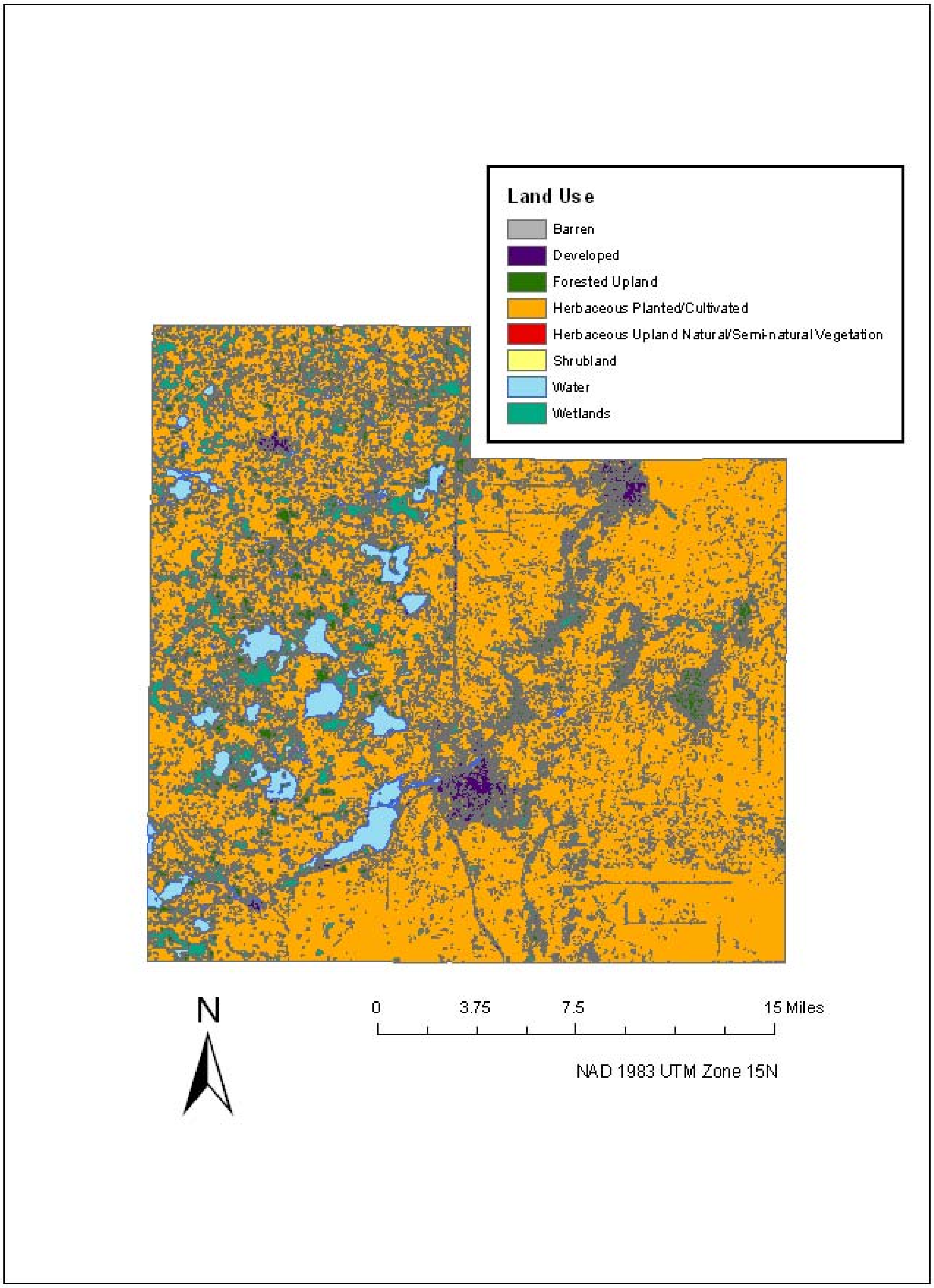


Figure 2: 1992 Land Cover Type in Rice County. This map, that corresponds to table 2, displays the types of land cover in Rice County in 1992. The data for this is from the NLCD (National Land Cover Database) and is projected using NAD 1983 UTM Zone 15N.

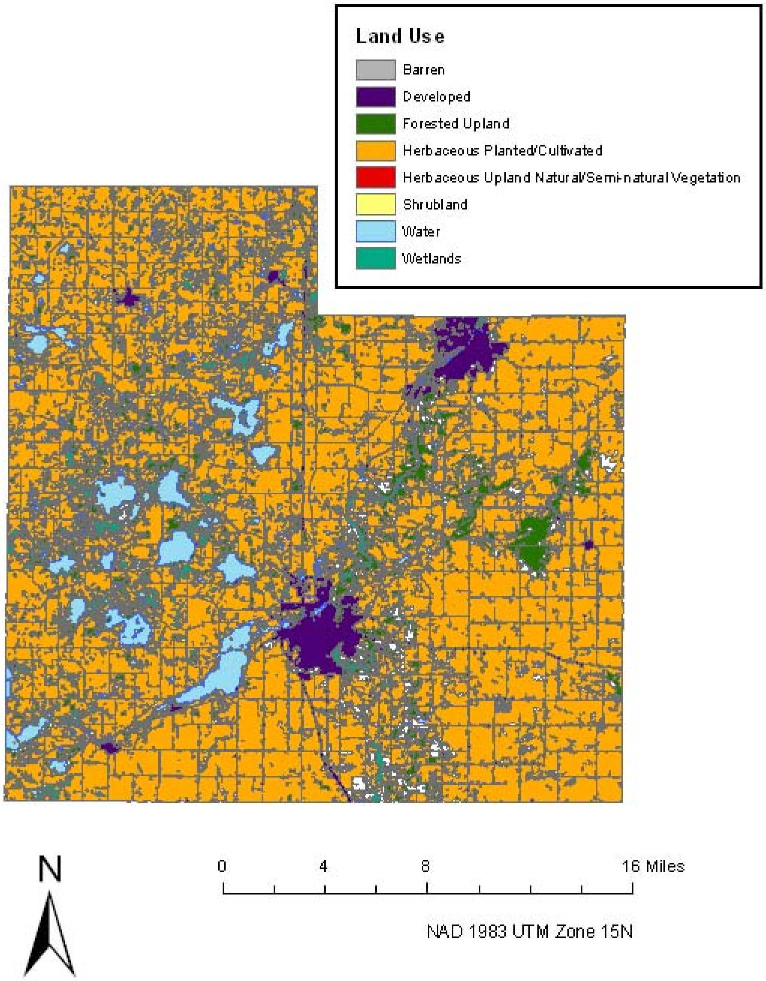


Figure 3: 2001 Land Cover Type in Rice County. This map corresponds to Table 3, of the land cover types in 2001. The different colors represent different land cover types, as stated in the legend of the map. This can be compared to the map of 1992 to see how land changed over the nine years. This data also comes from the National Land Cover Database

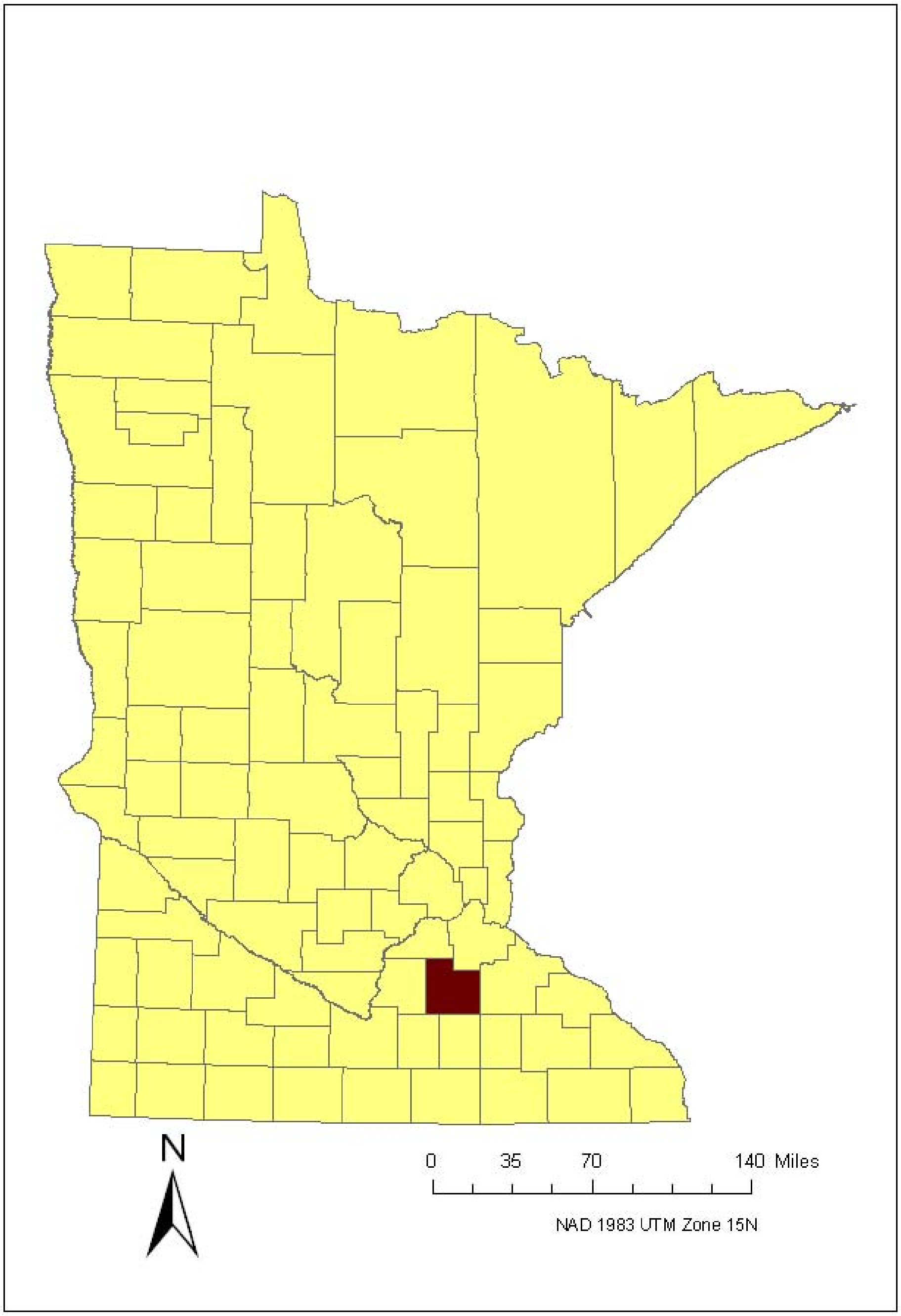


Figure 4: Study Area, the county in red is d County, the area we studied. This shows the geographic relationship between Rice County and Minnesota as a state.

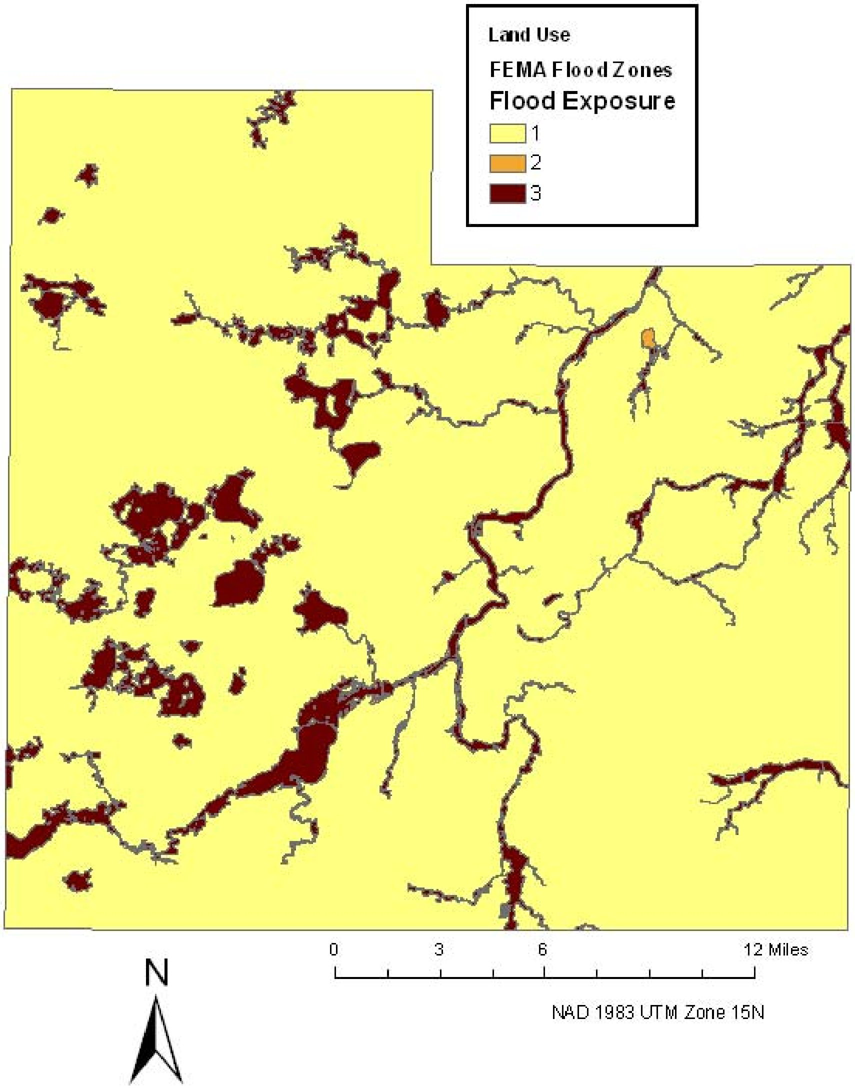


Figure 5: FEMA Flood Zones in Rice County. Areas with a flood exposure designation of 3 are in the 100 year floodplain, meaning there is a 1% annual chance of flooding in that area. Areas with a flood exposure designation of 2 have a 0.2% annual chance of flooding. Areas with a designation of 1 are in minimal risk flood areas. This data is from FEMA.

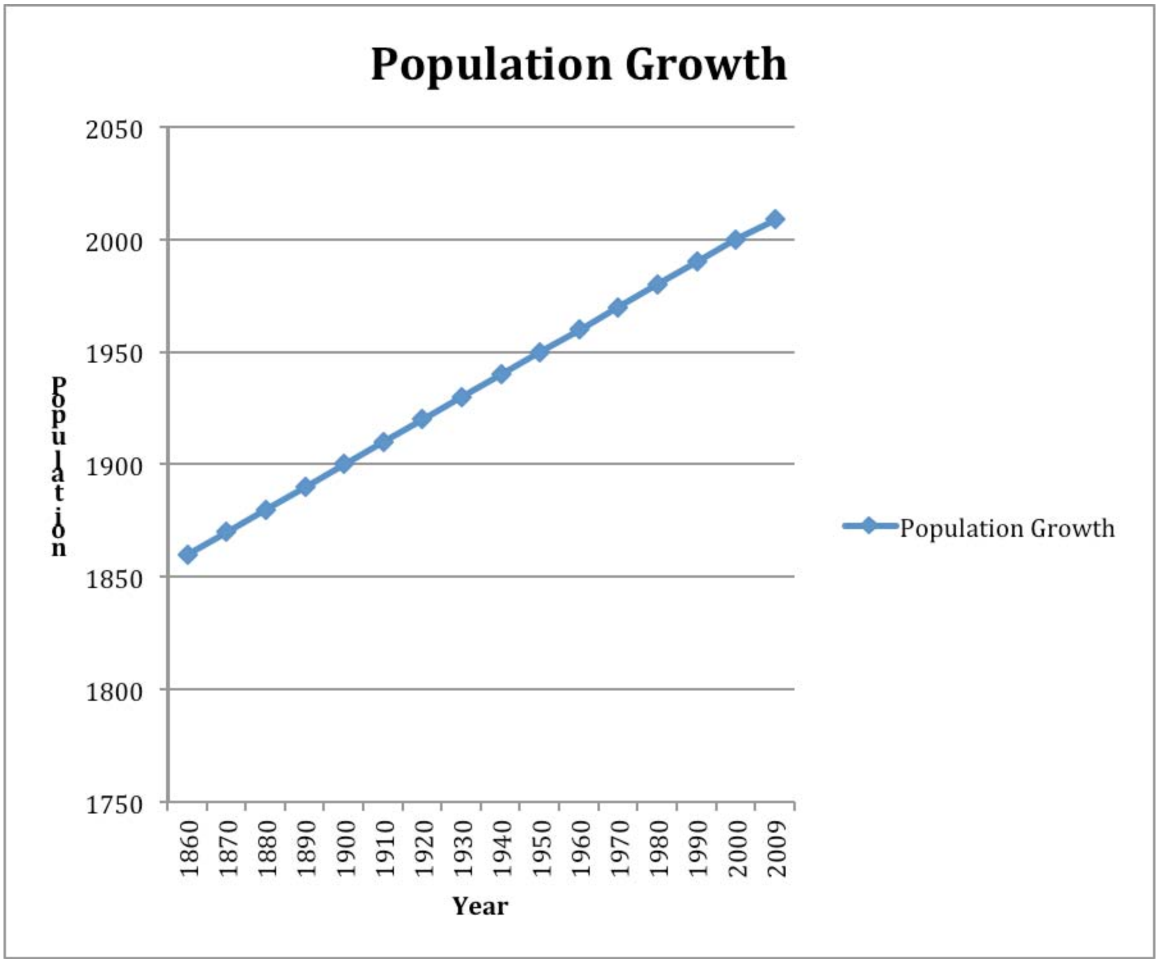
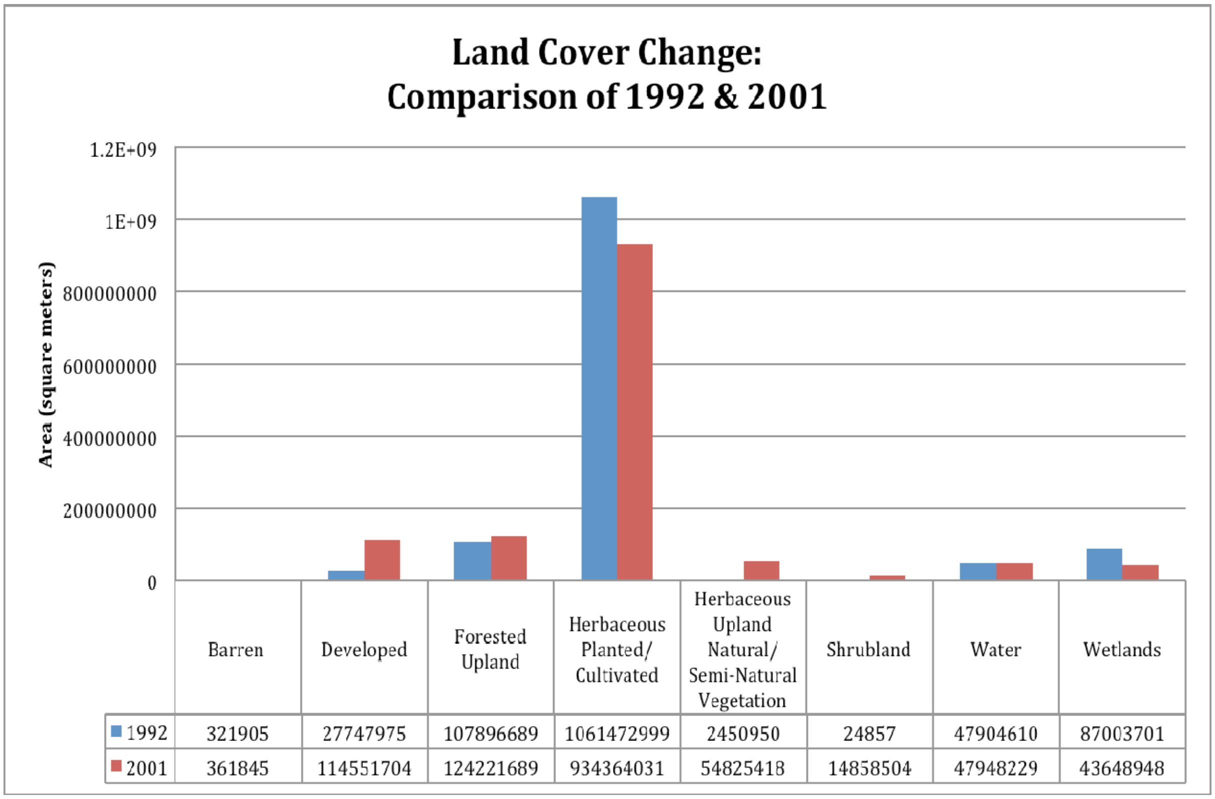
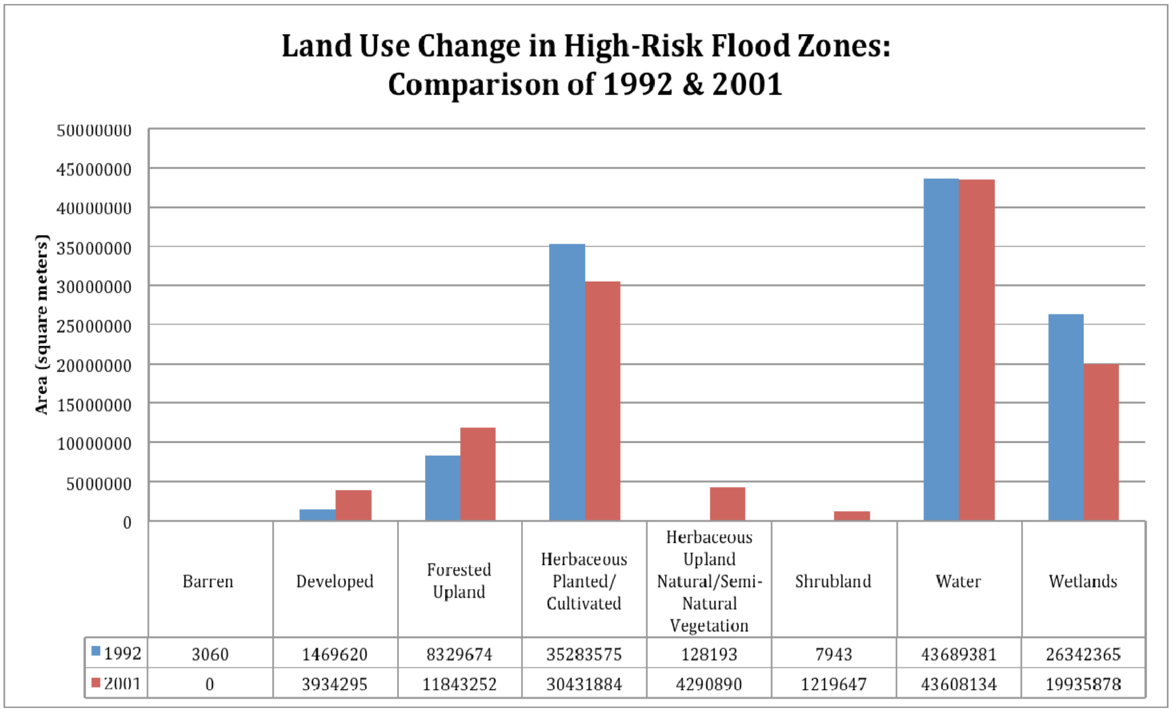


Figure 6: Population Growth in Rice County. Shows steady population growth from 1860 to 2009. This information comes from the US Census Bureau.



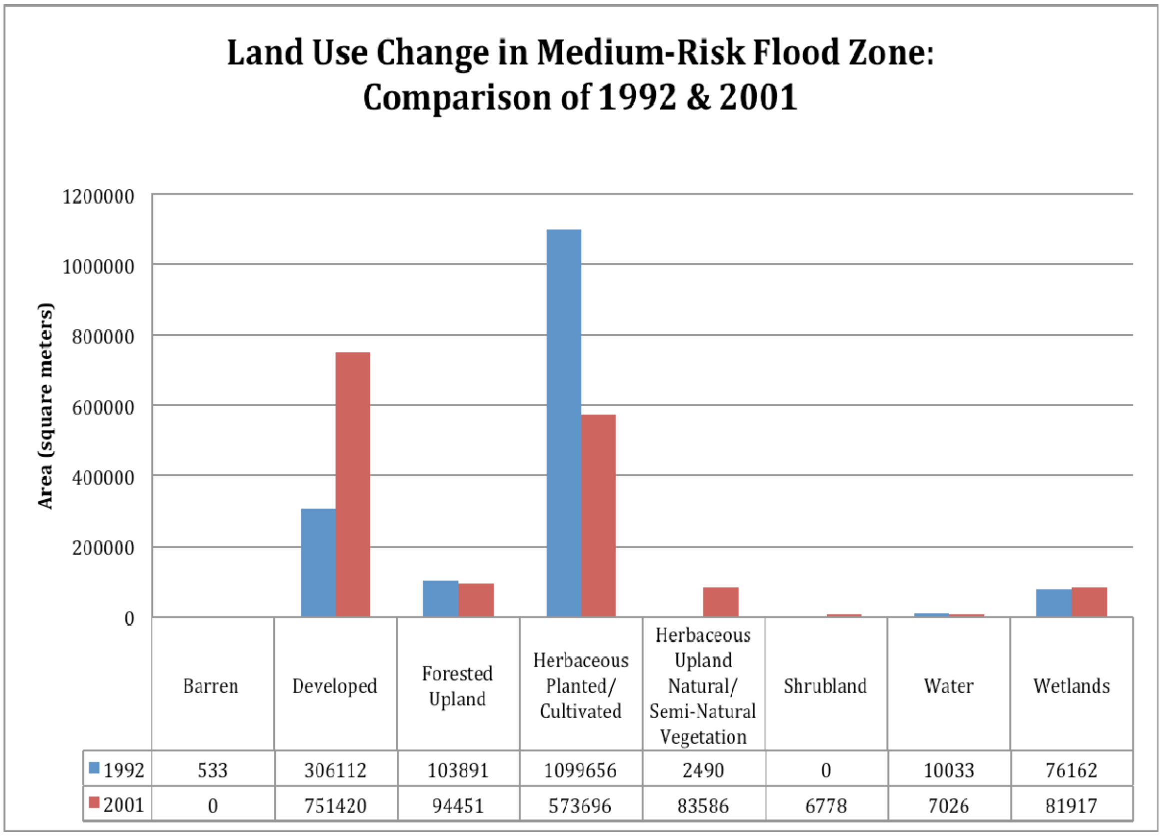
	Barren	Developed	Forested Upland	Herbaceous Planted/ Cultivated	Herbaceous Upland Natural/ Semi-Natural Vegetation	Shrubland	Water	Wetlands
🟦 1992	321905	27747975	107896689	1061472999	2450950	24857	47904610	87003701
🟥 2001	361845	114551704	124221689	934364031	54825418	14858504	47948229	43648948

Figure 7: Land Cover Types in Rice County. This graph compares the amount of each land cover type in all of Rice County for the years 1992 and 2001. This data comes from the NLCD datasets in vector form. The area is calculated in square meters, with the blue bar representing the 1992 areas and the red bar representing the 2001.



	Barren	Developed	Forested Upland	Herbaceous Planted/ Cultivated	Herbaceous Upland Natural/Semi-Natural Vegetation	Shrubland	Water	Wetlands
🟦 1992	3060	1469620	8329674	35283575	128193	7943	43689381	26342365
🟥 2001	0	3934295	11843252	30431884	4290890	1219647	43608134	19935878

Figure 8: Land Cover Types in High Flood Risk Zones in Rice County. This shows the areas of each land cover type present in the 100 year floodplain (1% annual chance of flooding) as indicated by FEMA. This data comes from the NLCD datasets in vector form. The area is calculated in square meters, with the blue bar representing the 1992 areas and the red bar representing the 2001.



	Barren	Developed	Forested Upland	Herbaceous Planted/ Cultivated	Herbaceous Upland Natural/ Semi-Natural Vegetation	Shrubland	Water	Wetlands
🟦 1992	533	306112	103891	1099656	2490	0	10033	76162
🟥 2001	0	751420	94451	573696	83586	6778	7026	81917

Figure 9: Land Cover Types in Medium Flood Risk Zones in Rice County. This shows the areas of each land cover type present in the 500-year floodplain (0.2% annual chance of flooding) as indicated by FEMA. This data comes from the NLCD datasets in vector form. The area is calculated in square meters, with the blue bar representing the 1992 areas and the red bar representing the 2001.

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Tile Drainage and its Effects on Flooding

Stephanie Allen, Tyler Mahony, and Maggie Sullivan

Introduction:

Tile drainage is a process used in agriculture for draining groundwater. In wet areas, farmers install drainage tiles approximately three to four feet underground in order increase their crop yield during the rainy season (Johnson et al., 2003). Tiles are underground sections of tubing or piping that water flows through. Agricultural land is improved through this process by effectively lowering the water table to improve root development, as well as cause the soil to dry out more quickly after heavy rains, and thaw more quickly after a cold winter (Johnson et al., 2003). Tiles used to be made of ceramics or cement and there would be spaces between each segment in order to let water in. Now, tiles are made of perforated plastic because it is cheaper and lighter. Because of the perforation, the tiles can be continuous and without a gap between segments. There are two main types of tiling; relief drains and interceptor drains. Relief drains "are used to lower the water table and allow the growth of vegetation" (Subsurface Drain, 2007) or to help remove excess surface water. "Interceptor drains are placed on slopes to prevent the soil from becoming saturated and to prevent slippage" (Subsurface Drain, 2007). They run perpendicular to the slope they are on and generally drain off to the sides.

In general, subsurface drainage systems increase the amount of water that flows in a stream or river. However, there is no data that suggests that tile drainage systems are the direct cause of flooding. There are many other factors in addition to subsoil drainage that have the ability to affect catchment flow. Tile drains increase the amount of water in a stream through baseflow. Baseflow is the water that flows as surface water but started out underground. Even in the dry season, when there is not much rain, baseflow can keep a stream flowing (Schillings, 2001). Also, during periods with high amounts of rainfall, tile drainage will have an even greater impact on streams because the water that is absorbed into the ground will be drained into rivers in larger amounts and more quickly than it would have been otherwise. This problem becomes even worse if the drainage system is at a steep incline. If this is the case then stream flow conditions can become ‘flashy.’ “This means that after even moderate rainfall, the [river] rises quickly and experiences a correspondingly rapid drop in level as the rain stops” (Little Cottonwood River, 2010). In addition, if the subsoil drainage system is exposed to high pressurization due to an intense rainfall or flaws in the piping systems, the residence time of the water will be affected. This will have an impact on the streams. With the data we have collected we can show how these basic principles apply to this specific flood. To present this claim, we researched the history of tile drainage, the water’s residence time in the soil, and whether or not these factors could possibly have an influence on the Cannon River flood.

Methods:

This study was conducted through research on previous experiments of this nature, as well as through analysis of the recent Cannon River Flood. It was this Cannon River Flood specifically that sparked our interest in this topic. The shear magnitude of the flood and the magnitude of the damage it inflicted on area near the river banks created a public desire to better understand the causes of such floods and ways to prevent future floods. The research we did was conducted in the months following the flood, while research and opinions were still easily accessible.

Results:

Increased precipitation due to a high intensity rainfall on September 22nd and 23rd 2010 led to increased water flow in the area. Tile drainage could possibly have impacted the water flow in such a way that led to a flood.

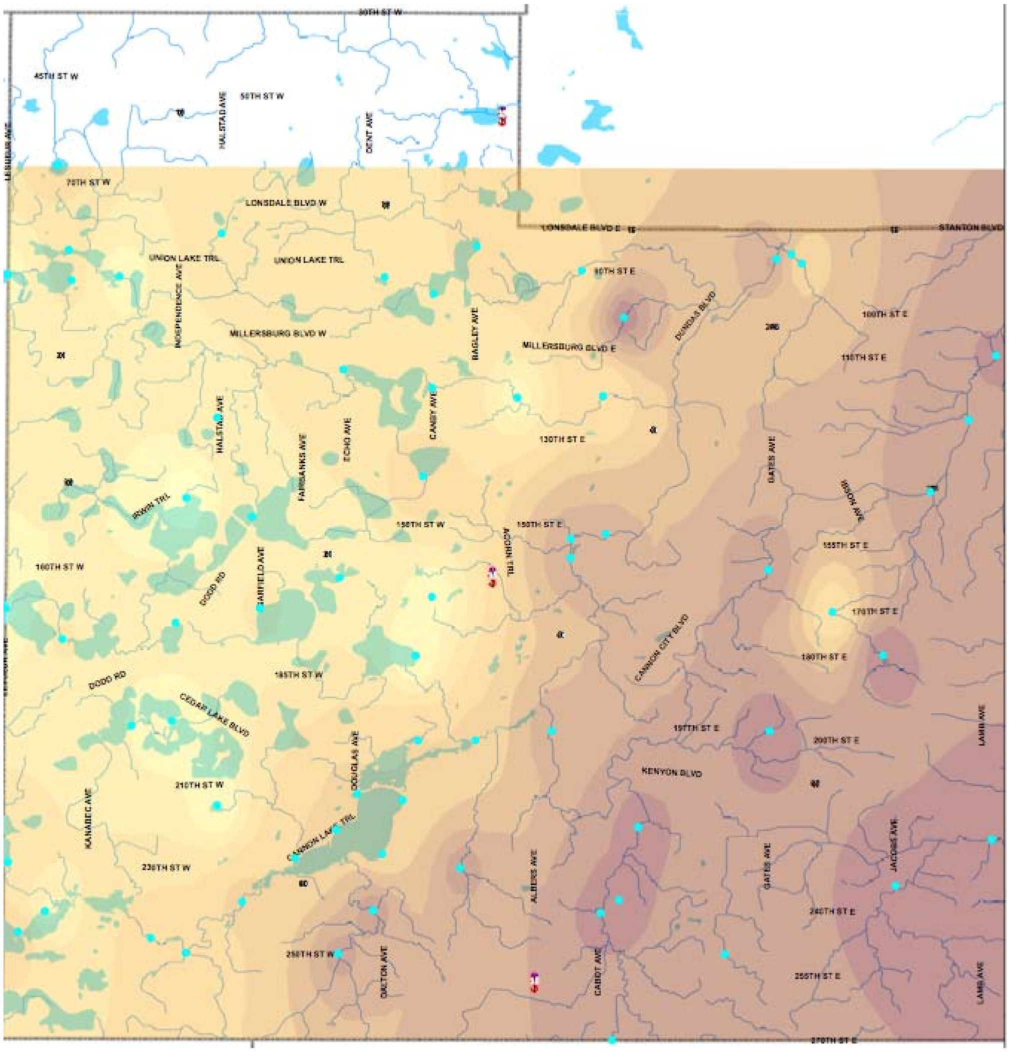


Figure 1: Map of measured nitrate levels in Rice County, using available tile drains. Ranging from yellow to dark red, with dark colors having higher concentrations of nitrate. From (Holschuh et al, 2009)

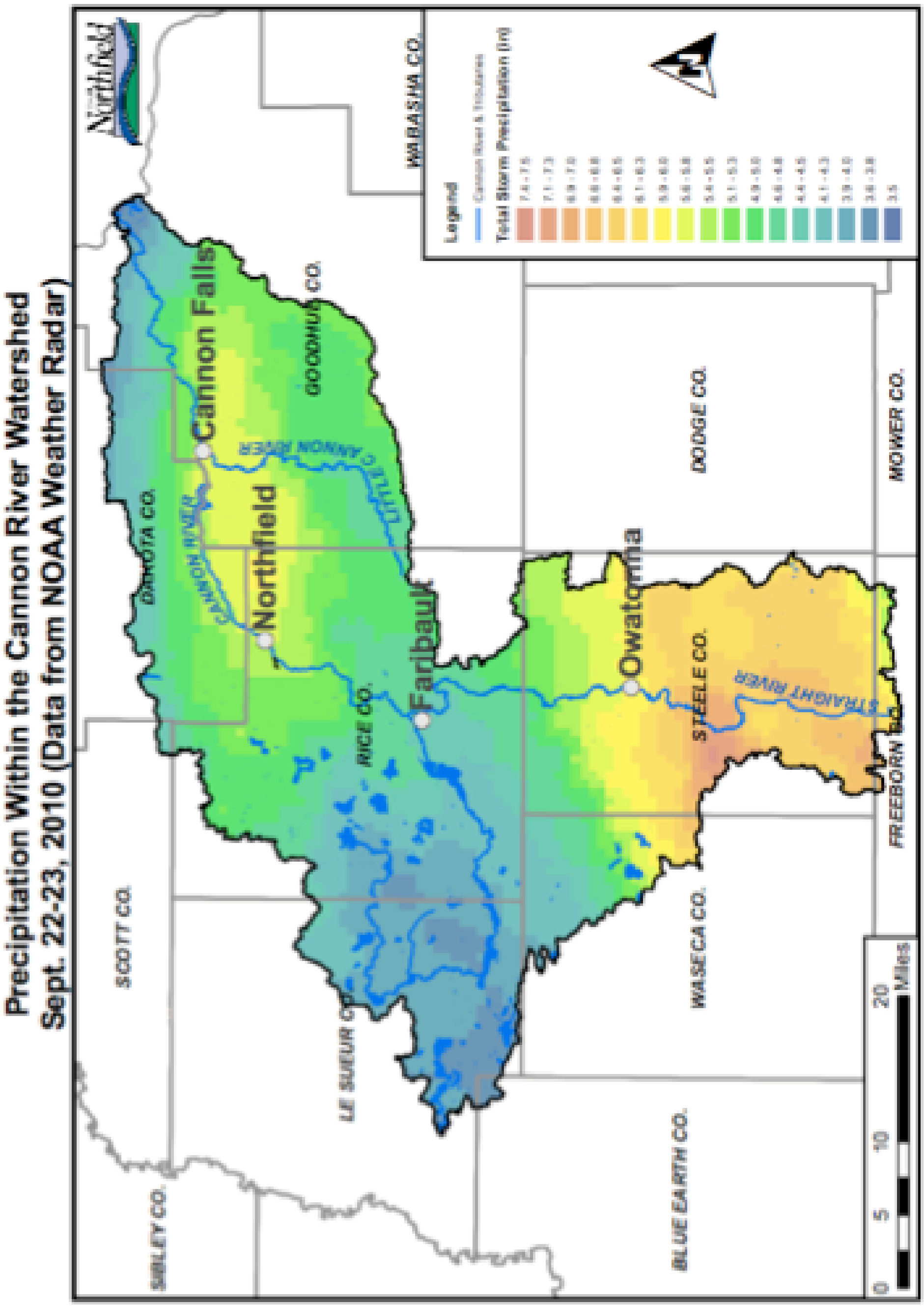


Figure 2: Precipitation within the Cannon River Watershed. From (Welch, 2010).

SECTION 2: CANON RIVER DISCHARGE

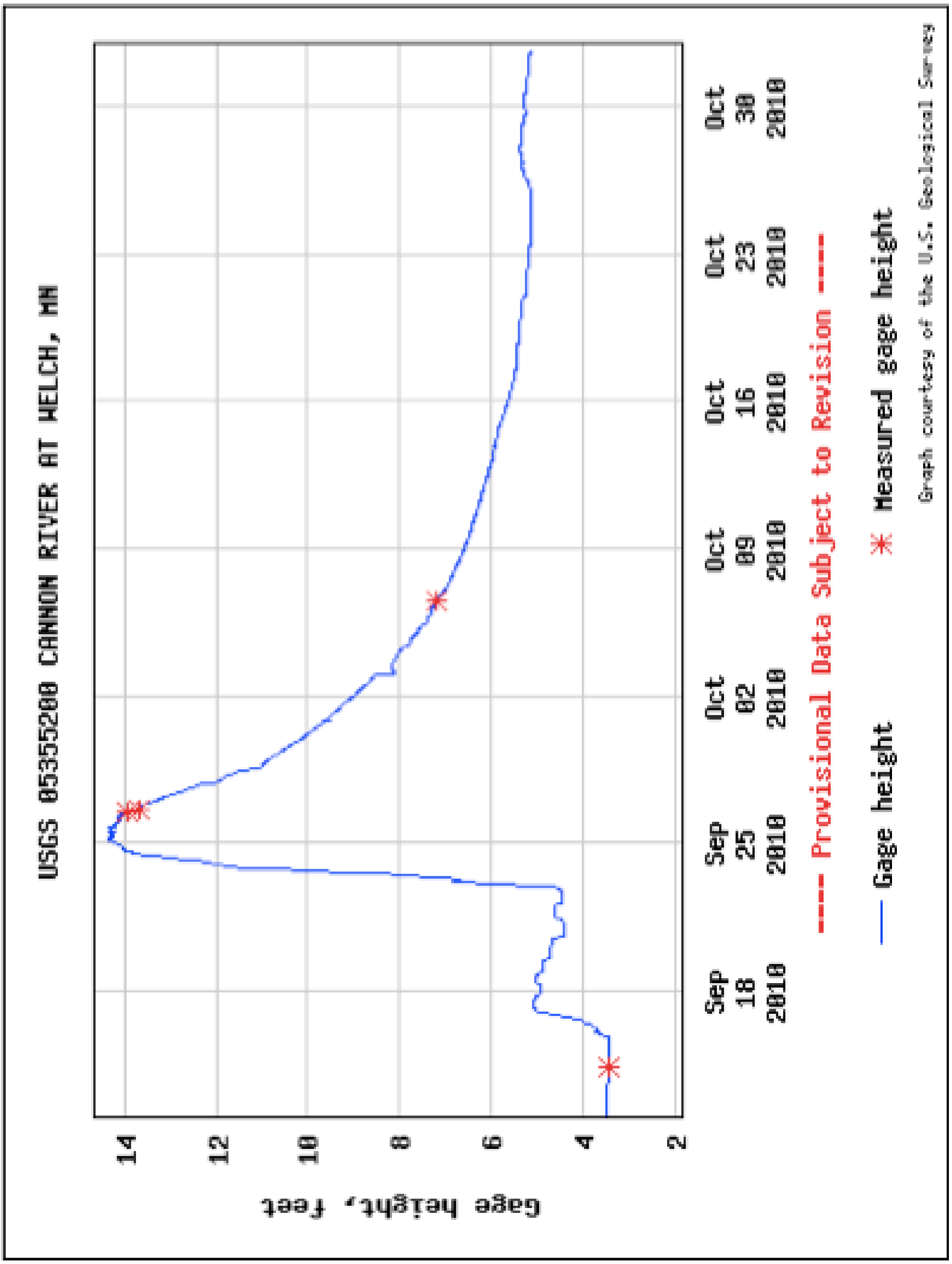


Figure 3: Cannon River gage height at Welch, MN. From (Gage Height, 2010).

Discussion:

Drainage, in its most rudimentary form, has been around since approximately 200 B.C., where references have been found relating to subsurface drains removing water. Tile itself, made first with clay, has been around since approximately 1 A.D., (Wilson, 2000) and was made by hand and installed manually until around 1848, when drainage tiles began to be mass produced by machines (McCorvie et al., 1993).

During the westward expansion of the 1800s, several laws were enacted in the hopes of tempting farmers to move west. Most laws related to agricultural practices such as tile drainage. The Swamp Lands Acts of 1849, 1850, and 1860, as well as the Gradation Act of 1854 established rules on the price of land and the ownership of land (Wilson, 2000) with the goal that land would be turned into productive agricultural units. Drainage was often a concern with the productivity of these Midwest land plots. With the help of such public policy as mentioned previously, the west was soon populated and the state of Minnesota was founded in the year 1585, with the first drainage act being passed in August of that same year.

This drainage act of 1585 was created ‘“to regulate and encourage the drainage of lands”’ and set up some basic rules as to how a farmer would go about legally placing tile in his land (Wilson, 2000). Up to this point, tile had all been made of clay. In the year 1862, pipes began to be produced using sand and cement; and in the 1970s, tile production becoming a local (Wilson, 2000). With these newly created developments in tile, tile drainage became much more common, with a total of 1,140 tile factories operating in the United States by the year 1880. With the popularity of tile gaining political attention, the State Drainage Commission was created in the year 1897 — an important occasion since it officially established a statewide structure to organize drainage projects (Wilson, 2000). It was soon after this, from the years 1910-1919, that America entered its decade of greatest drainage.

After this decade of intense drainage, attitudes began to shift from those of expansion, to those of conservation. With these changing views, the Drainage and Conservancy Act of Minnesota was passed in 1919, allowing district courts to establish drainage and conservancy districts (Wilson, 2000). However, the state's measures couldn't fully stop the intense agricultural drainage happening in the Midwest. In 1929, of the 35 states with drainage district legislation, the Midwest contained 61% of all land controlled by these districts (see figures 4 and 5); and in the year 1974, Indiana, Illinois, Iowa, Minnesota, and Ohio, contained nearly 60% of this drained land (McCorvie et al., 1993). In 1949, another great advancement occurred in drainage, when plastic tubes were introduced for drainage use, instead of the sand and cement drains for the previous century (Figure 6) (Wilson, 2000). Still focused in conservation, the Water Bank Program was created in 1976, designed to protect waters under economic pressure from drainage (Wilson, 2000). This policy of conservation is still carried in more modern legislation with the Wetland Protection Act of 1991, with the goal of "no new loss" in existing wetlands (Wilson, 2000). With the use of tile drainage existing throughout America's history, and the livelihood of the farmer depending on its efficiency, a fair amount of research has been done over the years to improve tile's capabilities.

Many scientists have attempted to explain the relationship between subsoil drainage and flooding. Although many other factors affect the severity of floods, it has been proven that tile drainage has an influence on the flow rate of water. Figures seven and eight illustrate this relationship through the examination of daily rainfall and drainage in an area east of France (Henine et al., 2010). The rate of water as it flows through the drainage system has an impact on the area's drainage basin, or catchment. As more water flows at a higher velocity into the catchment, the catchment water level will increase. Despite this fact, there is data supporting the concept that during periods of intense rainfall, pressurization may restrict and/or delay the tile's drainage process. (Henine et al., 2010). Impeding tiles or unusually high subsurface water levels are two possible causes for pipe pressurization. According to Heine's study, the storage of excess water in the soil leads to a delay of the peak discharge that can last upwards of 25 hours.

Figure nine is a perfect example of how water flows through a subsoil drainage system. This graph in Heine's experiment shows the delay of the peak flow in the event of an unusually heavy rainfall. Note that in this case, the influenced period (the duration during which water remains and travels through the soil) lasts for approximately one day. During the backflow period, water discharge dips into the negative, causing the delay of catchment flow. However, results concerning the overall flow rate were not recorded. Lacking this data, we are unable to assume that the tiles had a direct affect on catchment flow. Rather, we can make the claim that subsurface tile drains affect the duration of time water spends in the soil. Backflow causes water to remain in the soil for an artificially extended period of time before the second peak flow (Henine et al., 2010). This data can be related to the Cannon River flood that occurred on September 22nd and 23rd 2010 in Rice County, Minnesota. It is apparent that the presence of tile drainage affected the flood. However, with our data and collection of research, we are unable to determine to what extent.

Pipe pressurization is not the only factor that determines the impact of tile drainage systems. The size, material, and distance in between pipes are extremely important in determining the flow outcomes of subsurface drainage. Distance between tiles varies; however, the general distance found in Rice County is roughly 40 feet for the more recently installed tiles, and 80 feet for older models (Pohs, 2010). The more closely spaced the tiles are the faster the water will drain (Robinson, 1990). Figure ten displays the many factors to take into account while determining the position and spacing of a tile. In addition, Rice County's soil profile affects drainage (Figure 11). Rice County's agricultural land is composed mainly of mollisols—a high nutrient soil with a loose, low-density surface and a high water table (Anderson, 2010). Figure twelve is a sample from the Soil Survey of Rice County, Minnesota, showing a mollic composition. In Rice County's silty loam, water flows through tiles at a maximum rate of 5 feet per second. This high velocity of water flow has the potential to add to the severity of a flood (Subsurface Drain, 2007).

To conduct further research on this topic, it would be useful to contact farmers in Rice County, in order to obtain in-depth information on the location of tile drains. With this information, one would be able to create an accurate map of the density of tile drains in Rice County. Through further experiments in a controlled environment, researchers should be able to eliminate extraneous variables, and therefore obtain more accurate results of the direct effect of tile drainage on flooding.

Acknowledgments:

We would like to thank Professor Bereket Haileab for his help throughout the term advising us and helping us to organize this geologic study. We would also like to thank Tim

Vick, Charlie Priore, and Steven Pohs. Finally, we would like to thank the rest of our geology class, specifically the flood group for the use of their data and graphs.

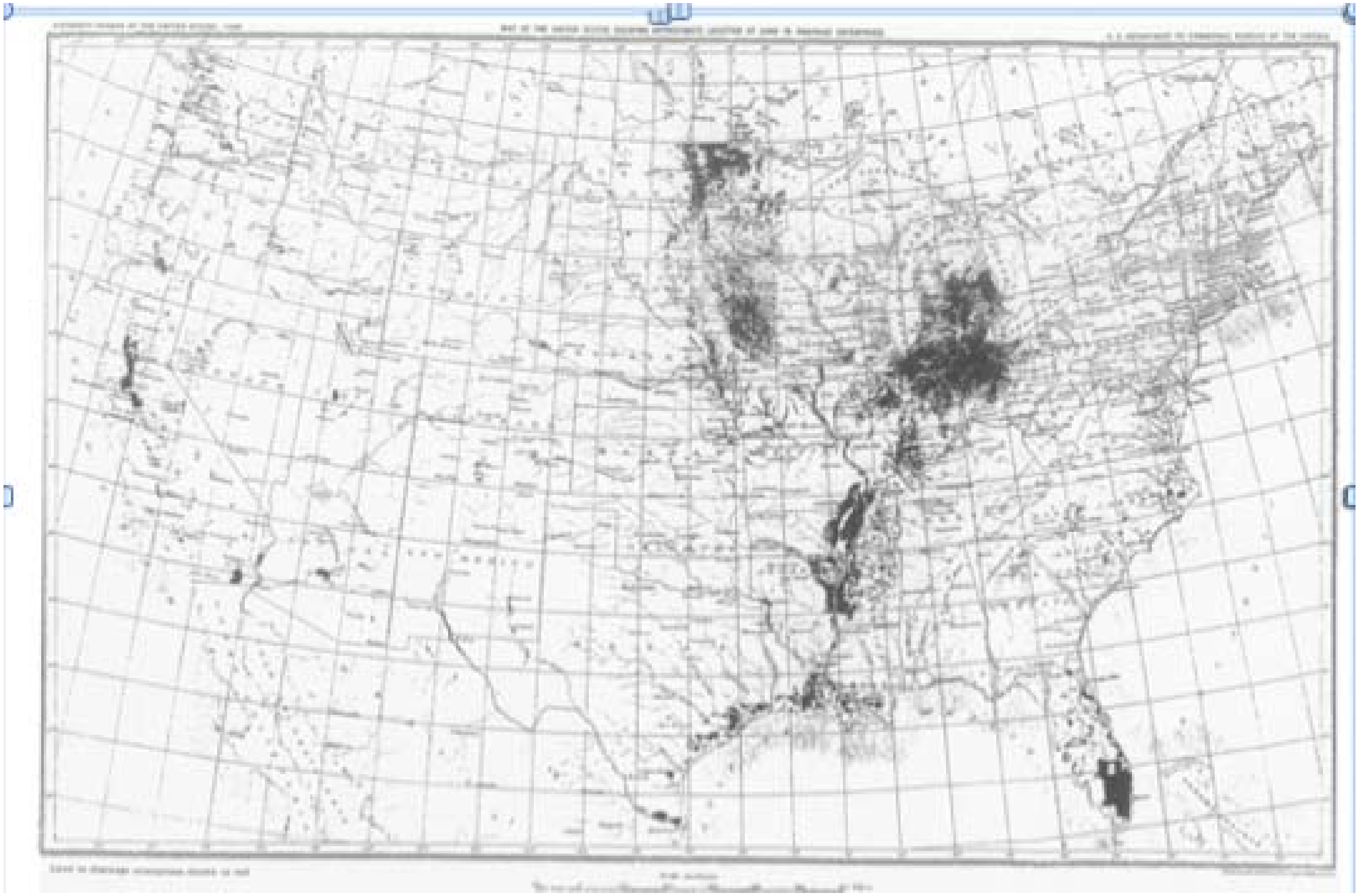


Figure 4: Location of land in drainage enterprises in the United States in1930. From (McCorvie et al., 1993)

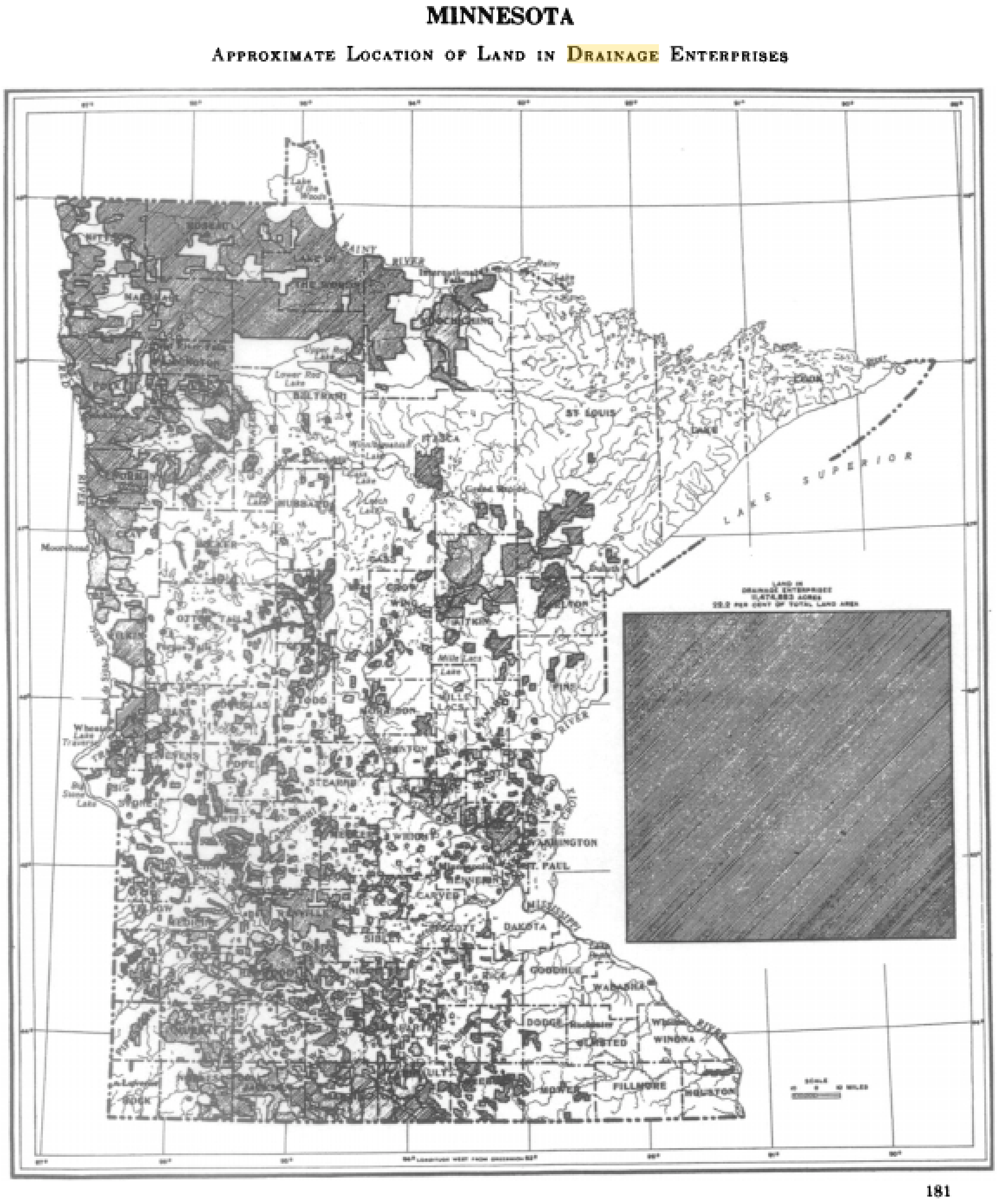


Figure 5: Location of drainage enterprises in Minnesota in 1930. From (McCorvie et. al, 1993).

Figure 6: This is an example of a newer tile being used today. This tile has a diameter of approximately 20 cm and made of a plastic. From (Johnson et al., 2003).

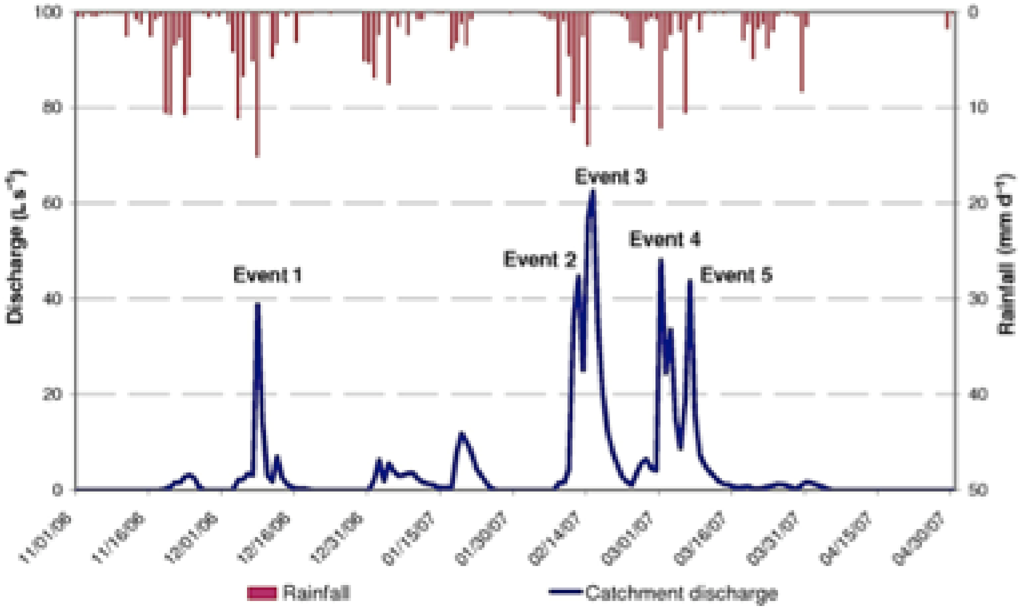


Figure 7: Rainfall-runoff characteristics for season 2006-2007 and peak flow events with a pressurized field collector. (Henine et al., 2010)

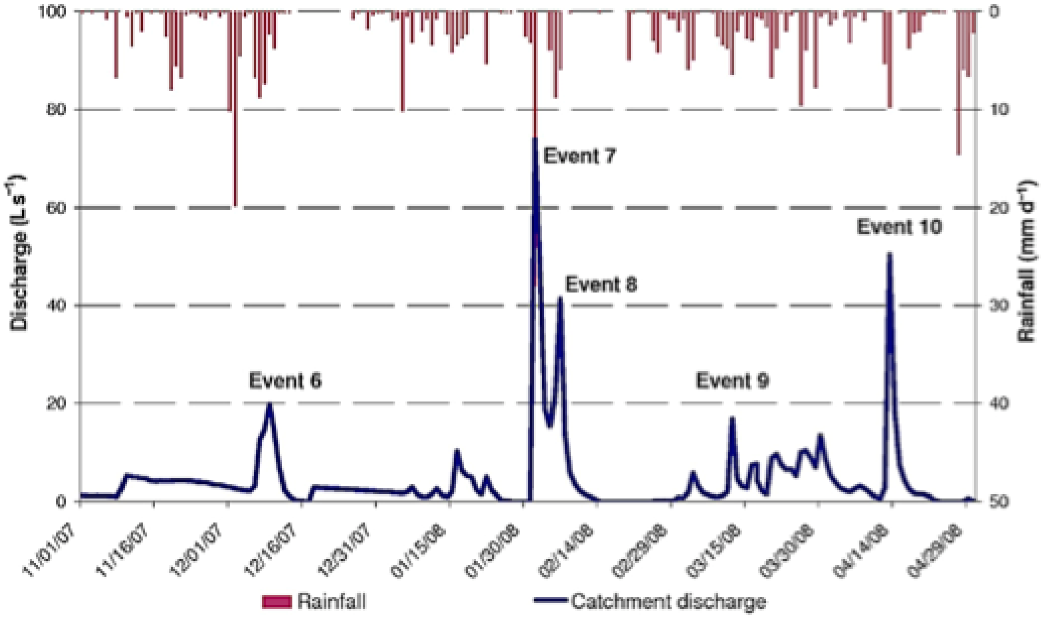
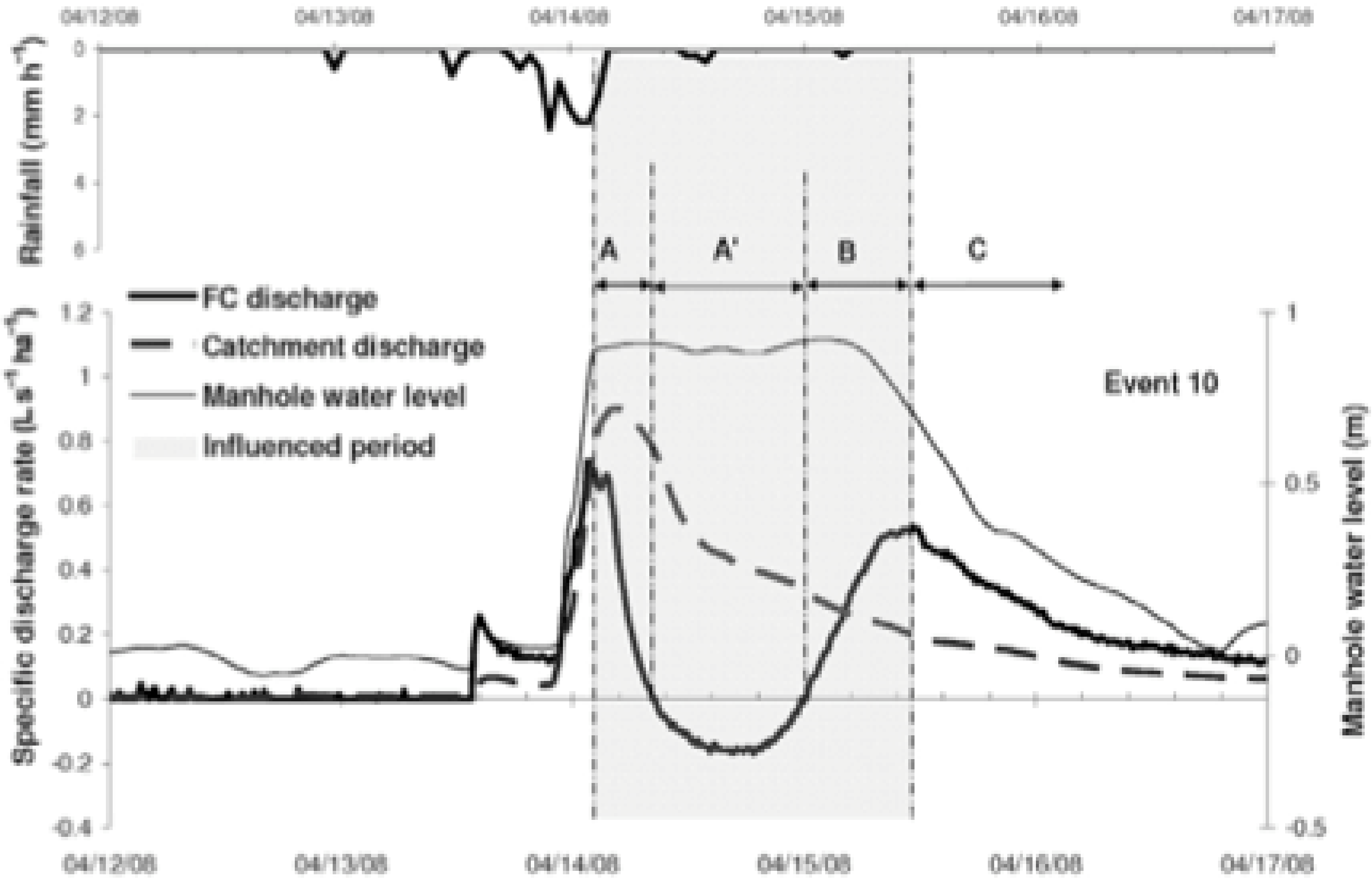


Figure 8: Rainfall-runoff characteristics for season 2007-2008 and peak flow events with a pressurized field collector. (Henine et al., 2010.)



Rainfall (mm h^{-1})
0
2
4
6
A
A'
B
C
FC discharge
Catchment discharge
Manhole water level
Influenced period
Event 10
Specific discharge rate (L s^{-1} ha^{-1})
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
Manhole water level (m)
1
0.5
0
-0.5
04/12/08
04/13/08
04/14/08
04/15/08
04/16/08
04/17/08

Figure 9: Discharges from the field and catchment, the case of a strong influence on field discharge with four stages: first peak discharge (A); backflow (A'); second peak discharge (B); and recession (C). From (Henine et al., 2010).

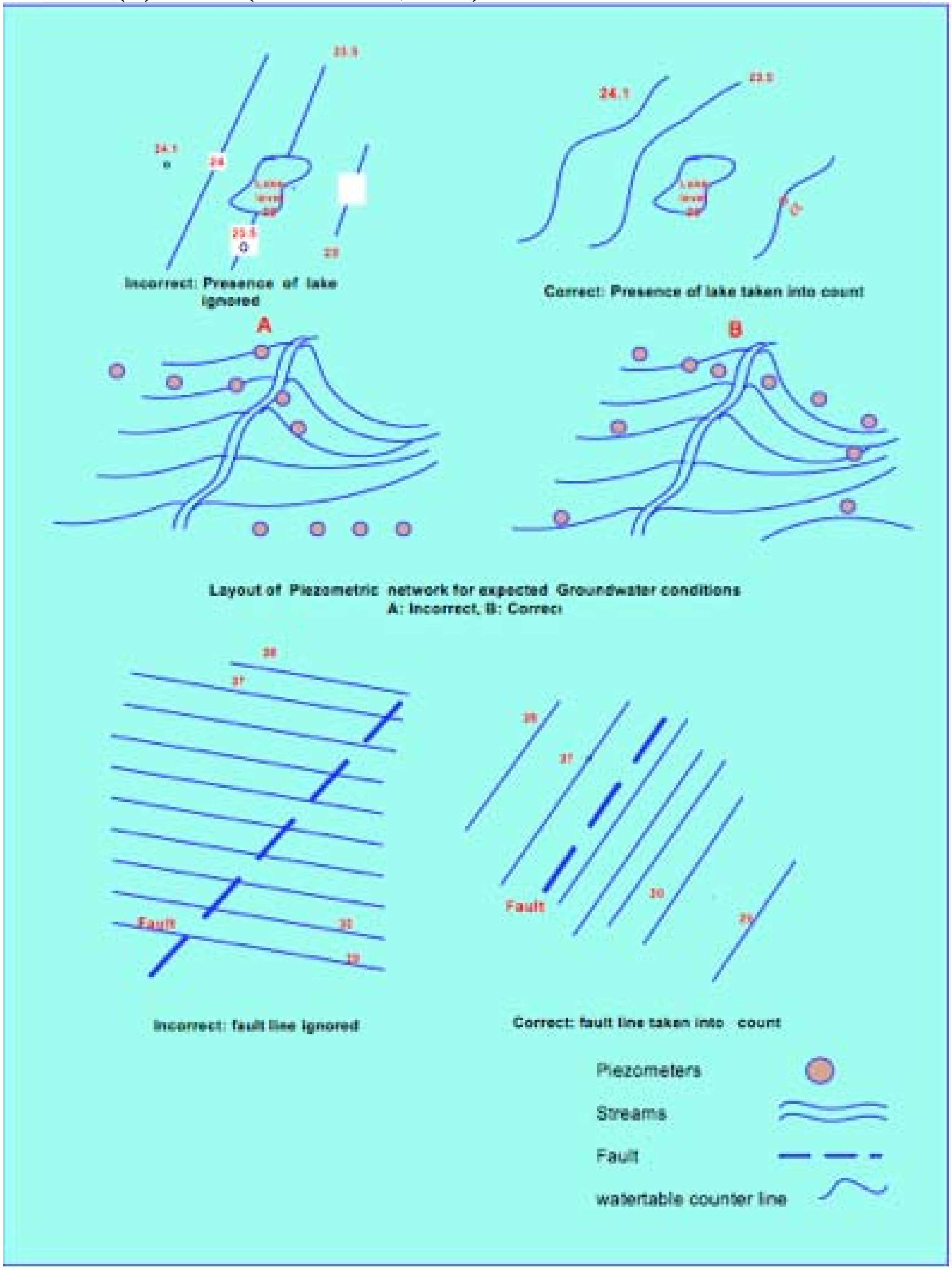
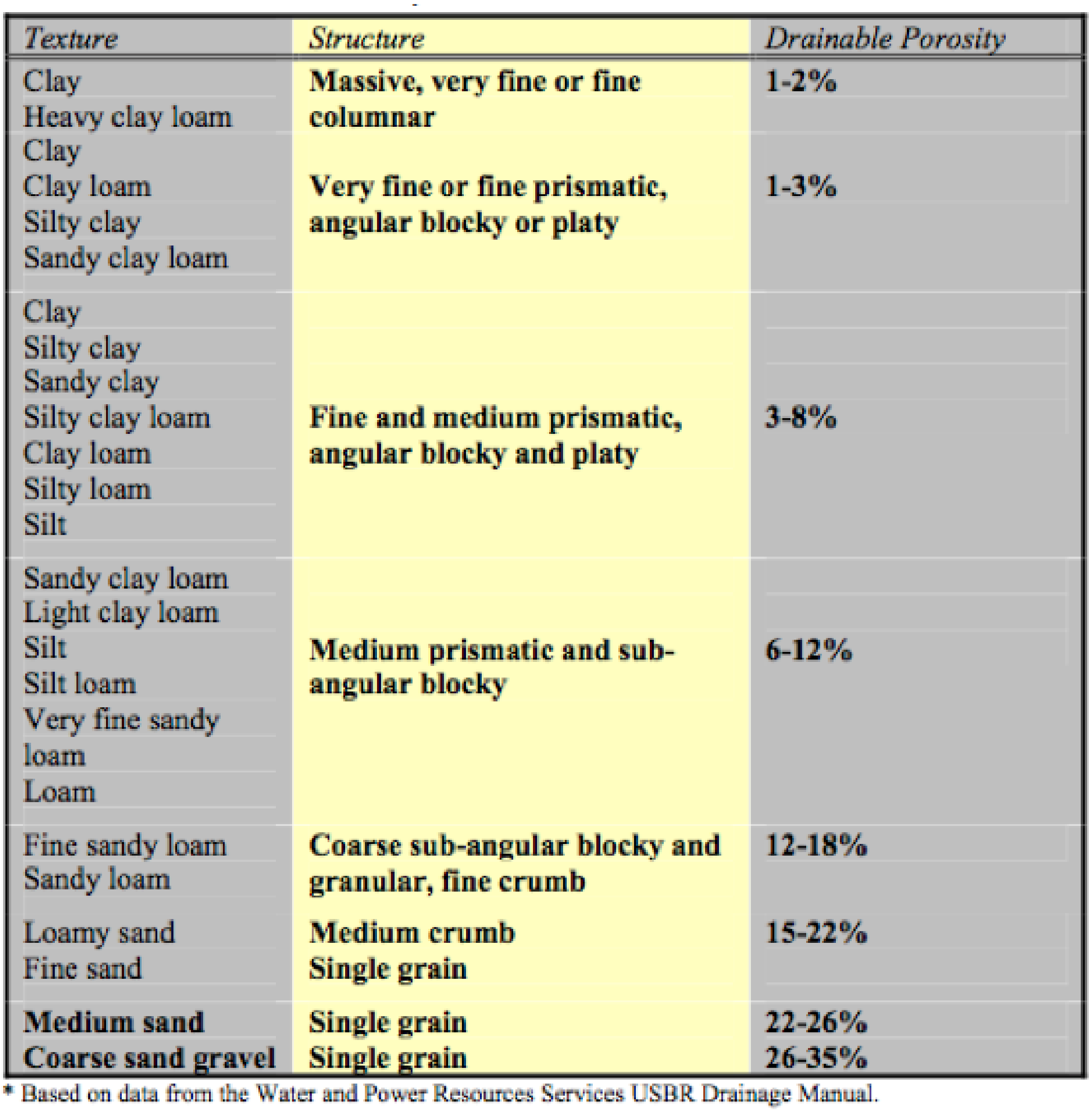


Figure 10: Proper and improper ways of installing tile drains in different situations. From (Kahlown, 2004).



Texture	*Structure*	*Drainable Porosity*
Clay Heavy clay loam	**Massive, very fine or fine columnar**	**1-2%**
Clay Clay loam Silty clay Sandy clay loam	**Very fine or fine prismatic, angular blocky or platy**	**1-3%**
Clay Silty clay Sandy clay Silty clay loam Clay loam Silty loam Silt	**Fine and medium prismatic, angular blocky and platy**	**3-8%**
Sandy clay loam Light clay loam Silt Silt loam Very fine sandy loam Loam	**Medium prismatic and sub-angular blocky**	**6-12%**
Fine sandy loam Sandy loam	**Coarse sub-angular blocky and granular, fine crumb**	**12-18%**
Loamy sand	**Medium crumb**	**15-22%**
Fine sand	**Single grain**	
Medium sand	**Single grain**	**22-26%**
Coarse sand gravel	**Single grain**	**26-35%**

* Based on data from the Water and Power Resources Services USBR Drainage Manual.

Figure 11: Drainable Porosity Values as Related to Soil Texture and Structure*. From (Kahlown, 2004).

Figure 12: Profile of Nerwoods loam. The mollic epipecion extends to a depth of about 50 centimeters (20 inches). The upper sediment is in contact with the till at a depth of about 115 centimeters (45 inches). Depth is marked in centimenters. From (Beck, 2000).

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Frequency of Flooding in Southern Minnesota

By

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Fall 2010, Introduction to Geology

Carleton College

Northfield, MN

INTRODUCTION

Major Historical Floods

Major flooding in Minnesota is a long-standing problem. In almost every year since the Federal Emergency Management Agency (FEMA) started keeping records, there has been a "Major Disaster Declaration" for severe storms or flooding in Minnesota (FEMA, 2010). There have been some cases where a majority of the counties in the state have been affected by a single flood. For example, in the spring of 1997, the Red River and the Upper Minnesota River flooded, breaking many of the existing flood records in Minnesota. 58 of Minnesota's 87 counties were declared federal disaster areas (FEMA, 2010) and the flood damages and associated economic costs were an estimated $2 billion (MN Department of Natural Resources, 2010).

Major floods occur all over the world, and their effects on civilization make them worthy of our attention. For example, in Europe, a similarly disastrous flood occurred in the summer of 2010. Austria, the Czech Republic, Germany, Hungary, Slovakia, Serbia, and the Ukraine were affected (European Flood Alert System, 2010), at least 37 people died and an estimated 2.5 billion Euros worth of damages occurred (Pm, 2010).

Also in 2010, Pakistan experienced one of the worst floods in Pakistani history. 82 districts were affected, destroying at least 1.89 million homes and injuring or killing thousands of people. The flooding occurred when climate change caused monsoon rainfall to reach record volumes of water, overflowing the Indus river basin. The Indus river basin had flooded before, most significantly in 1973 and 1976, but not nearly to the extent of the 2010 flood (ReliefWeb, 2010).

Another flood that resulted from heavy rainfall was the Yellow River flood of 1887 in the Henan province of China. The rainfall overwhelmed and caused a rupture of the dykes that contained the river. Spilling out from the dyke breaches, the ensuing flood covered 50,000 square miles, killing 900,000 people (Gunn, 1920).

Causes of Flooding

Flooding is a natural occurrence. Floods are normal consequences of stream flow in a continually changing environment. The water cycle has caused floods for a large part of Earth's history, and will continue to cause them as long as the cycle continues to run.

Precipitation is the largest cause of flooding. Rain and snowfall often occur in an inconsistent pattern, and are sometimes concentrated in a way that releases large amounts of water in a short period of time. There have been instances in which amounts of rain that would normally occur over several months have come down in single days. When this happens, the parts of the water cycle affected, such as rivers and streams, are thrown out of balance, often overflowing their regular levels. This is what would be defined as a flood--when water overflows its usual boundaries onto what is typically land mass.

Usually flooding occurs in rivers and streams. However, coastlines can be subject to flooding from tsunamis, hurricanes, and high tides. Sea levels have also risen over long periods of time as a result of global warming melting ice caps.

Flooding can also result from man-made causes, especially from dam and levee failures. Dam failures have occurred several times throughout history. The St. Francis Dam, near Saugus, California, failed in 1929 killing 450 people. The Johnstown, Pennsylvania dam, built of earthen material (soil and rock) collapsed after a period of heavy rainfall in 1889. The flood killed 2,200 people. In Italy in 1963 landslides moved into the reservoir behind the Vaiont Dam, causing water to overtop the dam killing more than 3,000 people. Additionally, during Hurricane Katrina, the levees designed to prevent flooding failed, and led to disastrous conditions for a long period of time (Nelson, 2010).

Aside from dam and levee failures, other man-made construction issues can cause flooding. Poor sewage and draining systems can result in flooding, and dredging rivers away from their natural courses sometimes proves to be problematic. Furthermore, agricultural use or development of flood plains often erodes the soil, worsening many flooding areas (UK Environmental Law Association, 2009).

Geology of the Minnesota

The current geology and topography of the state was influenced by the most recent ice age, approximately 20,000 years ago, and its aftermath. When ice, which covered most of the state, melted, it formed Lake Agassis, a massive lake larger than the combined Great Lakes would be today. The glaciers also left the depressions where current lakes sit, and deposits of limestone that caused the formation of the Karst topography present throughout the state (Advameg, 2010).

Aquifers in the state of Minnesota are mostly unconfined, meaning their upper boundary is not enclosed by a confining layer. In general, the water table is within tens of feet of the ground surface, which is relatively close (MN Department of Natural Resources, 2010). Flat prairie dominates the landscape, except for the hills and river valleys of the southeast, and the iron ore-rich mountain ranges in the northeast.

Minnesota has more inland water than any other state besides Alaska, with over 15,000 lakes and many wetlands, rivers and streams. Lake Itaska, in the northwest, is the source of the Mississippi River, which drains three-fifths of the state (Advameg, 2010). Numerous streams and drainage ditches cover the state (Figure 1). Welch MN is located near the northeastern edge of the Lower Mississippi River Watershed Basin. Average annual precipitation is distributed unequally over the state, with the southeast corner having the highest average annual precipitation, and the northwest corner having the lowest (Figure 3). Northfield MN is located in the area with the highest average annual precipitation.

Purpose

This paper will discuss the history and frequency of floods in Rice, Goodhue and Dakota counties in Southern Minnesota from 1916-2010, including the September 2010 flooding of the Cannon River. Data will be analyzed regarding frequency of floods, peak flow, and precipitation.

FINDINGS AND DISCUSSION (See APPENDIX B for Figures)

On the Cannon River, the five months with the highest average flow (in cubic feet per second, 1958-2002) are, in order from greatest to least: April, March, June, May and July (Figure 10). Peak flow has occured in the following months: September (2010), February (2009), June

(2008, 2005), March (2007), and April (2006). High flows also occurred in August and October 2007. The peak flows occuring in September 2010 and February 2009 occured in months which typically do not experience peak yearly flow.

In the 8th climate division (which includes Rice County where the Welch measuring station on the Cannon River is located), during the months of September from 1895-2010, September 2010, and to a lesser degree, September 2005, experienced significantly more rainfall than previous Septembers (Figure 11). Both of these periods of high rainfall are reflected in the streamflow graphs (Figures 4 and 9), and could explain the high peak flow for September 2010.

It is obvious that historically, peak flow has occured in the spring, presumably as a result of snowmelt (Figure 10). However, in 2010, 2009, 2008, 2007, and 2005, peak flow or high flow has occured at times of the year when high discharge cannot be attributed to snowmelt. It is likely that in these cases, high flow was caused by high levels of precipitation.

The highest average monthly flow occuring in the month of April, is just over 1,400 cubic feet/second (Figure 10). The peak flow for 2010 was just slightly over 20,000 cubic feet/second, which is vastly greater than the average peak flow for a given year. As well, the average peak flow for the month of September is only just under 400 cubic feet/second, making the peak flow of September 2010 even more drastic. Over the past five years, the peak flow has never exceeded 7000 cubic feet/second except in September 2010.

There is not a clear yearly pattern as to when floods will occur. (Figures 12-15). On the Vermillion River near Empire, MN (Dakota County), there are two peak flows well above the averages for the surrounding years (Figure 12). The highest annual peak flow at this location was recorded at 6570 cubic feet per second (cfs) in September of 1992, and the 2nd highest was recorded at 3592 cfs in June of 1998. The Cannon River at Northfield, MN (Rice County) the highest annual peak flow was recorded as 8370 cfs in April of 2001 (Figure 13). However, this is not much higher than several other peak flows. The measurements of streamflow for the Cannon River at Northfield range from around 500 cfs to 8370 cfs. On the Cannon River at Welch, MN in Goodhue County (Figure 14), the highest peak stream flow was recorded in April, 1965 at 36100 cfs. Every other stream flow measured from 1916 to 2000 were below 25000 cfs. On the Striaght River near Faribault, MN (Rice County), the highest annual peak flow was 6080 cfs in June, 2004 (Figure 15). However, there is a wide range of peak levels, and the highest is not really significant in this case. No pattern of flooding by year is apparent.

<u>September 2010 Flood</u>

The September 2010 flood on the Cannon River was called by many a “100 year flood.” When the flood first occurred, people in town were overheard saying that they had never seen a flood this size hit Northfield. The town’s GIS technician, Brian Welch, said the water level was “one to one and a half feet higher than the predicted 100-year flood mark”. While the most recent flooding of the Cannon River was certainly huge, by no means was it the biggest in 100 years (Figure 16).

Defining flood magnitude by time intervals in this way can be misleading, because multiple floods the size of the most recent flood can occur much more often than their classification would suggest. Several floods of any magnitude can happen in just a few years, as evidenced by the last few major floods that occurred on the Cannon River as measured by the Welch, MN station (Figure 16). Human interaction has contributed to the irregularity of the natural cycle of flooding and complicated the methods of measuring its effects. “The actual number of years between floods of any given size varies a lot,” according to the U.S. Geological Survey website. “Big floods happen irregularly because the climate naturally varies over many years. We sometimes get big floods in successive or nearly successive years with several very wet years in a row.” Downtown Northfield, for example, is built right on top of the river, and the drastic effects of the flood, such as the destruction of Froggy Bottom’s, can overemphasize the magnitude of a flood (Rook, 2010).

CONCLUSION

From the data collected and analyzed in this report, it is impossible to find a distinct pattern in the occurrence and magnitude of floods, either seasonally or over periods of years. Peak streamflow varies from year to year both by small and large increments, along no clear pattern. Although average monthly peak streamflow for the Cannon River follows a general curve, peak flows for recent years do not seem to fit into this pattern. Also, when floods do occur, their magnitude varies greatly with no obvious pattern. Floods can be reasonably expected to occur during spring snowmelt and fall precipitation, although the latter cause has, in recent years, proven unpredictable. Floods that presumably occurred due to rainfall have occurred during the summer and fall months over the past six years. Although historically snowmelt has caused greater flow in the Cannon than rainfall has at other times of the year (summer, fall), in recent years (Figure 10), autumn rainfall has caused peak flow and is therefore worthy of attention.

Future Work

In order to further study this topic, we would analyze more data about floods in the region, and see how this data compares to our current findings.

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APPENDIX A: Glossary (Mitton, 2005)

Cubic feet per second: the rate of discharge representing a volume of 1 cubic foot passing a given point in 1 second. It is equivalent to approximately 7.48 gallons per second, 449 gallons per minute, or 0.02832 cubic meters per second. The daily mean discharges reports in the daily value tables numerically are equal to the daily volumes in cfs-days, and the totals also represent volumes in cfs-days.

Discharge or flow: the volume of water (or more broadly, volume of fluid including solid and dissolved phase material) that passes a given point in a given period of time.

Drainage area (of a site on a stream): the area measured in a horizontal plane that has a common outlet at the site for its surface runoff. Figures of drainage area given herein include all closed basins, or noncontributing areas, within the area unless otherwise specified.

Drainage basin: a part of the Earth’s surface that is occupied by a drainage system with a common outlet for its surface runoff.

Gage height (G.H.) is the water-surface elevation referenced to the gage datum. Gage height is often used interchangeably with the more general term “stage,” although gage height is more appropriate when used with a reading on a gage.

Gage values are values that are recorded, transmitted, and/or computed from a gaging station. Gage values typically are collected at 5-, 15-, or 30- minute intervals.

Ground-water level: the elevation of the water table or another potentiometric surface at a particular location.

Mean discharge: the arithmetic mean of individual daily mean discharges during a specific period.

Peak flow (peak stage): an instantaneous local maximum value in the continuous time series of stream flows or stages, preceded by a period of increasing values and followed by a period of decreasing values. Several peak values ordinarily occur in a year. The maximum peak value in a year is called the annual peak; peaks lower than the annual peak are called secondary peaks. Occasionally, the annual peak may not be the maximum value for the year; in such cases, the maximum values occurs at midnight at the beginning or end of the year, on the recession from or rise toward a higher peak in the adjoining year. If values are recorded at a discrete series of times, the peak-recorded value may be taken as an approximation of the true peak, which may occur between the recording instants. If the values are recorded with finite precision, a sequence of equal recorded values may occur at the peak; in this case, the first value is taken as the peak.

Recurrence interval: also referred to as return period, the average time, usually expressed in years, between occurrences of hydrologic events of a specified type (such as exceedances of a specified high flow or non-exceedance of a specified low flow). The terms “return period” and “recurrence interval” do not imply regular cyclic occurrence. The actual times between occurrences vary randomly, with most of the times being less than the average and a few being substantially greater than the average.

Streamflow: the discharge that occurs in a natural channel. Although the term “discharge” can be applied to the flow of a canal, the word “streamflow” uniquely describes the discharge in a surface stream course. The term “streamflow” is more general than “runoff” as streamflow may be applied to discharge whether or not it is affected by diversion or regulation.

Water level: the water-surface elevation or stage of the free surface of a body of water above or below any datum, or the surface of water standing in a well, usually indicative of the position of the water table or other potentiometric surface.

Water table: the surface of a ground-water body at which the water is at atmospheric pressure.

Water-table aquifer: an unconfined aquifer within which is found the water table.

(Mitton, 2005)

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USGS. (Designer). (2010). *2008 discharge, cubic feet per second cannon river at welch, mn*. [Web]. Retrieved from http://waterdata.usgs.gov/nwis/dv?cb_00060=on&format=gif_default&begin_date=2007-11-05&end_date=2008-11-05&site_no=05355200&referred_module=sw

USGS. (Designer). (2010). *2007 discharge, cubic feet per second cannon river at welch, mn*. [Web]. Retrieved from http://waterdata.usgs.gov/nwis/dv?cb_00060=on&format=gif_default&begin_date=2006-11-05&end_date=2007-11-05&site_no=05355200&referred_module=sw

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USGS. (Designer). (2010). *2005 discharge, cubic feet per second cannon river at welch, mn*. [Web]. Retrieved from http://waterdata.usgs.gov/nwis/dv?cb_00060=on&format=gif_default&begin_date=2004-11-05&end_date=2005-11-05&site_no=05355200&referred_module=sw

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APPENDIX B: Figures

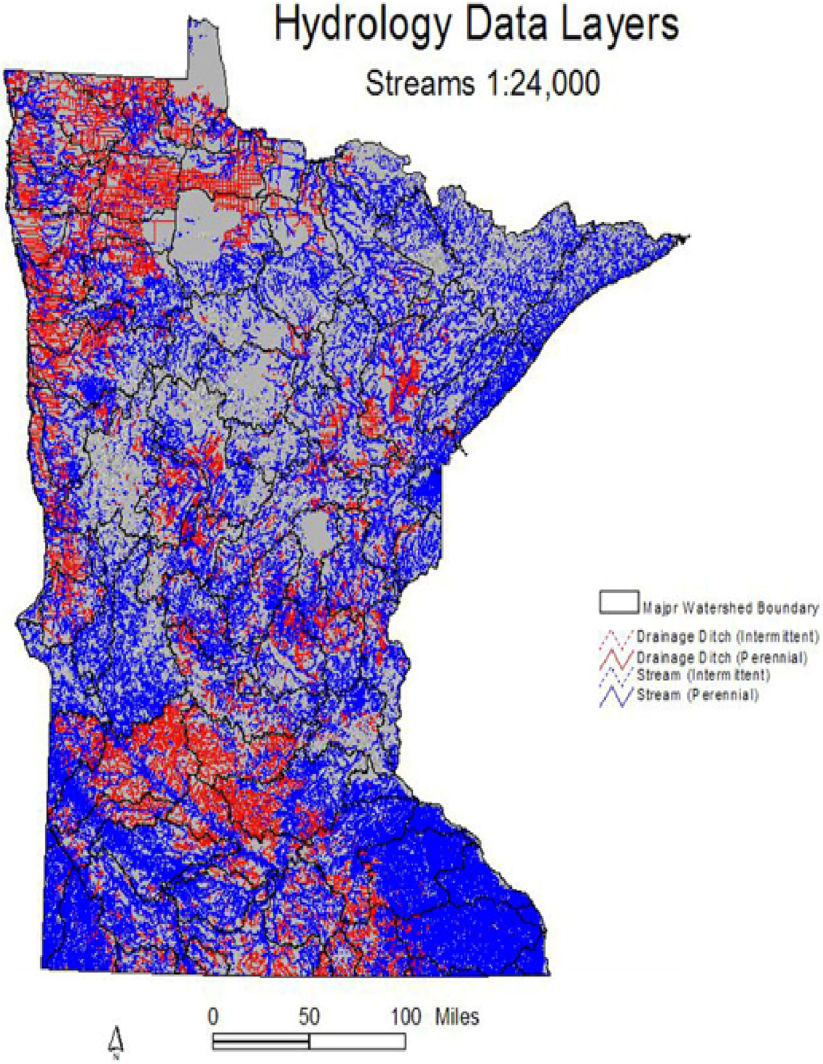


Figure 1
Hydrology Data Layers of Minnesota

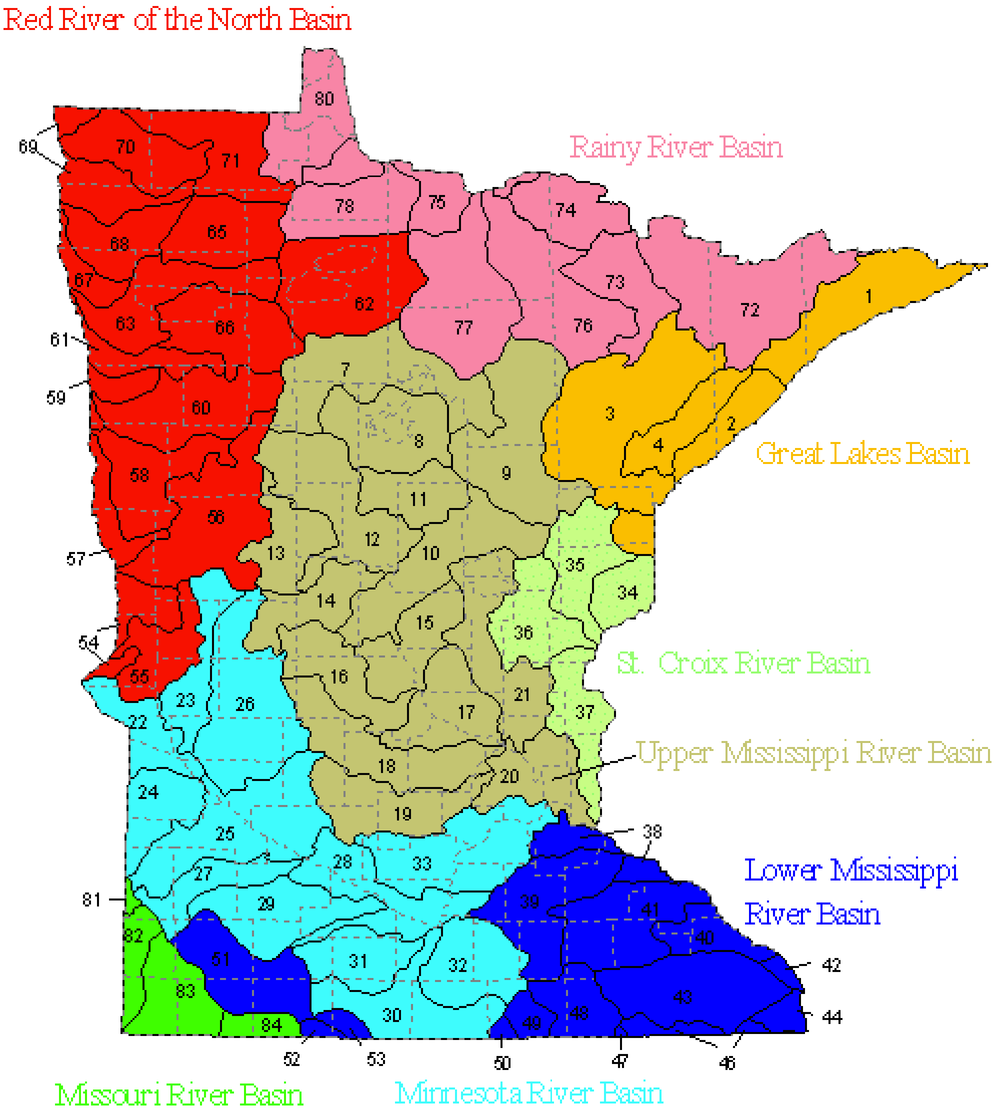
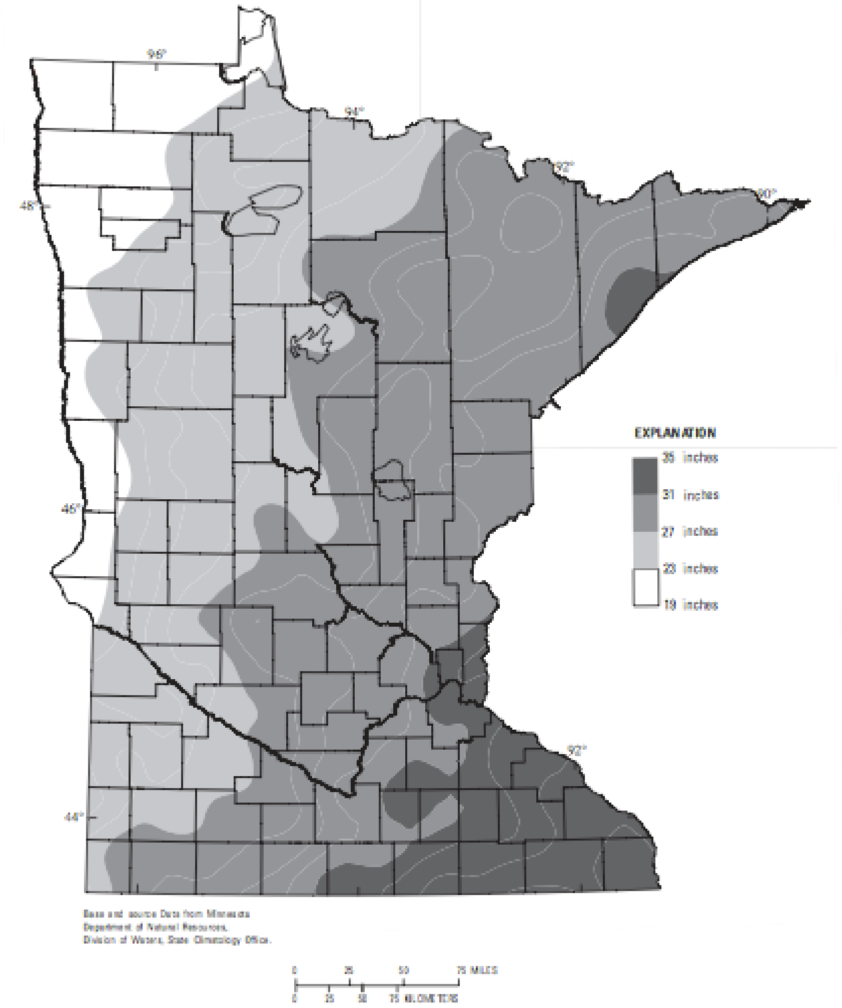


Figure 2: Minnesota's watershed basins
This map shows the 8 major basins and 81 major surface water watersheds
Minnesota's watershed basins



Base and source Data from Minnesota Department of Natural Resources, Division of Waters, State Climatology Office.

Figure 3: Average annual precipitation, in inches, for 30-year period, 1971-2000, in Minnesota.

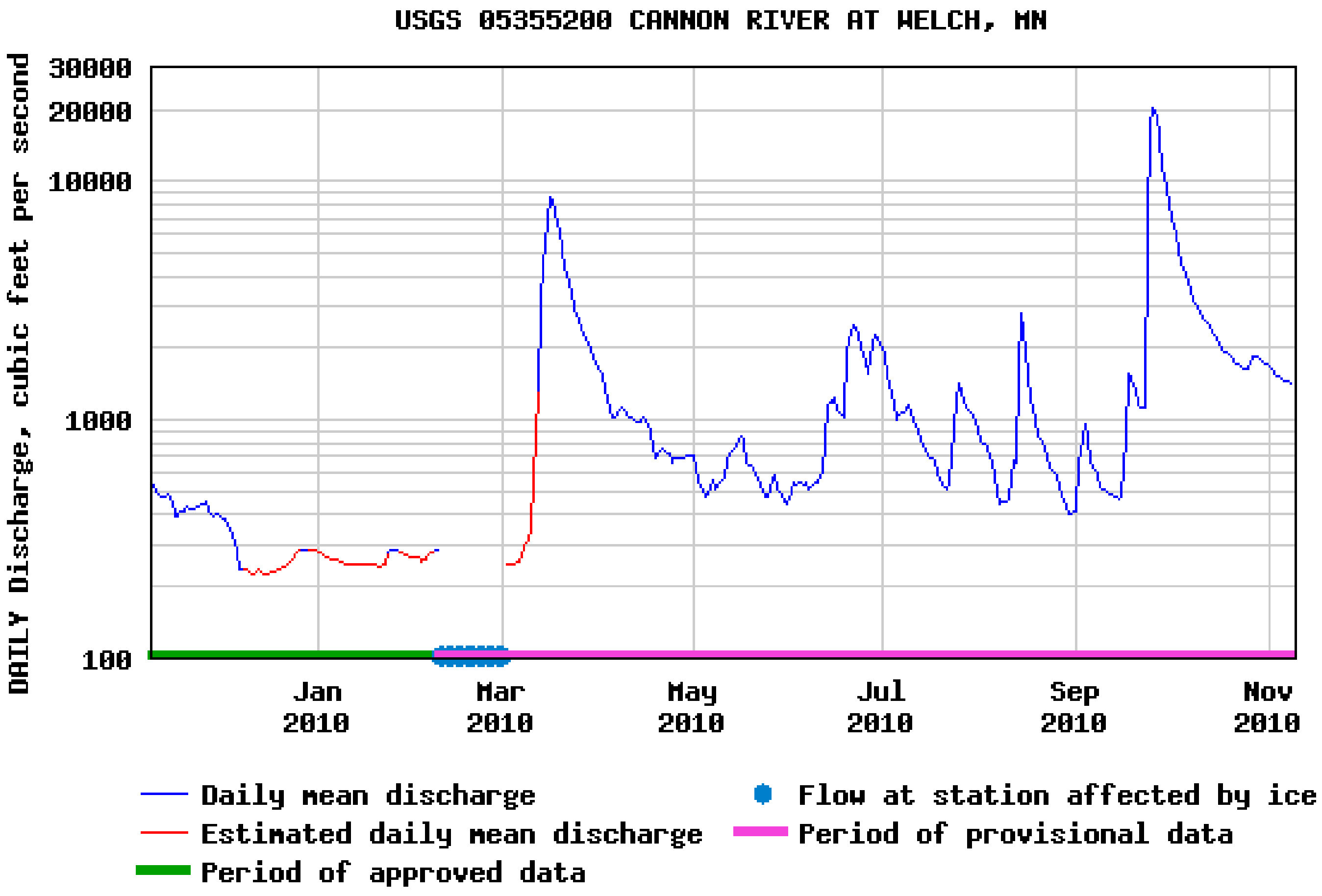


Figure 4: Daily Discharge in cubic feet per second over water year 2010

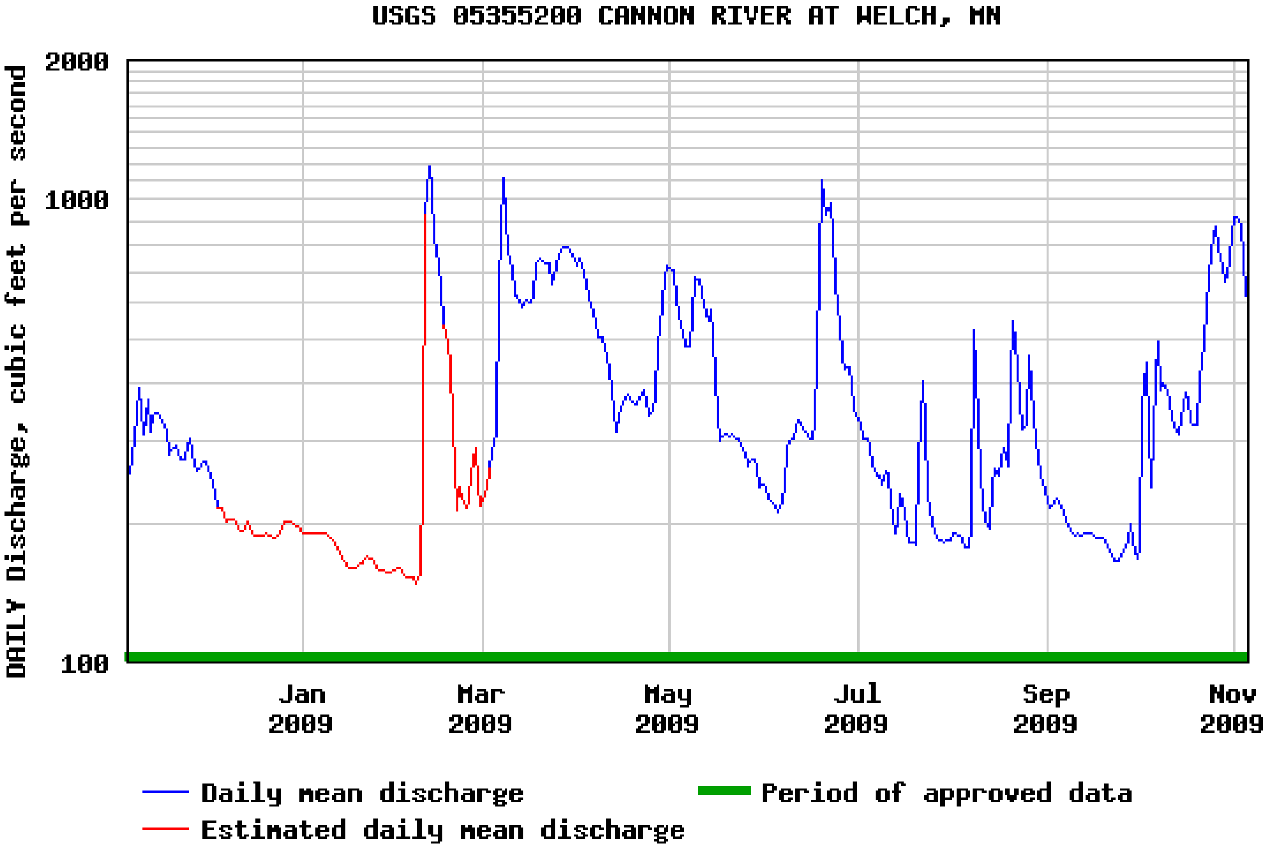


Figure 5: Daily Discharge in cubic feet per second over water year 2009

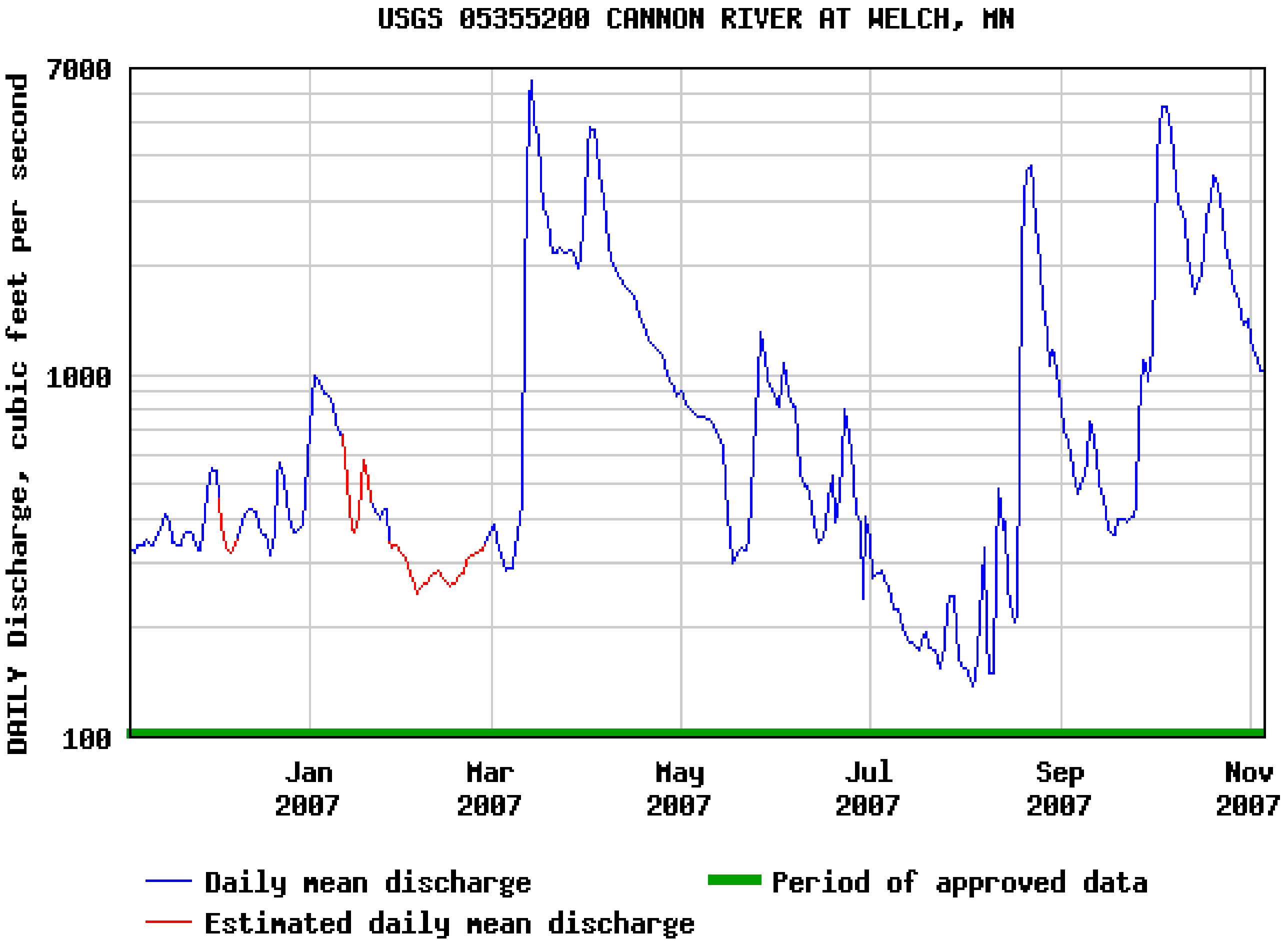


Figure 7: Daily Discharge in cubic feet per second over water year 2007

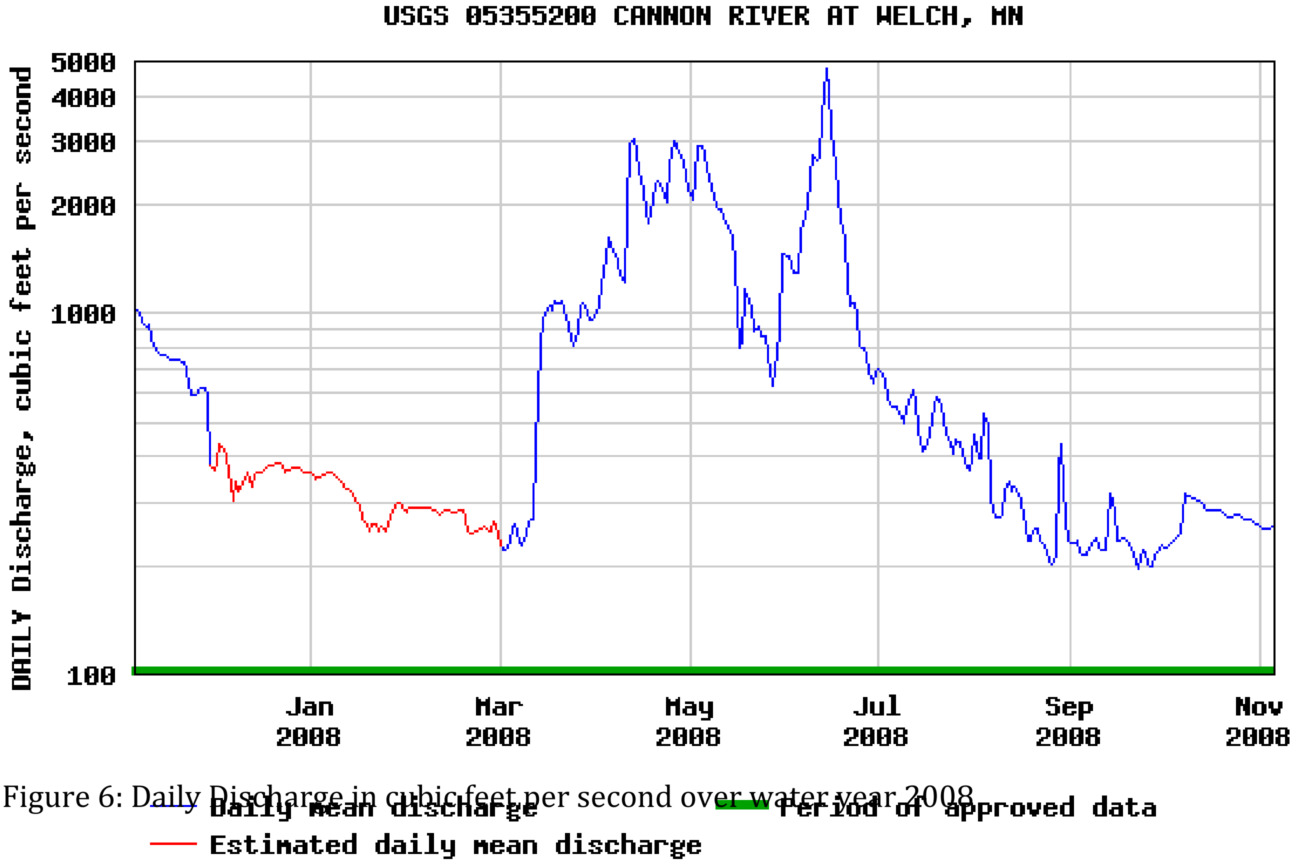


Figure 6: Daily Discharge in cubic feet per second over water year 2008

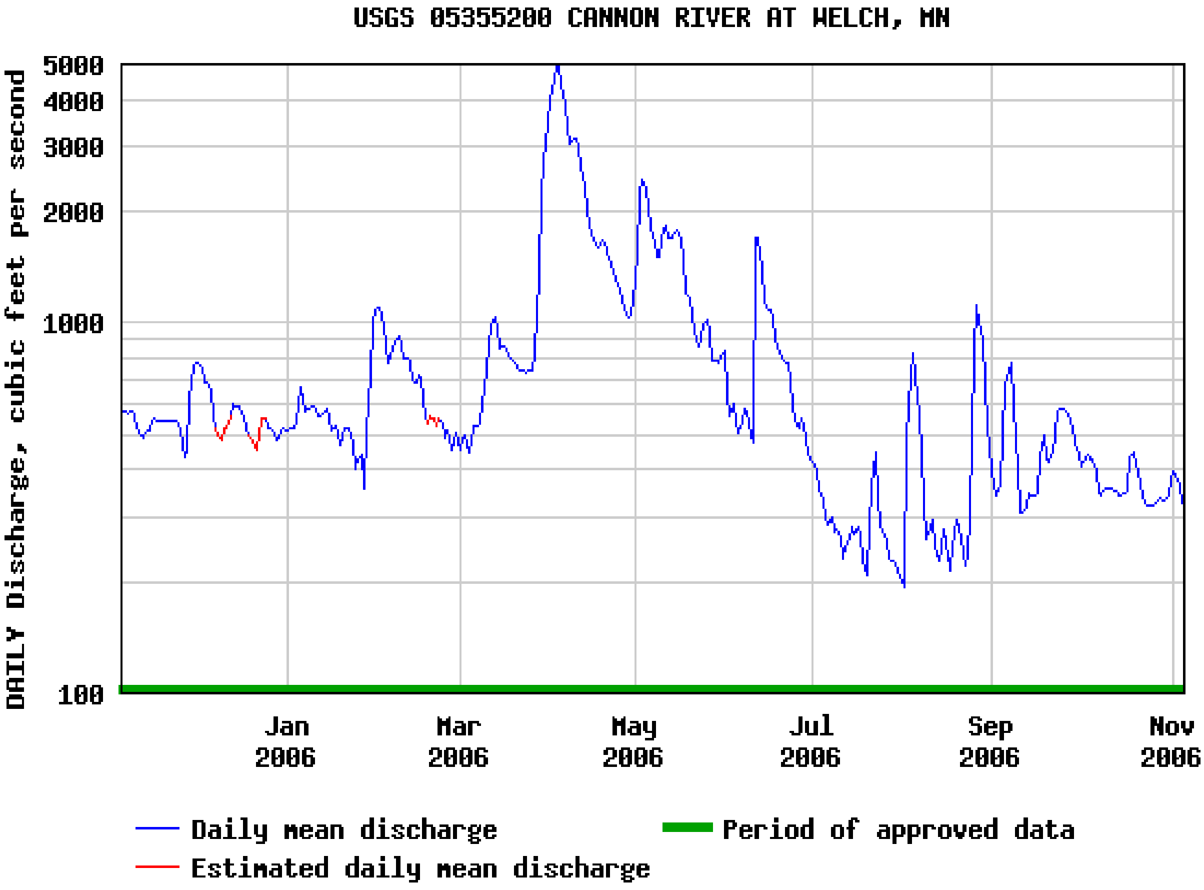


Figure 8: Daily Discharge in cubic feet per second over water year 2006

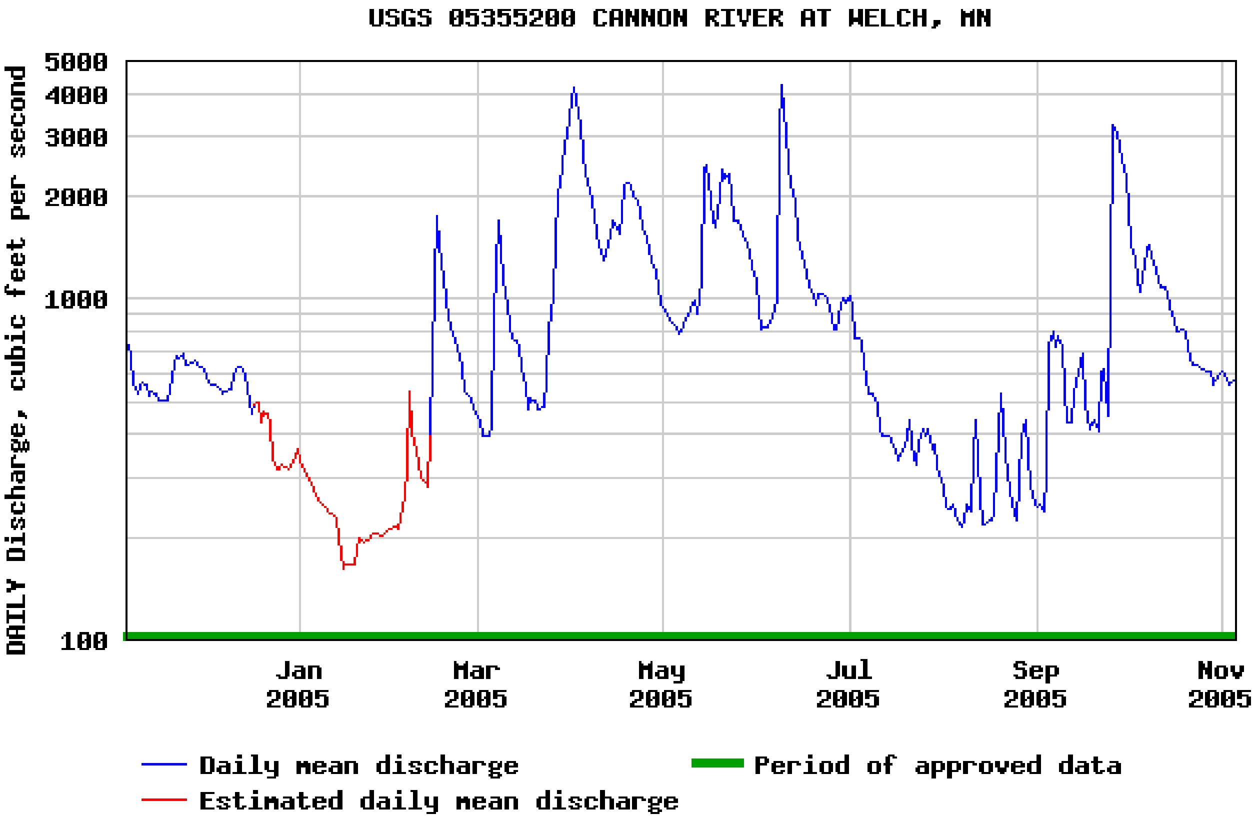


Figure 9: Daily Discharge in cubic feet per second over water year 2005

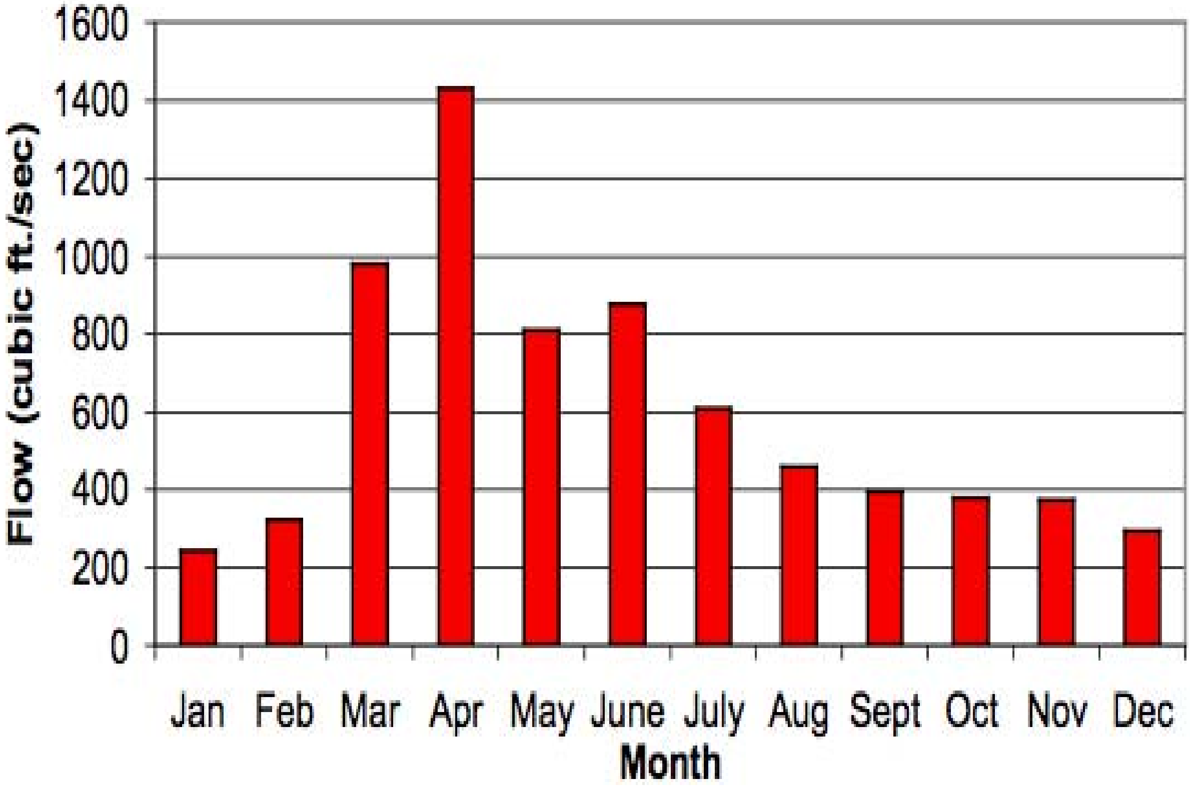


Figure 10: The Average monthly flow of the Cannon River at Welch USGS gauge Station (1958-2002)

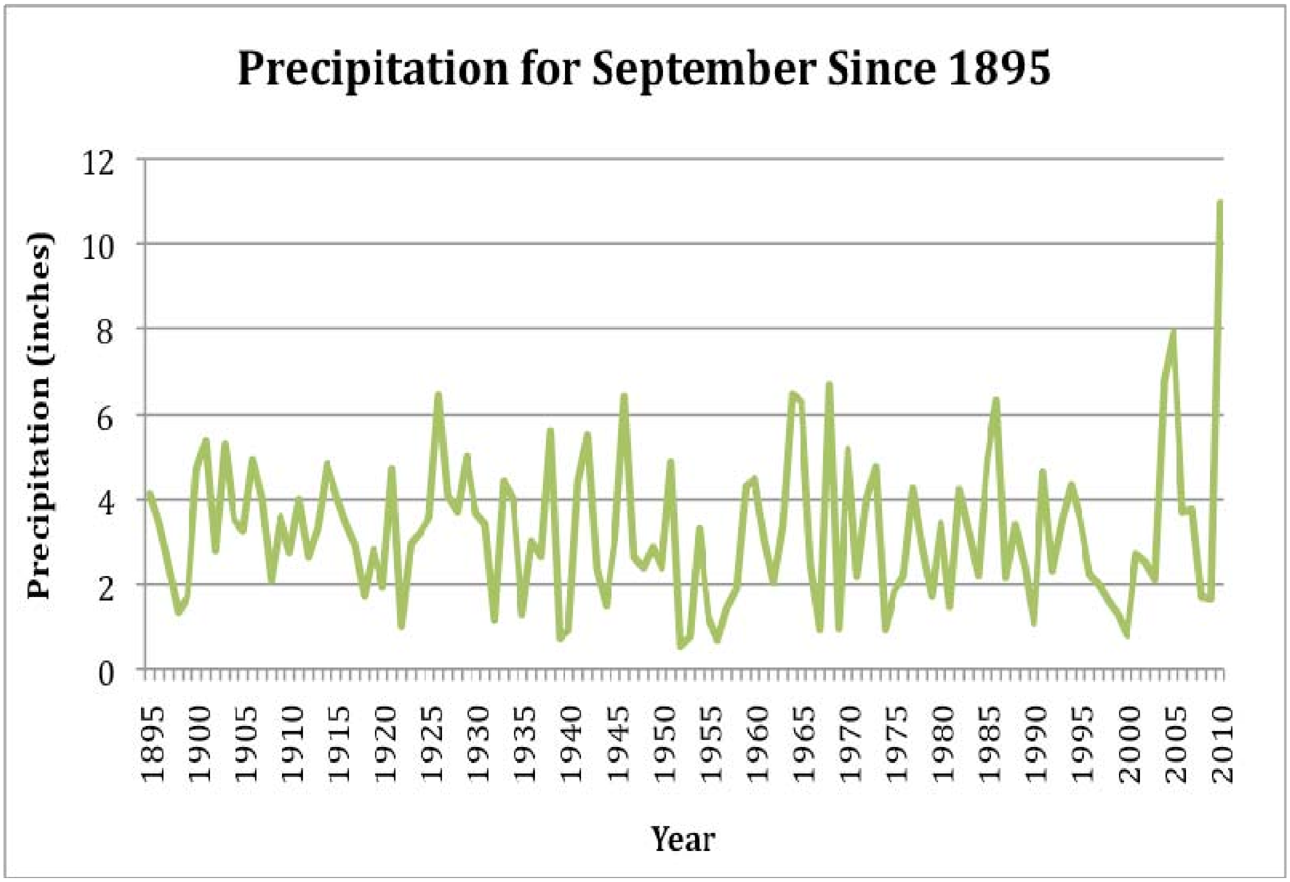


Figure 11: Precipitation in inches from 1895 to 2010

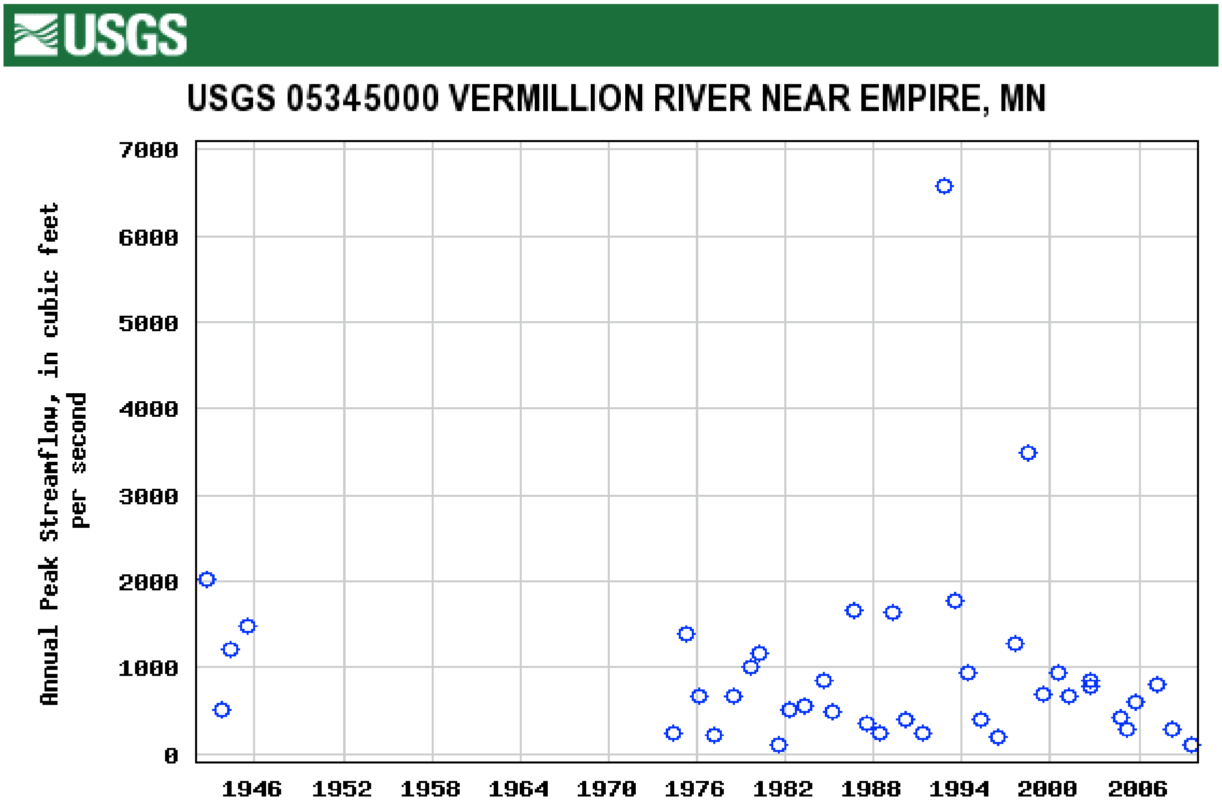


Figure 12: Annual peak streamflow in cubic feat/second from 1946 to 2006 on the Vermillion River near Empire, MN

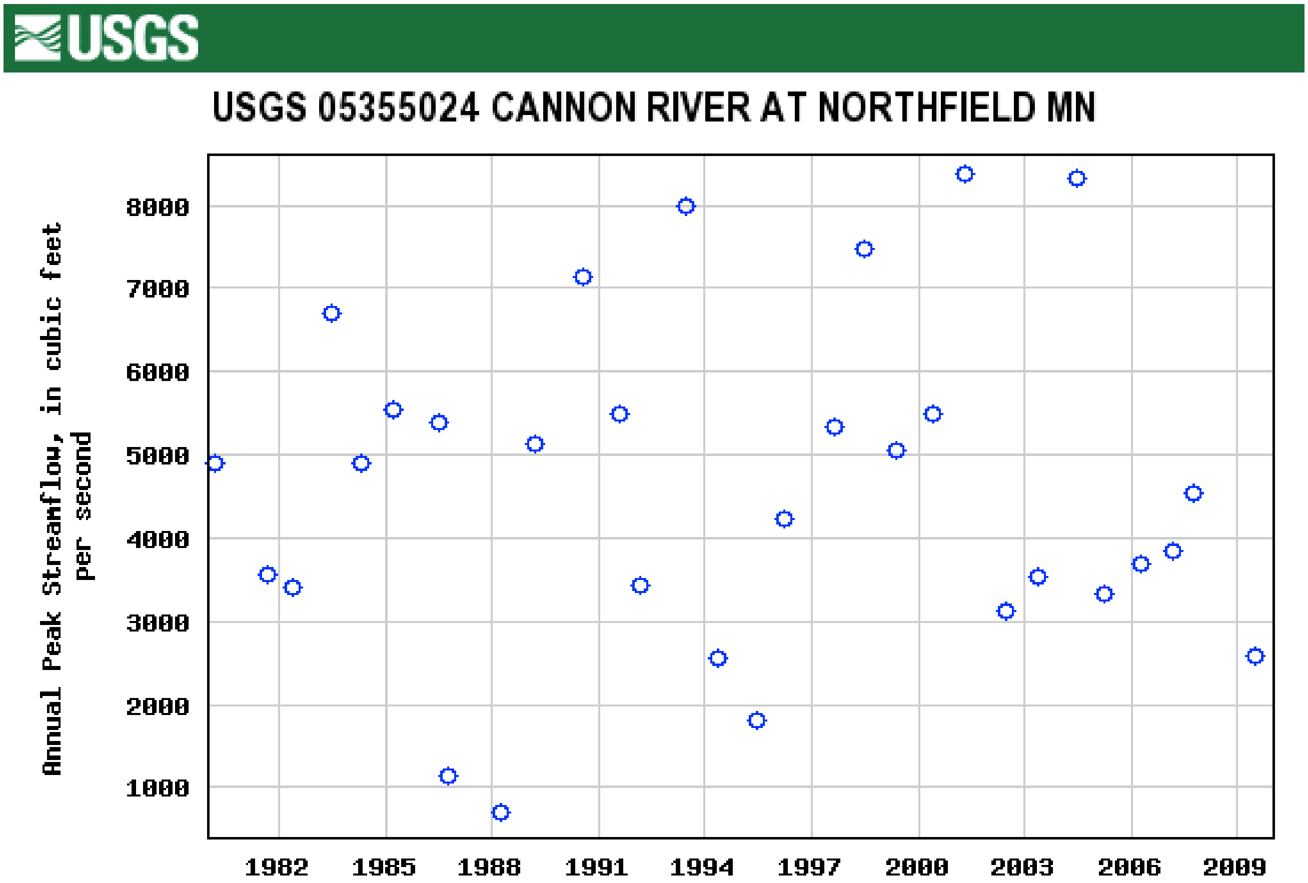


Figure 13: Annual peak streamflow in cubic feat/second from 1982 to 2009 on the Cannon River at Northfield, MN

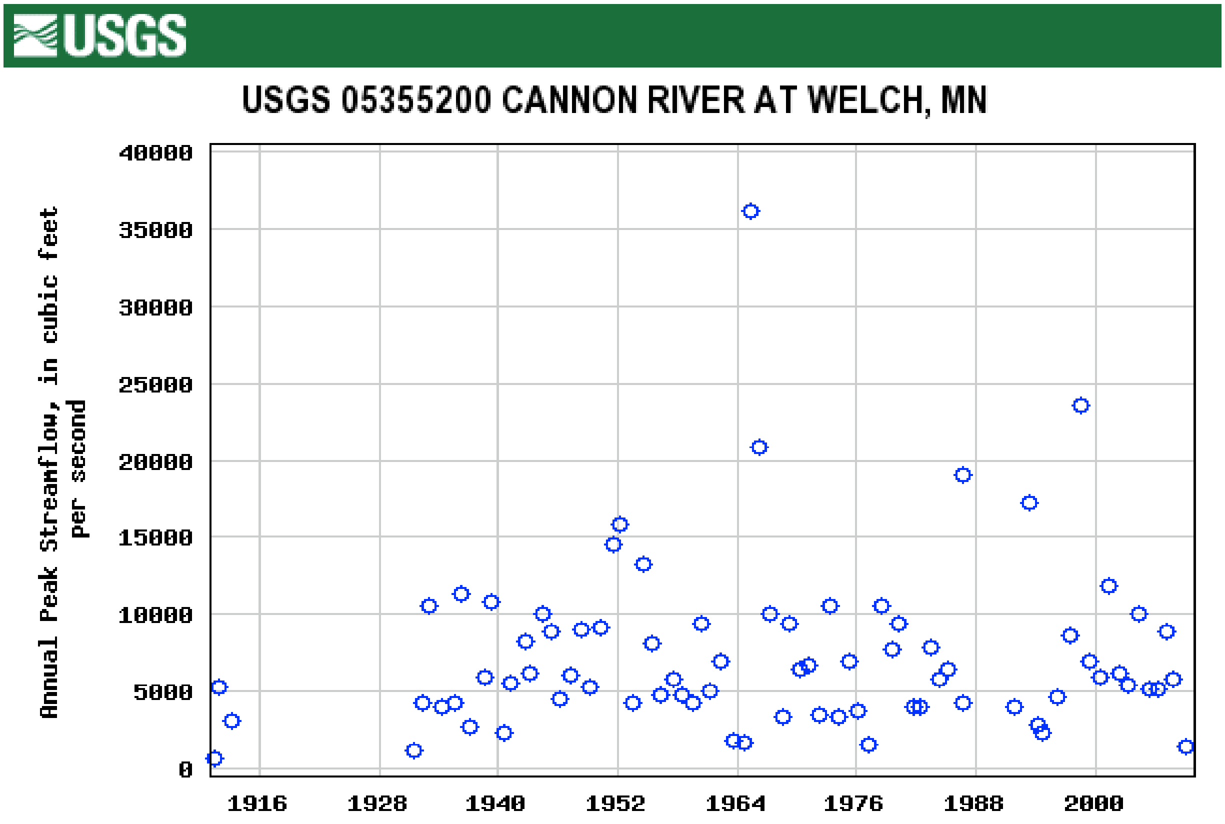


Figure 14: Annual peak streamflow in cubic feat/second from 1916 to 2000 on the Cannon River at Welch, MN

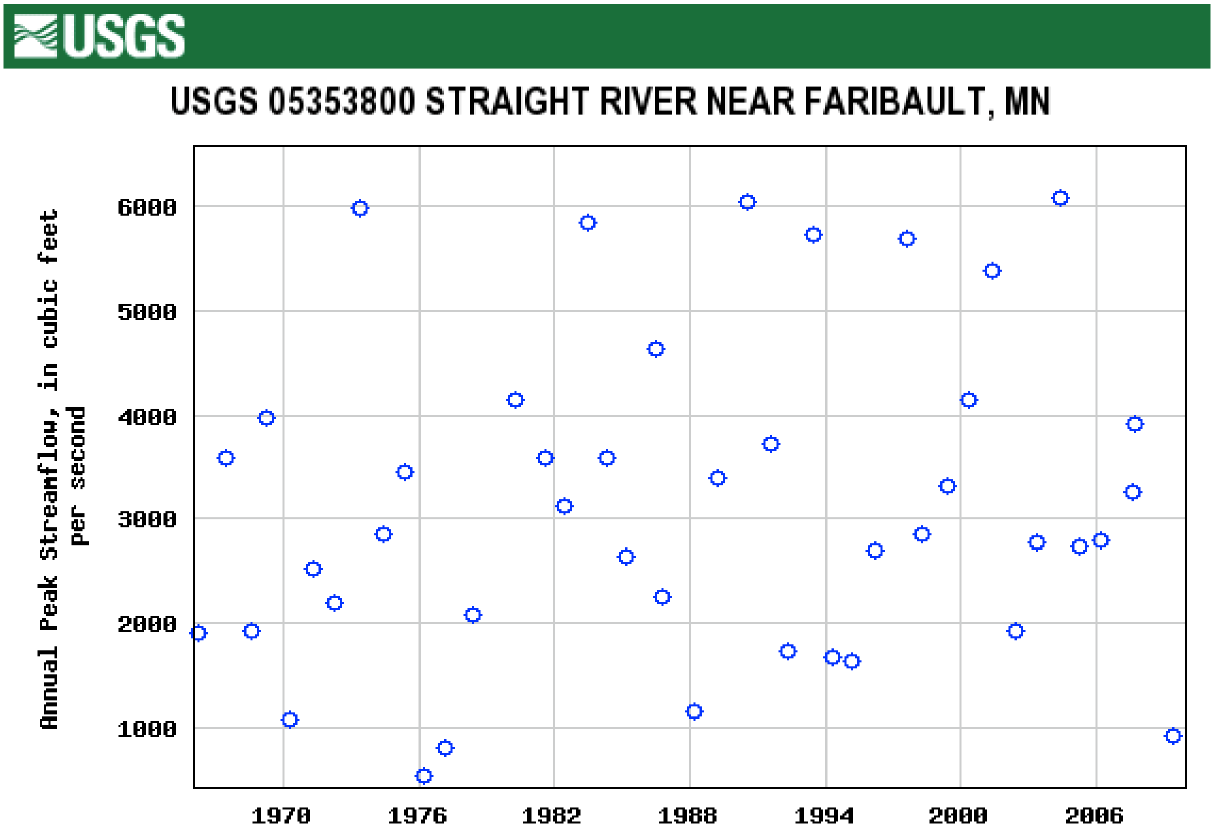


Figure 15: Annual peak streamflow in cubic feat/second from 1970 to 2006 on the Straight River near Faribault, MN

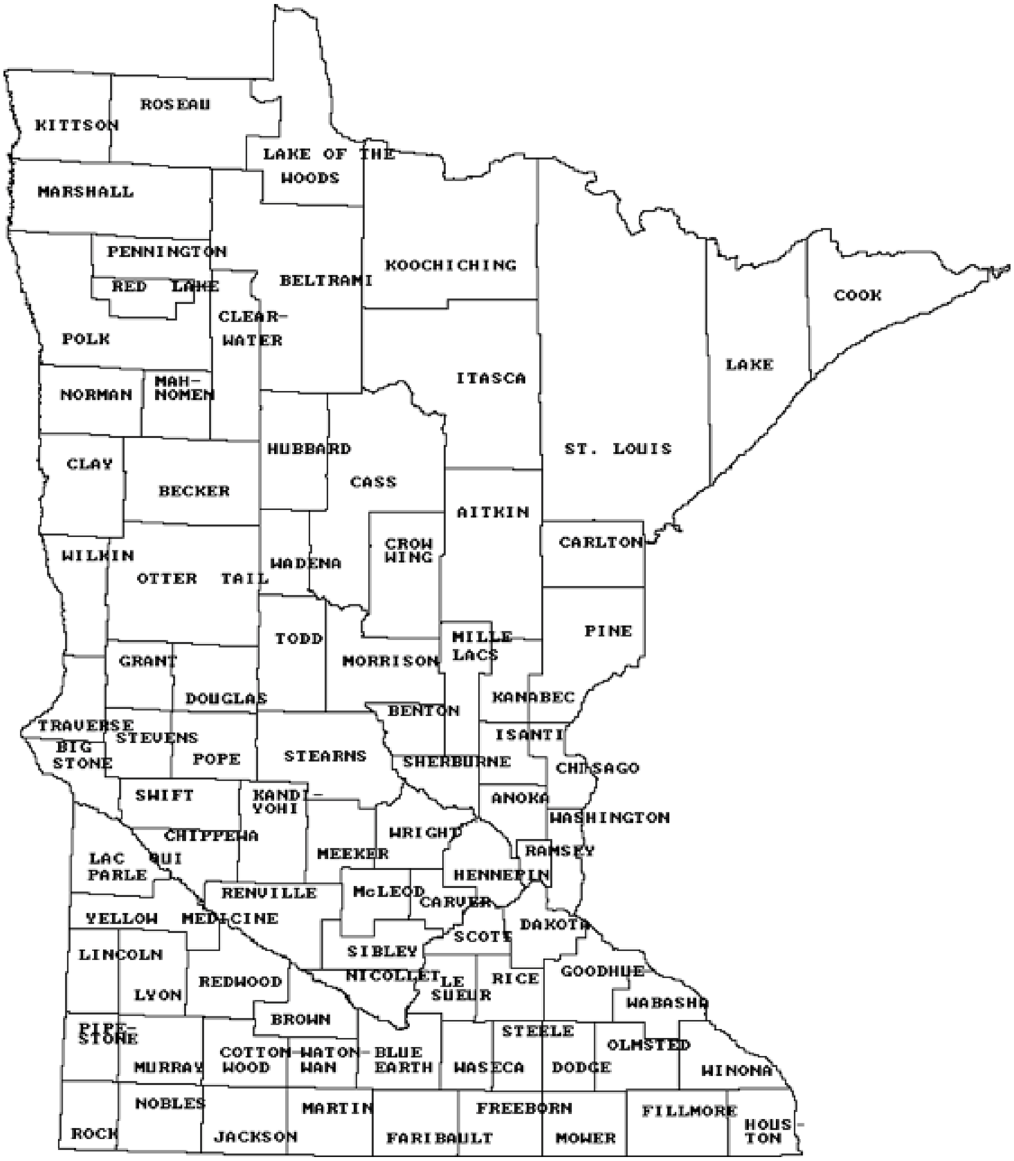
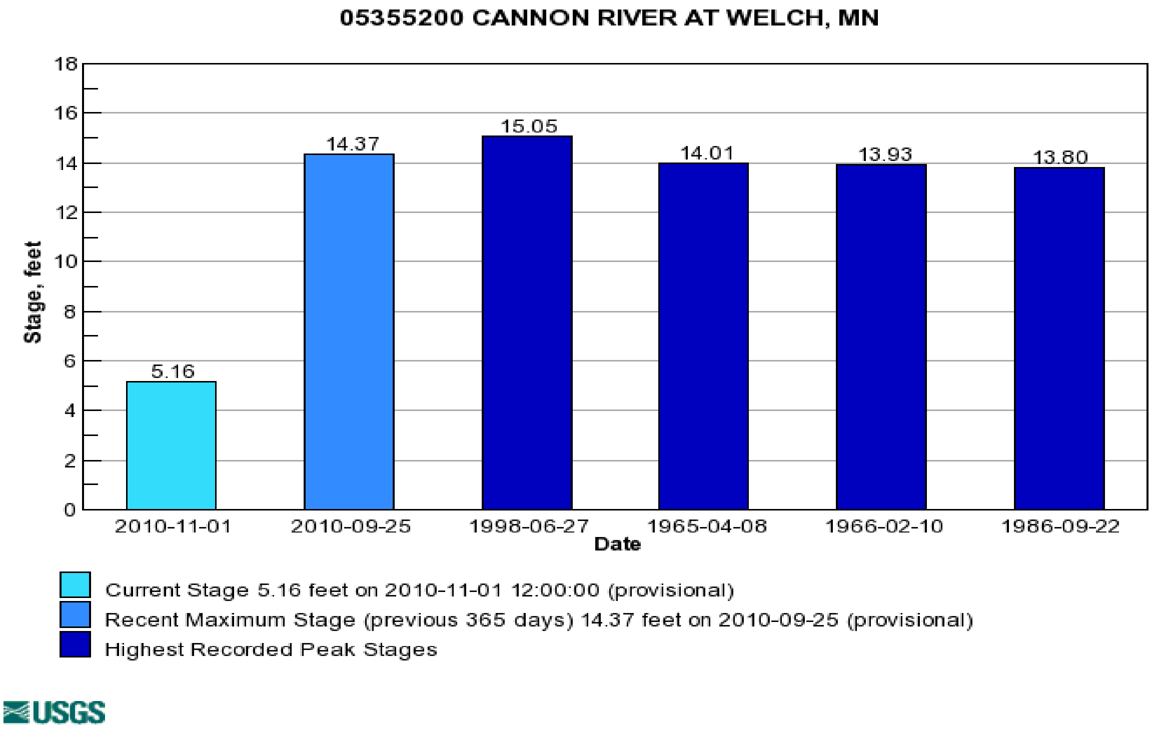


Figure 16: County Map of Minnesota


05355200 CANNON RIVER AT WELCH, MN
Stage, feet
18
16
14
12
10
8
6
4
2
0
5.16
14.37
15.05
14.01
13.93
13.80
2010-11-01
2010-09-25
1998-06-27
1965-04-08
1966-02-10
1986-09-22
Date
Current Stage 5.16 feet on 2010-11-01 12:00:00 (provisional)
Recent Maximum Stage (previous 365 days) 14.37 feet on 2010-09-25 (provisional)
Highest Recorded Peak Stages
USGS

Fall Flood 2010

Photo credit: Will Biagi

Jonah Simonds, Ellie Youngblood and Will Biagi

Introduction to Geology

November 17th, 2010

Introduction

Northfield is a city of about 17,000 residents, located in the north-central part of Rice County, Minnesota. The Cannon River Flood Plane, which runs directly through the city, has been heavily developed in recent years. While the upper and lower third of the Northfield Flood Plane, aside from a sewage plant, consists mainly of open land, the central third features sizable commercial, residential and educational establishments. Flooding in Northfield is not uncommon and, of the five largest floods recorded in the city's recent history, four were due to snowmelt in the warmer spring months. The fifth, which occurred in September 2010, was unexpected and highly rare due to its unique timing in the year: because it was in the early Fall, the flooding had nothing to do with snowmelt and was primarily the result of an exorbitant amount of rainfall ("Flood Insurance Study: City of Northfield, MN, Rice County").

This flood in the Fall of 2010 has been proclaimed by the City Council to be a 135-years flood. Between the 22nd and the 23rd of September, six inches of rain fell in Northfield and the Cannon River rose unprecedented amounts, peaking sometime on Saturday the 25th flowing at 20,100 cubic feet per second (Figure 2.2). The water level rose half a foot higher than the predicted 100-year flood mark previously established by the City, to a whopping fourteen and a half feet (Figure 2.1). Mayor Mary Rossing declared an official State of Emergency and requested the aid of the National Guard. Although no lives were lost in the flood, the people of Northfield suffered both economic and psychological damages that, almost two months later, are still being repaired (Northfield City Hall Meeting).

In the wake of the flood, the City was brimming with data and accounts collected by the Police, the City, and citizens alike. Because of both the importance and recentness of this disaster for the town of Northfield, we took on the task of putting together a comprehensive report of the flood (Northfield City Hall Meeting).

This paper will give an overview of the flood as can be reported accurately a month and a half after the event. We will present both a timeline of the flood, including personal accounts of both citizens and government figures, and also a discussion concerning raw data of the Cannon River during and in the aftermath of the flood.

Methods

In our study of the effects and impact of the Fall 2010 Flood in Northfield, Minnesota, we gathered data from multiple sources. Rain started pouring over much of Southern Minnesota on September 22nd, 2010 and stopped falling by September 24th. Various members of our group collected data early on in the flood event when we went down to the waterfront in Downtown Northfield to help sandbag and observe the impact of the rising water. One member of our group took video of the flooded West-Gym Field on Carleton College's campus on September 23rd while a light drizzle continued to fall (Figure 3.10). Hundreds of pictures were collected the next day before the river's flow peaked. Our group photographically recorded the level of the water relative to the parking lot behind the Archer House, the 2nd and 4th Street bridges, and the submerged Northfield River Walk (Figure 3.3 & 3.4). All pictures were taken from the East side of the Cannon River. We continued to take pictures on September 24th and 25th.

After much of the water receded from the football field at Laird Stadium and the West-Gym Field of Carleton College, one member of our group went out and photographically documented the sediment that the flooded Cannon had deposited there.

Aside from documenting photographically and experiencing the flood first-hand, our group members also attended a City Hall meeting on October 25th, exactly one month after the flow of the Cannon River peaked. There, we heard a presentation about the timeline of events from Police Chief Mark Taylor, observed a PowerPoint presentation by City Engineer Katy Gehler, and heard first-hand accounts of some of the damage done to the property of the citizens of Northfield, including the owner of Froggy Bottoms Restaurant, Dave Hvistendahl (Figure 3.7 & 3.8; Northfield City Hall Meeting). We were fortunate enough to be given two gigabytes of data in the form of maps, graphs, charts, and photos from the City of Northfield pertaining to events before, during, and after the flood earlier this year. The data presented in this report will be from our own pictures and videos, along with maps, graphs, and charts from the City of Northfield. Through the generosity of other Carleton College students studying the flood, we will also present a map detailing the extent of flood waters in Carleton's Lower Arboretum (Figure 4.1).

Results

Our results can be broken down into roughly four sections: data on the storm from September 22nd and 23rd, 2010; data on the Cannon River discharge during the flood event; effects of the Flood on the City of Northfield and Carleton College; and effects of the Flood on Carleton College's Lower Arboretum. Our data provides both a quantitative and a visual record of the Fall Flood of 2010 and also seeks to contextualize the flood event against the normal conditions of the Cannon River, the City of Northfield, Carleton College, and Carleton's Lower Arboretum.

SECTION 1: THE STORM

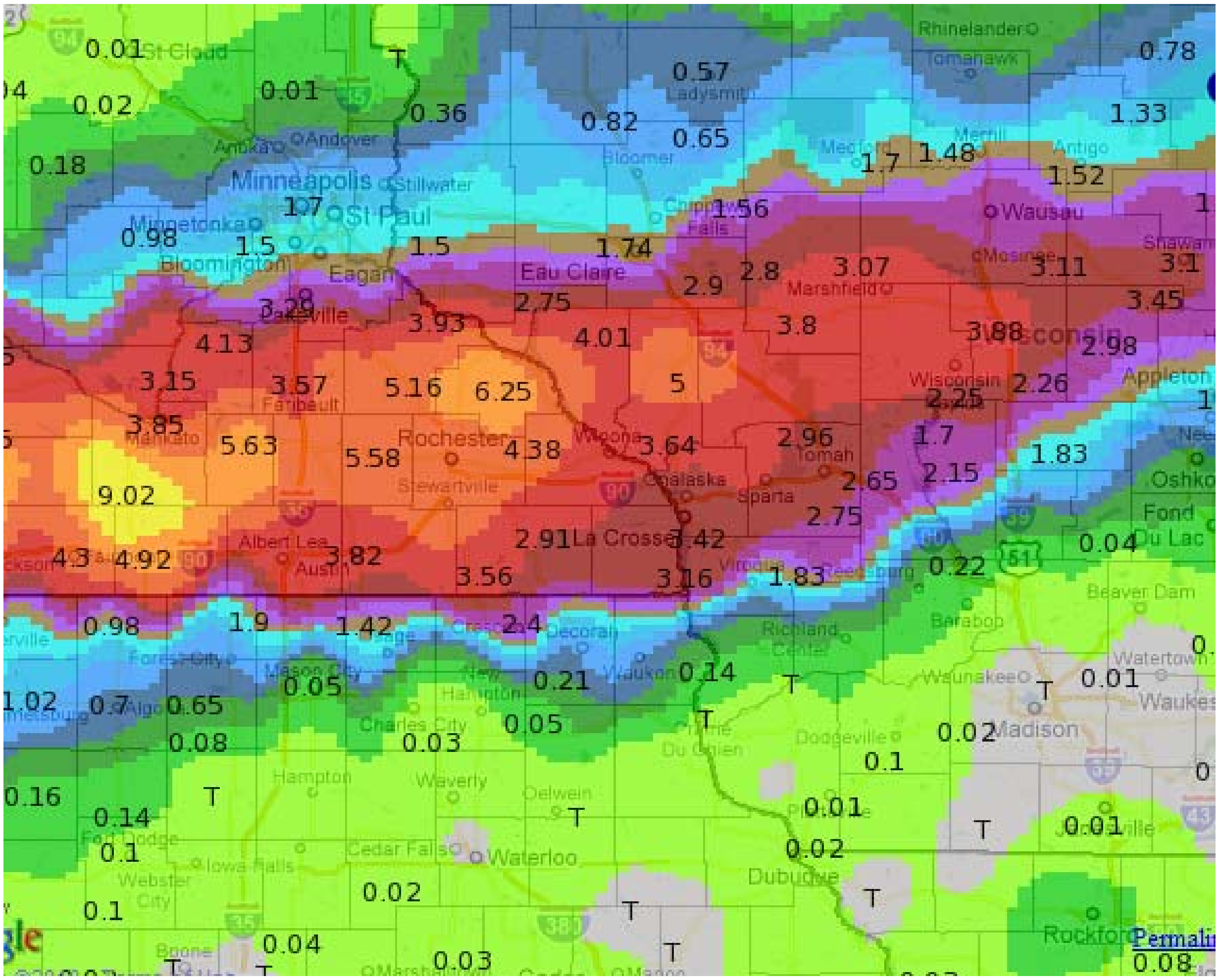


Figure 1.1: Regional rainfall data for the September flood event storm. The map encompasses South-Eastern Minnesota, North-Eastern Iowa, and Western Wisconsin. Brian Welch.

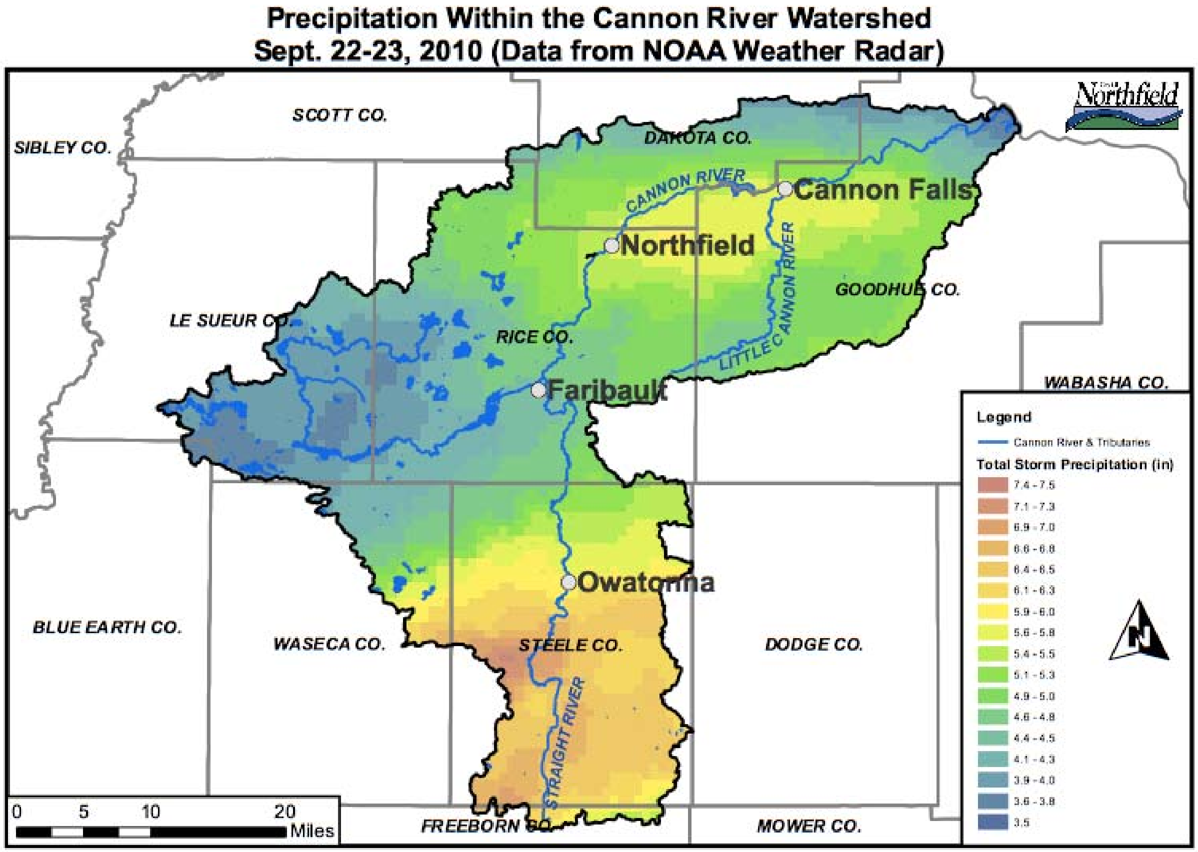


Figure 1.2: This map shows in color the drainage basin for the Cannon River and the amount of rainfall it received on September 22-23rd, 2010. Brian Welch.

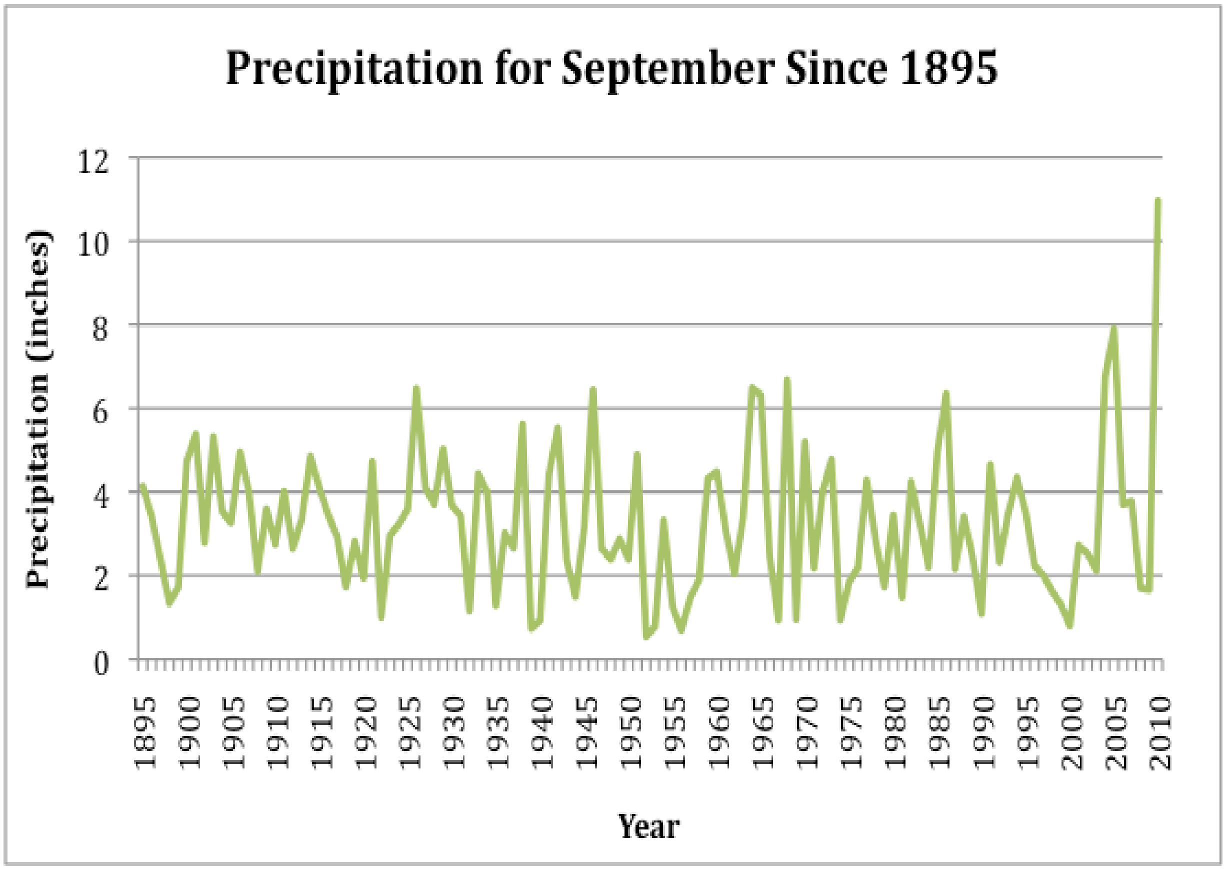


Figure 1.3: Rainfall trends for the month of September in Nortfhfield, MN, for the past 115 years. Rainfall group.

SECTION 2: CANON RIVER DISCHARGE

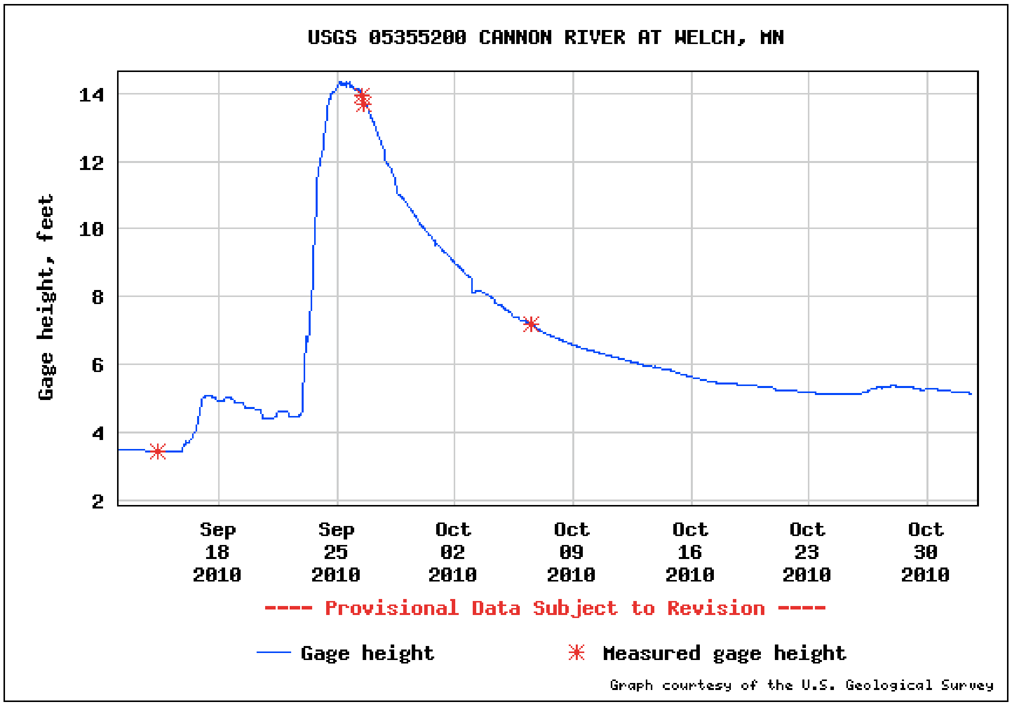


Figure 2.1: Cannon River gage height at Welch, MN. USGS.

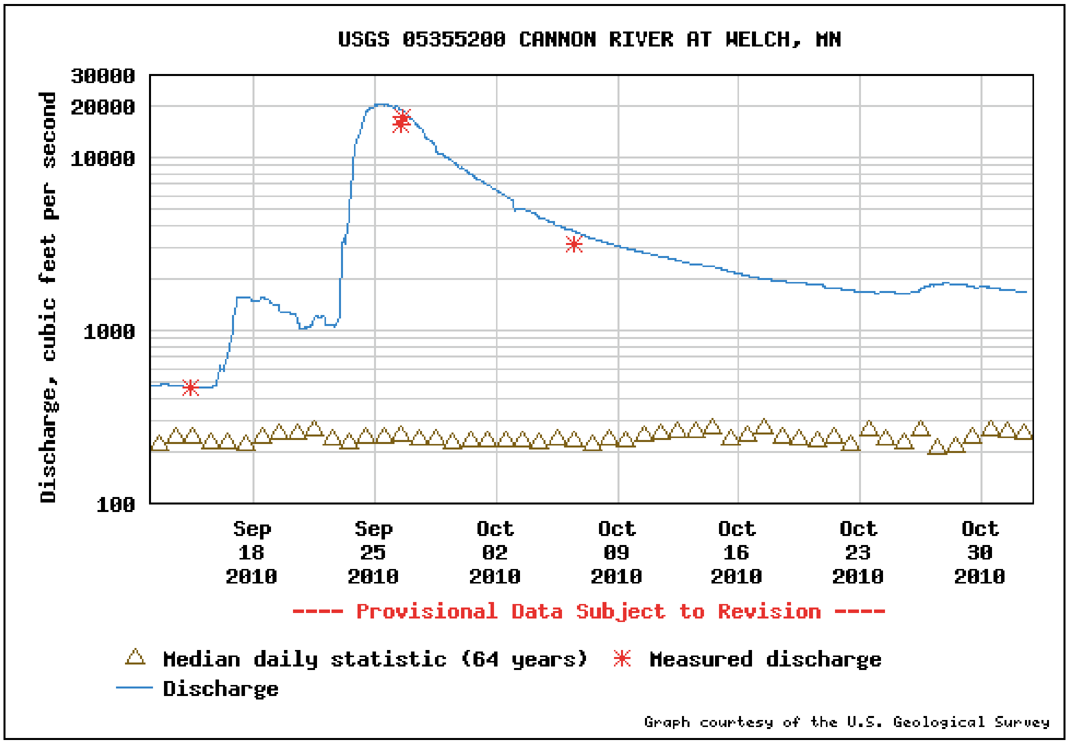


Figure 2.2: Cannon River discharge data at Welch, MN. USGS.

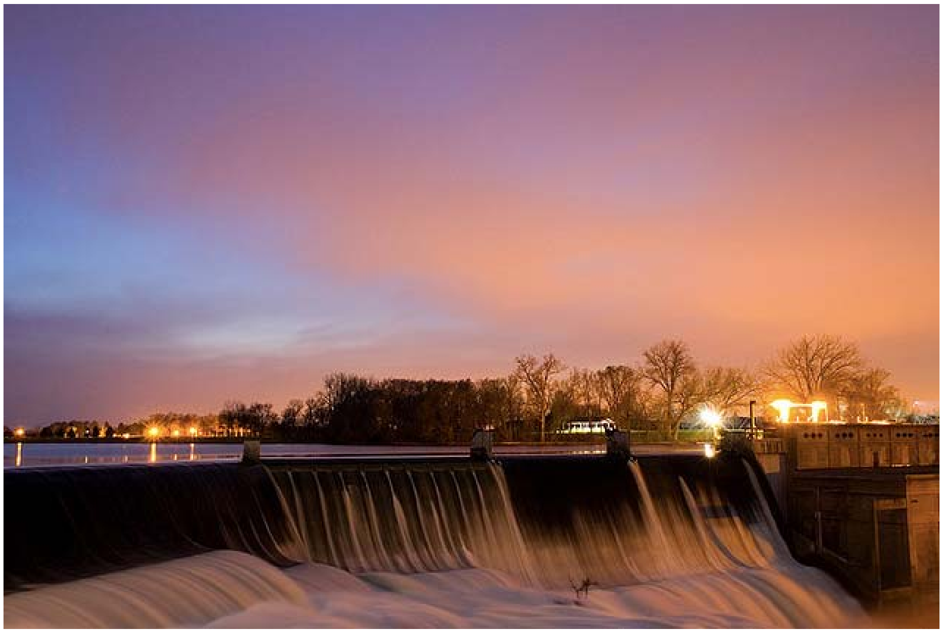


Figure 2.3: Lake Byllesby Dam at normal discharge level, April 2006. The Lake Byllesby Dam is located south of Faribault, upstream of Northfield. Adam Holte. http://www.flickr.com/photos/adamholte/126739078/sizes/z/in/photostream/

Figure 2.4: Lake Byllesby Dam at peak discharge level, September 25th, 2010. The Dam was not built to hold back the volume of water flowing through the Cannon River on September 25th and consequently overtopped. Rabidscottsman. http://www.flickr.com/photos/21151899@N03/5023092601/sizes/z/in/photostream/

SECTION 3: EFFECTS ON NORTHFIELD AND CARLETON COLLEGE

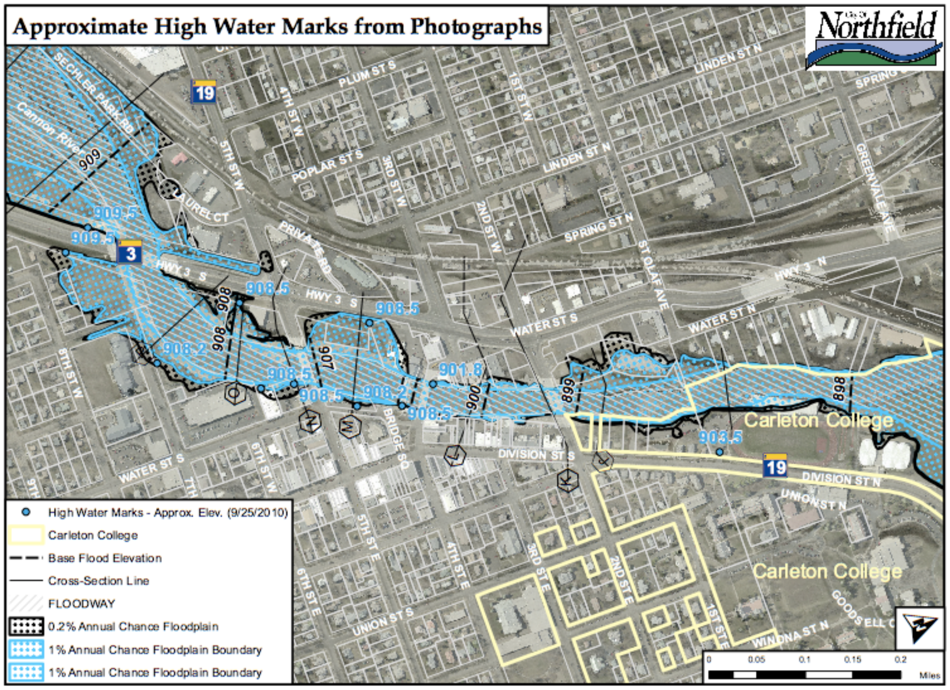


Figure 3.1: Approximate high water marks in downtown Northfield. Blue shading represents FEMA's expected 100-year flood area. Black represents FEMA's expected 500-year flood area. Brian Welch.

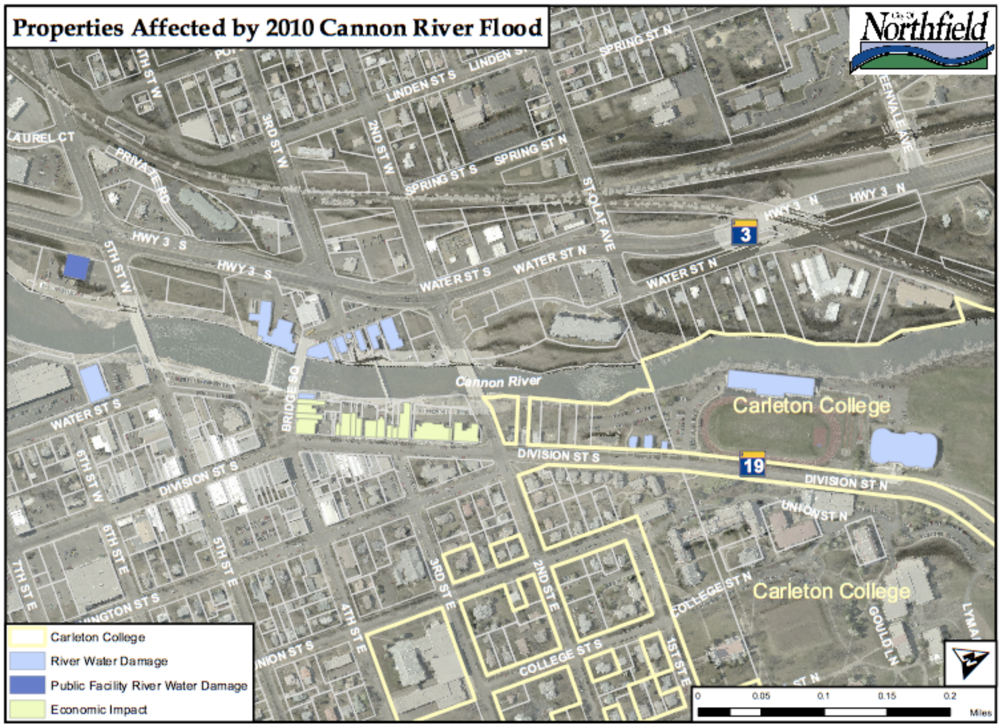


Figure 3.2: Properties affected by the flood in downtown Northfield and Carleton College. Brian Welch.

Figure 3.3: View from the East Bank of the Cannon River of the Water Street Bridge in April of 2010 with seasonally normal flow. Public domain.

Figure 3.4: View from the East Bank of the Cannon River of the Water Street Bridge on September 25th during peak flow. Griff Wigley.

Figure 3.5: View from the Cannon River, upstream towards Water Street Bridge and Dam on July 17th, 2010. Griff Wigley.

Figure 3.6: View from the East Bank of the Cannon River upstream towards Water Street Bridge and Dam on September 25th, 2010. Griff Wigley.

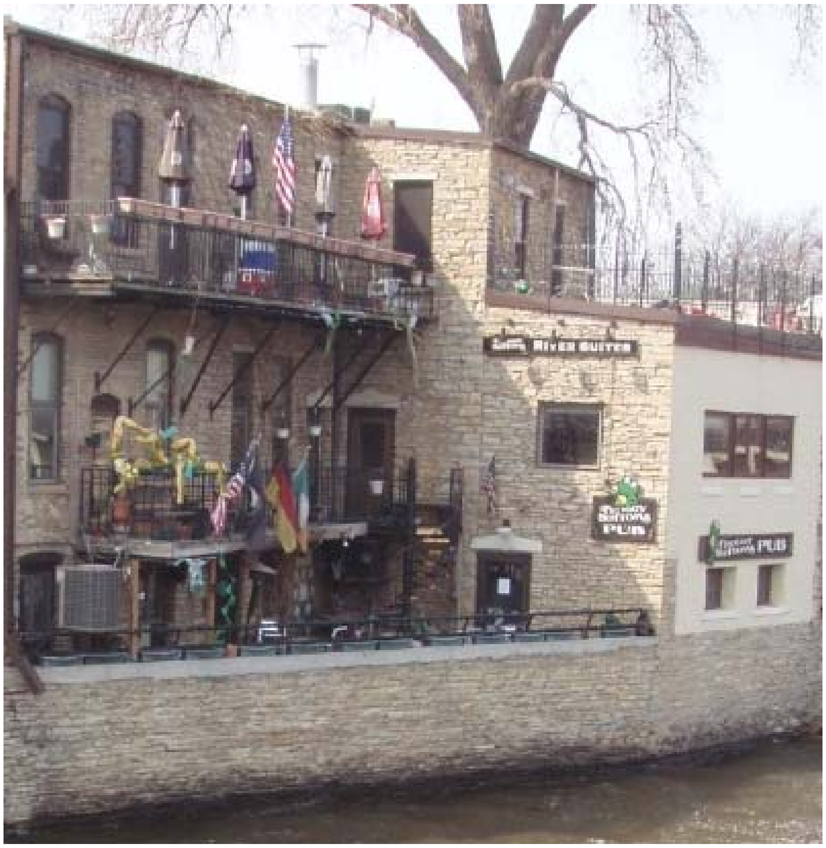


Figure 3.7: View from East Bank of the Cannon River towards Froggy Bottom's Pub during normal flow. Public domain.

Figure 3.8: View from East Bank of the Cannon River towards Froggy Bottom's Pub during peak flow on September 25th, 2010. Griff Wigley.

Figure 3.9: Comparative aerial views of Water Street Bridge and Dam, from 2008 and September 27th, 2010, respectively. Composite by Alice Carson. http://picasaweb.google.com/northfieldminn/AerialViewOfFloodingSept2010#5522397044710386354

Figure 3.10: Comparative aerial views of West Gym building, Laird Field, and Cannon River, from 2008 and September 27th, 2010, respectively. Composite by Alice Carson. http://picasaweb.google.com/northfieldminn/AerialViewOfFloodingSept2010#5522397054091618978

Figure 3.11: Extent of flooding on Laird Field, September 25th 2010. Soccer goalposts are barely visible poking above the floodwaters. Griff Wigley.

Figure 3.12: Carp removal from Northfield Riverwalk, September 27th, 2010. A specimen of Asian Carp is visible in the hands of the flood cleanup worker in the red jumpsuit. Carp as large as

five feet long were observed sheltering in the eddies of the Cannon shoreline during the flood event. Griff Wigley.

SECTION 4: EFFECTS ON CARLETON'S ARBORETUM

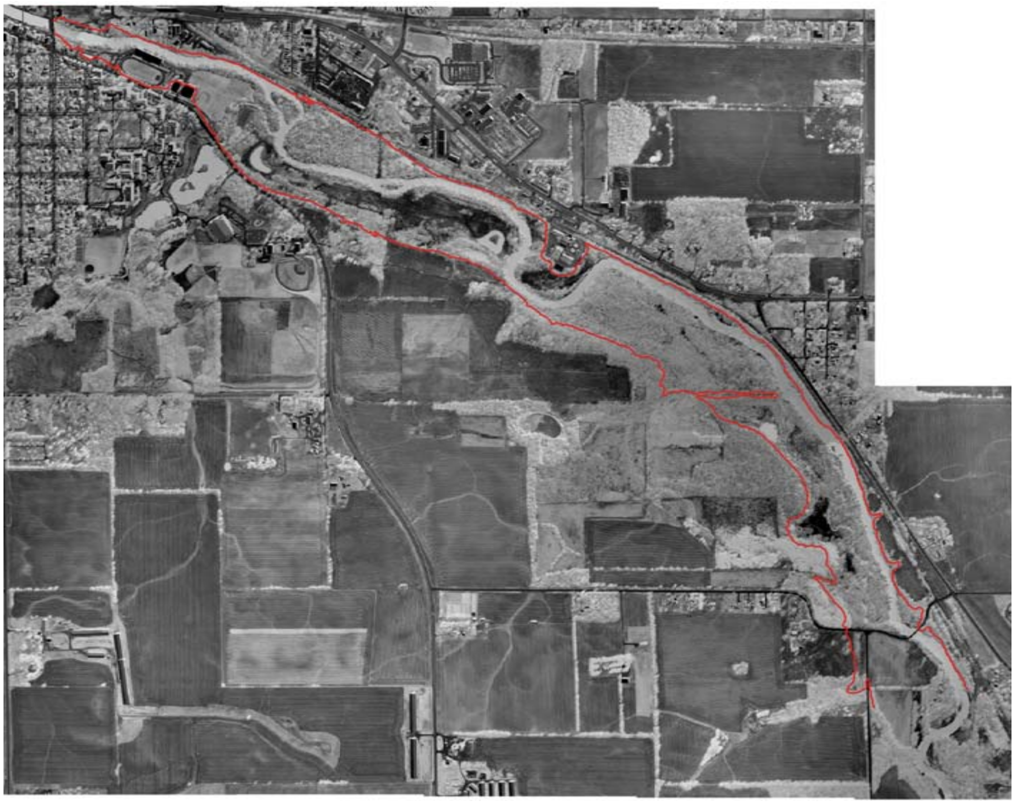


Figure 4.1: Extent of flooding in the Carleton Lower Arboretum. The red line marks the furthest extent that the floodwaters of the Cannon River reached during the event. The map was made using GIS data from observations of high water and flood marks on the vegetation within the Arboretum. Colin Sinclair and Robin Reich.

Figure 4.2: Aerial photograph of the Cannon River, Laird Field, and Lower Arboretum on September 27th, 2010. The normal path of the river can be observed as a brown strip to the right of the flood area. Griff Wigley.

Figure 4.3: Aerial photograph of Laird Field, Lower Lyman Lake, and Lower Arboretum on September 27th, 2010. The football and track field on the left of the picture are completely submerged. Griff Wigley.

Figure 4.4: Flooding in Lower Arboretum, September 25th, 2010. Griff Wigley.

Figure 4.5: Trail closed due to flooding in Lower Arboretum, September 25th, 2010. Griff Wigley.

Figure 4.6: Aerial view of the New Waterford Bridge and the Old Iron Bridge in Lower Arboretum on September 27th, 2010. The normal path of the Cannon River can be observed as a brown strip to the left of the flood area. Griff Wigley.

Figure 4.7: Old Iron Bridge, viewed from New Waterford Bridge on September 25th, 2010. Griff Wigley.

Discussion

The objective of this project was to collect data, observations, and first-hand accounts of how the flood affected the City of Northfield economically, socially, and psychologically. The goal was to interpret these various observations and to draw conclusions about the preparedness, impact, and long-lasting effects the Fall Flood of 2010 had on the City of Northfield, along with Carleton College. In a City Hall meeting on October 25th, 2010, attended by all three members of our group, we heard about the flood from the City Council, the Police, and Northfield residents. To open the City Hall meeting, we heard from the Mayor of Northfield, Mary Rossing. She spoke about how this flood was estimated to be a 135-150 years flood and how it demonstrated the preparedness of both the city and the current Emergency Management System. She stressed how important communication is during any emergency event and how the City's firefighters and police officers aided in keeping communication channels open during the disaster and through the present. The Mayor then went on to detail the main concerns of the City while dealing with the flood. She described how the first priority was volunteer/responder and public safety. The next was protecting public infrastructure, mainly the Safety Center and the wastewater treatment plant, both of which were in imminent danger of flooding while the Cannon was rising. The Safety Center houses the City's emergency communications mainframe: if this had flooded, Northfield's digital mainframe (which handles all Internet Technology processes along with communications) would have been underwater, crippling the entire emergency response operation (Northfield City Hall Meeting).

Aside from these public structures, the City also worked to assist affected private property owners. However, one startling account from a woman who co-owns a building whose basement flooded, included her recollection of calling the City and being informed that, "Residents and businesses are on your own." She later went on to describe how this was the initial policy of the City, a fact that would instill feelings of total isolation in a time when more help than ever was needed (Northfield City Hall Meeting).

As far as responding to the flood, the City was essentially caught off guard and unable to make any predictions about the River's activities because of its odd timing and magnitude. After the water overtopped the dam in Owatonna, some twenty-six miles south of Northfield, the City still didn't have any idea of how high or how quickly the water would rise. Northfield consulted a hydrologist from the National Weather Service on the issue and gathered that this flood was a very unusual, late summer event and that it was unclear how much water was involved. Additionally, there was no model in place for predicting the floodwater from the Cannon River in the case of a rainfall event this severe. No water-level gauges were in place during the flood, and there are so many factors that influence storm water that it was difficult to accurately project how much rain fell and how it would affect the Cannon River. Northfield received approximately six inches of rainfall over a 48-hour period from September 22nd to the 24th. The City had a model for a 100-year flood, but the high water marks of this flood surpassed those estimates by a foot and a half in some places (Figure 3.1; Northfield City Hall Meeting).

The City Council also presented a rough estimate for how much damage was done to Carleton College – roughly 5.5 million dollars. College officials sent out this figure to all students and staff on October 21st through the campus email service (Northfield City Hall Meeting; Rogers).

The City also detailed how new loan programs were being put in place to assist small businesses along the river that were affected by the flood. After all members of the City Council were done asking questions, the podium was opened up to the public. We heard from Dave Hvistendahl, the co-owner of Froggy Bottoms River Pub and Suites, a restaurant in downtown Northfield along the Cannon River. Mr. Hvistendahl gave a rough estimate of the damage to his property alone, around 300,000 dollars total. Days after the flood, a sign appeared in the window of Froggy Bottoms that read, “Froggy Bottoms Pub is closed indefinitely due to Fall flooding” (Hvistendahl). Mr. Hvistendahl also went on to propose a series of changes to the recording methods of water levels and plans for teaching residents how to sandbag for future flooding incidents. In one expansive account of his own experience with the flood he told the council that we as a community must take action now to help prevent such large amount of damage from occurring in the future (Northfield City Hall Meeting).

Conclusion

The Cannon River Flood of September 2010 proved to be a formidable test for the City of Northfield. Although this was one of the largest floods in the last 135 years, this disaster could have been much worse. Although there were serious economic damages to both public and private property, this was labeled a “minor disaster” because there was no loss of life, something that would have turned a manageable, though challenging, disaster into a catastrophe. When the river was rising fastest, the communications hub for all emergency response at the Northfield Safety Center came perilously close to being submerged; this would have prevented contact with the Police or the Fire Department for both emergency and non-emergency situations, a vital function for any city, let alone one in the midst of an official State of Emergency. Although the City’s response to the flood was somewhat delayed, and the general consensus was that things could have been better organized, most agree that the flood was handled relatively well given the severity and unpredictability of this type of event.

This disaster has opened a dialogue between the Police force, the City Council, and citizens about the quality of the emergency response plan of Northfield. Debates are circling around whether or not there should be a standardized emergency plan for when the Cannon River reaches certain heights. Also, this flood exposed the large grey area concerning the City’s stance on providing aid to private property owners within Northfield who are affected by the disaster at hand. Up until this most recent flood, the City had never done so, but the severity of this specific disaster required a different response. Will this set a precedent for the future, or should private property owners assume that they are on their own? Additionally, the flood has provided leverage to some townspeople who seek changes in certain City policies. One private property owner explained that although she owns an alleyway adjacent to her building, she allows the City to utilize it in order to access the river and sewer system. So, if the City is using it often, should they have to help her pay off the damages caused by the flood? These topics, which may seem trivial on a day-to-day basis, become crucially relevant when an event as rare and dramatic as this specific flood occurs.

It will be interesting to see not only how the City's policies regarding disaster response evolve, but also how the relationship between the City and the Cannon River does as well. In the future, the effects of this flood will continue to manifest themselves both economically and environmentally. Floods of this scale remind us that natural bodies such as rivers are constantly changing and affecting the land around them. Rivers are unpredictable, and although humans can attempt to induce control through dams and other technologies, the river will ultimately act as it's meant to. Whether or not surrounding cities are affected is not a factor in this natural evolution. Monitoring changes in the soil content, erosion rates, the Cannon River's flow itself, and other factors affecting the Flood Plane will become more relevant as time goes on, and should be taken with high priority. Although the City is concerned mainly with the economic restoration of Northfield, we believe they should not ignore these other factors of the land we live on, factors that led to and were affected by this flood.

Acknowledgements

We would like to extend a huge thank you to the City of Northfield: our data and accounts were born from the generosity and willingness to share of the City Council, the Engineering Division, the Northfield Police, and the citizens of the City. We would like to especially thank Mayor Rossing, Northfield GIS Technician Brian Welch, and Northfield Police

Chief Mark Taylor for their extra efforts in helping us compile information. We would also like to thank our Professor, Bereket Haileab, for helping us throughout this term to focus our project and give it life with his spunk and gumption, as well as the help of the group studying rainfall in our class for their data. Also, a huge thank you to Isaac Sinclair and Robin Reich from the Geomorphology class for their data on the flooding of the Carleton Arboretum. We would also like to thank Griff Wigley for his phenomenal photographs.

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SPRING CREEK AND NORTHFIELD WATER

Introduction to Geology Fall 2010: Bereket Haileab

Claire Bosworth, Margaret Kutcher, Becca Kilman

INTRODUCTION:

The bedrock geology of the Rice County region is mainly sandstone, limestone and shale. The major rock formations represented include the Franconia Formation, the St. Lawrence Sandstone, the Jordan Sandstone, the Prairie Du Chien Group, the Platteville Limestone, the Decorah Shale, and the St. Peter Sandstone. (Fig. 1., Battis, 2010)

Rice County's main water resource comes from groundwater. These groundwater aquifers store water in connected pores and cracks. The primary aquifer system in the County is the Saint Peter-Prairie due Chein-Jordan aquifer as well as the Saint-Lawrence-Franconia aquifer and the Galina aquifer. City wells access water from the Jordan Sandstone portion of the aquifer (DNR). The Water Division of Northfield has four wells that rotate on a daily basis and a fifth, which is no longer in use. Each well has a capacity of approximately two million gallons, which is enough to meet the daily demand of Northfield for a majority of the year. Well 2 draws from a combined aquifer, cased at a depth of 109 feet which is the level of the Prairie du Chien aquifer and has a total depth of 400 feet. This well also draws from deeper Jordan aquifers. Wells 3, 4, and 5 only draw from the deeper Jordan aquifer as they are cased at a depth of 318 feet and have a total depth ranging from 365 to 405 feet (MDH, 2001).

Overall, the aquifer system in the Rice County region is particularly porous because it contains karst topography with many sinkholes, and cave streams. Contamination is a serious problem throughout the largely agricultural region of Rice County with the greatest concern focused on the hazardous waste seeping into groundwater aquifers (DNR).

Since the surface water in the region will eventually be part of the groundwater, monitoring and studying it is vitally important. The abundance of surface water resources in Rice County is attributable to glacial activity and includes many lakes, rivers, streams, and wetlands (see Figure 2). The Cannon River is one of two large rivers in the County and it forms the largest watershed, as it drains 80% of the County (DNR). The interaction between the surface water and groundwater is close and involves the surface water recharging the ground water through precipitation seeping through the land and discharge from streams especially in Eastern Rice County (DNR). In Northeastern Rice County, the aquifer is very near to the surface, making the recharge of the aquifer the most direct and, therefore, sensitive to pollutants and contamination of surface water.

One of the most important ways pollutants are added to the surface water is through agriculture. Notably, the land use in Rice County is mostly agricultural, with the population concentrated in the two largest cities, Faribault and Northfield (see Figure 3). Also, as of March 2003, there were 1163 feedlots operating throughout the county with at least ten animals in them (see Figure 4). These are fairly evenly distributed throughout the county, with many located close to rivers or lakes (22 are within 300 feet of the Cannon River and 85 are within 1000 feet of a lake, according to the Rice County Water Resource Management Plan). These factors can add to the pollution of the surface area of the region and, therefore, are an important aspect to consider in working to protect the groundwater of the County.

This study, therefore, will focus on one of the minor watersheds in Northeastern Rice County, the Spring Creek watershed, which flows into the Cannon River in the city of Northfield. It is only one example of the surface water in Rice County, but the health and properties of this stream directly impacts the groundwater of the area and the drinking water of the city of Northfield. Our study aims to provide a framework for a system of monitoring the levels of dissolved oxygen, temperature, conductivity, salinity and nitrate along Spring Creek. We hope to implement continuous monitoring of the creek along with analysis to determine the health of Spring Creek over time as one of the vital sources for the recharging of the aquifer.

After an initial evaluation of our method and results, we will begin a preliminary analysis of Spring Creek levels and encourage further investigation in the future.

METHOD:

In order to analyze the water chemistry of Spring Creek, we used various instruments at each of our eight sites. We used a Model 85 Yellow Springs Instrument to measure salinity, conductivity, dissolved oxygen and temperature. We also took samples of the water from each site, which we later tried to analyze for nitrate anions in the laboratory using a NexSens WQ Nitrate ISO Probe, although it has not yet successfully worked.

We collected water samples and measurements once a week from September 28, 2010 through November 3, 2010 at eight sites along Spring Creek. The sites were located as follows: (A) 44.42786 'N 93.15981 'W on the corner of Dennison Blvd. and Country Road 81; (B) 44.43228’N 093.14104’W on the South end of Hall Ave; (C) 44.44590’N 093.14093’W on the corner of Hall Ave and Sumac Lane; (D) 44.44934’N 093.14074’W before the golf course on Hall Ave; (E) 44.45696’N 093.14513’W after the gulf course on Wall Street; (F) 44.46107’N 093.14954’W before Lyman Lakes; (G) 44.46405’N 093.15422’W after Lyman Lakes; and (H) 44.46553’N 093.15582’W before Spring Creek flows into the Cannon River (see Figure 5). By doing this we can analyze all the sites along Spring Creek to determine the quality of water that will eventually seep into the aquifers that supply city wells with drinking water.

RESULTS:

Measurements at site A were only possible on the initial testing day, September 27th due to lack of water at the site on later dates. There was also no water at Site B on October 20th resulting in a lack of data for these dates. This probably is due to different levels of rainwater throughout the six weeks that we were collecting samples (see Figure 6). For complete table of collected results, see Table 1.

Overall, the temperature values ranged from 5.7°C to 17°C throughout the six weeks of the study at all eight sites. As seen in Figure 8, the general trend showed a decrease in temperature, except for on October 13th when sites C, D, and G increased slightly.

In the beginning three weeks of the study, the salinity levels at site B were 0.4ppt, and at site C were 0.2ppt. Aside from these early differences in specific sites, the salinity remained constant at 0.3ppt across sites (see Figure 7).

Although we took measurements of dissolved oxygen, our results seem were erratic and therefore showed no overall patterns or trends. This is clearly visible in the variability of the data in Figures 9 and 10, showing both the percent and mg/L as Dissolved Oxygen measures.

The conductivity results are shown in Figure 11 without being corrected for the temperature differences, and Figure 13 after being corrected. The corrected conductivity results range from 385.8μs to 793μs. Generally, the sites follow similar trends over the weeks, with Site C consistently having lower conductivity and the sites farther downstream increasing in conductivity (see Figures 12 and 14 for graphs comparing the sites).

Nitrate samples have been collected and are awaiting analysis.

DISCUSSION:

After collecting and analyzing the data from the eight points along Spring Creek, we found that the temperature dropped as the weather got colder, salinity stayed relatively constant and conductivity varied by site. In addition, our measurements of dissolved oxygen in the creek water show no coherent pattern, which indicates that there were errors with the instrument we were using for measurement. The short-term patterns we found are not surprising. The water temperature decreased as the air temperature did as well. The salinity was fairly constant, which was what we would expect in a creek such as this one.

The conductivity levels appear to follow some patterns, in that the downstream water has higher conductivity than most of the upstream water, but these patterns are inconclusive due to the short time span of monitoring. The goal in measuring the conductivity is to "indicate the total inorganic mineral content" in the water (Drinking Water Quality Standards, page 7). Therefore, in order to analyze the conductivity, it is most helpful to change the conductivity into a measure of Total Dissolved Solids (TDS), which is regulated in the Secondary National Drinking Water Standards from the EPA. These standards are not enforced, but are simply used as a guideline for regulation of drinking water. Using a calculator from Lenntech (Water Treatment Solutions) website, we estimated the TDS in Spring Creek, which we could then compare to the EPA secondary standard, which finds that drinking water should not have more than 500 ppm TDS. Looking at our data in this way shows that only one data point strays above the EPA standard, but the levels are not far off from the standard (see Figure 15). Especially since our estimation techniques are not very specific and could vary depending on the chemical makeup of the TDS we are measuring, this is concerning and shows the need for continued monitoring to ensure that these waters are not above EPA standards for TDS.

For all of our data collection, the short period of time spent monitoring means that the information is largely inconclusive. Instead of using these data for current analysis, therefore, they should act as a baseline for future monitoring of Spring Creek. There have been recent and rapid changes in the housing and agricultural development of the city of Northfield. The population, according to US Census Data, has increased from 10,235 residents in 1970 to 17,147 residents in 2000 and the number of housing units has also increased substantially. There were 2,365 housing units in 1970 and 5,119 in 2000 and between 1990 and 2000 there was a 19.4% increase in houses (US Census Bureau). The most recent changes can be seen in a comparison of two aerial views from 2003 and 2008 of the city of Northfield in Figures 16 and 17, respectively. Although these images only show the differences in five years, the shifts have been notable visible. Due to the proximity of these recent developments to Spring Creek, it is probable that there has been a notable shift in the water quality of the surface water. Since Spring Creek ultimately recharges the groundwater aquifers, Northfield's water source, it is extremely important to understand and monitor the impact and effect of these changes.

The continuation of this project of monitoring the surface water in Spring Creek will allow future researchers to analyze the changes in surface water quality as the city of Northfield continues to change and grow. Along with the analysis of conductivity, temperature, and salinity that were begun by this project, analyzing nitrate levels, pH, dissolved oxygen, turbidity, or flow rate could be fruitful additions to the data. Simply by continuing this data collection over a longer period of time will enhance our understanding of the state of the water in Spring Creek and the future of the watershed into which it feeds.

ACKNOWLEDGEMENTS:

We would like to thank Professor Bereket Haileab who worked with us through this project, steering us in the right direction with his enthusiasm and support and helping us run the nitrate samples. We would also like to thank Doug Lien, the Northfield Water Division Manager, who met with us to discuss the Northfield water and its relation and relevance to Spring Creek and this project. Our teaching assistants Adam and Sarah have also assisted us both in visiting our sites and in evaluating our information.

Our weekly site visits would not have been possible without the help of Tim Vick from the Geology Department who helped us organize transportation and prepare our instruments. Additionally, we would like to acknowledge previous Carleton geology students whose prior work and current research was extremely helpful in completing our project.

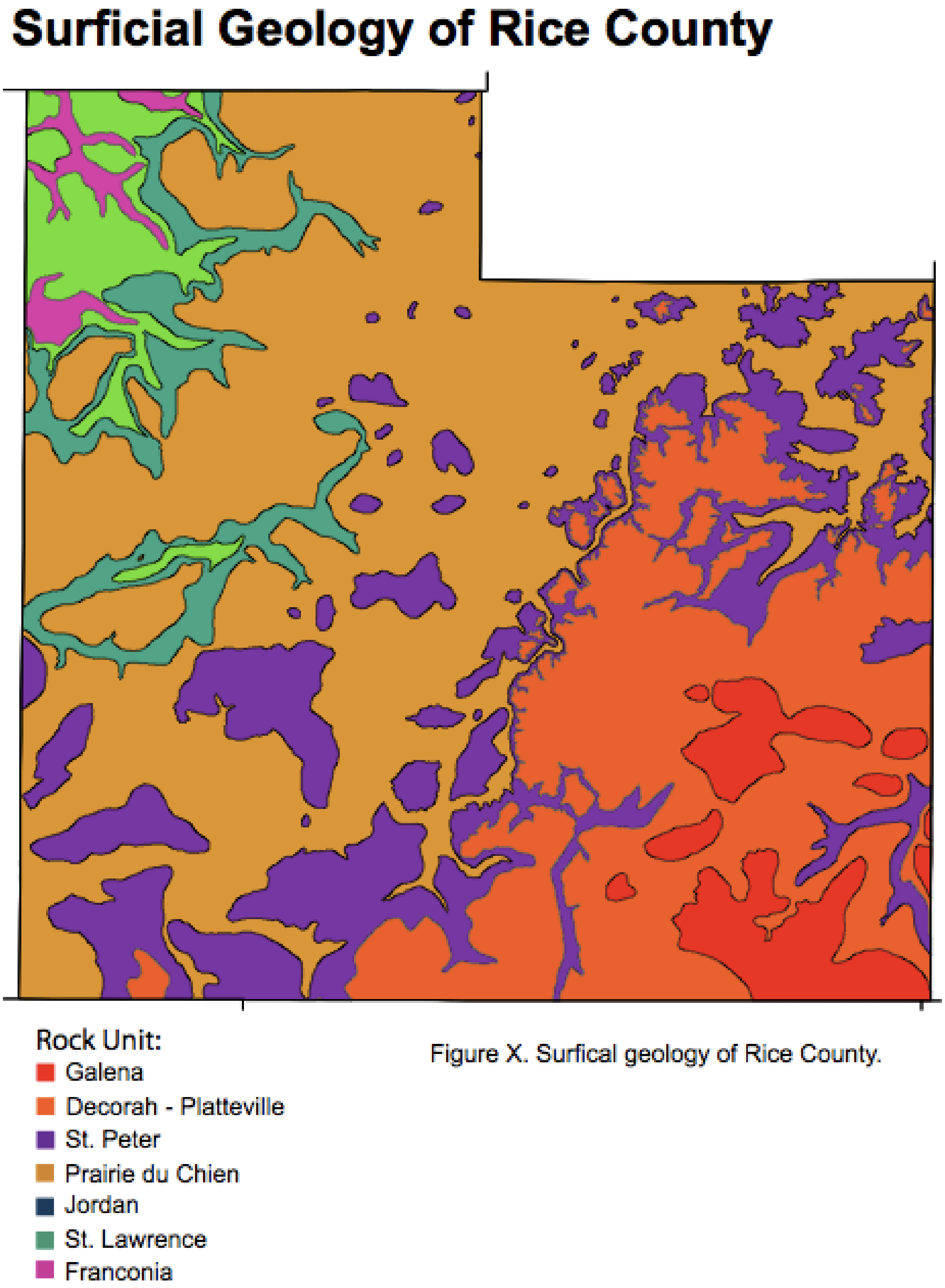


Figure 1: Surficial Geology of Rice County (Battis, et. al, 2010)

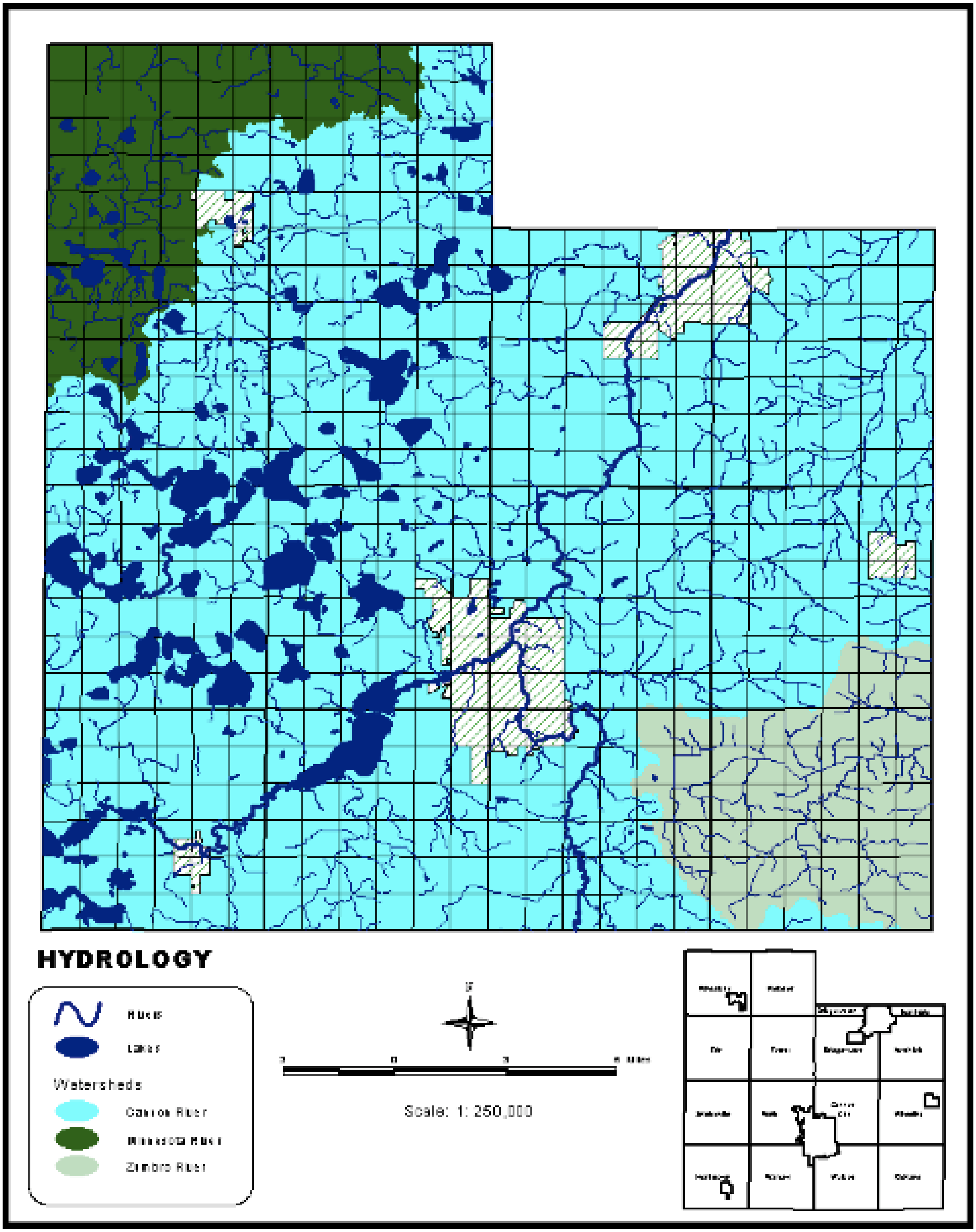


Figure 2: Hydrology of Rice County, Minnesota (Minnesota Department of Natural Resources)

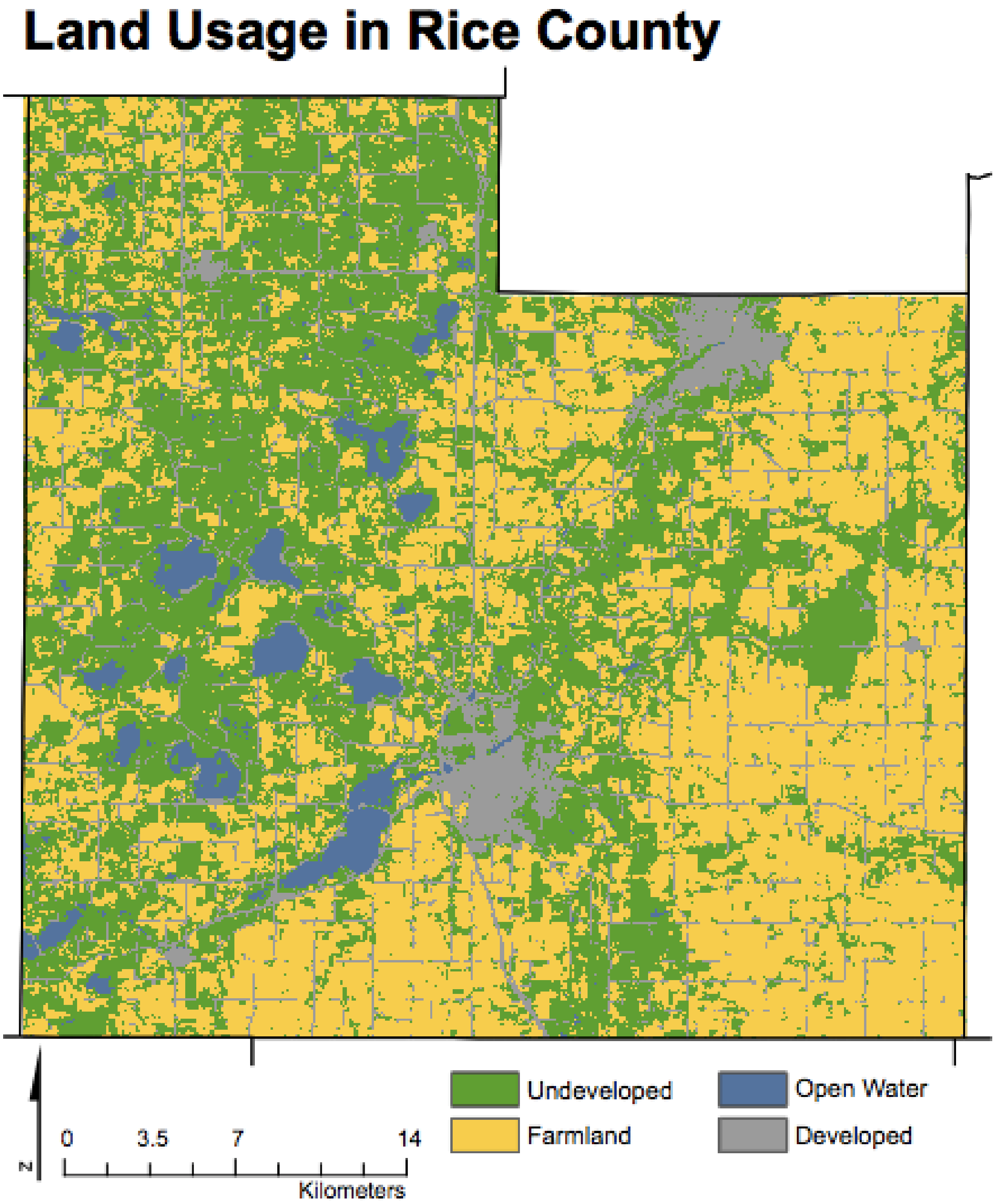


Figure 3. Land use cover within Rice County. Undeveloped land includes woods, prairie, and grassland. Farmland includes agricultural land and pasture lands. Developed land used for residential and commercial purposes or roadway. Open water includes lakes, streams and rivers (Battis, et. al., 2010)

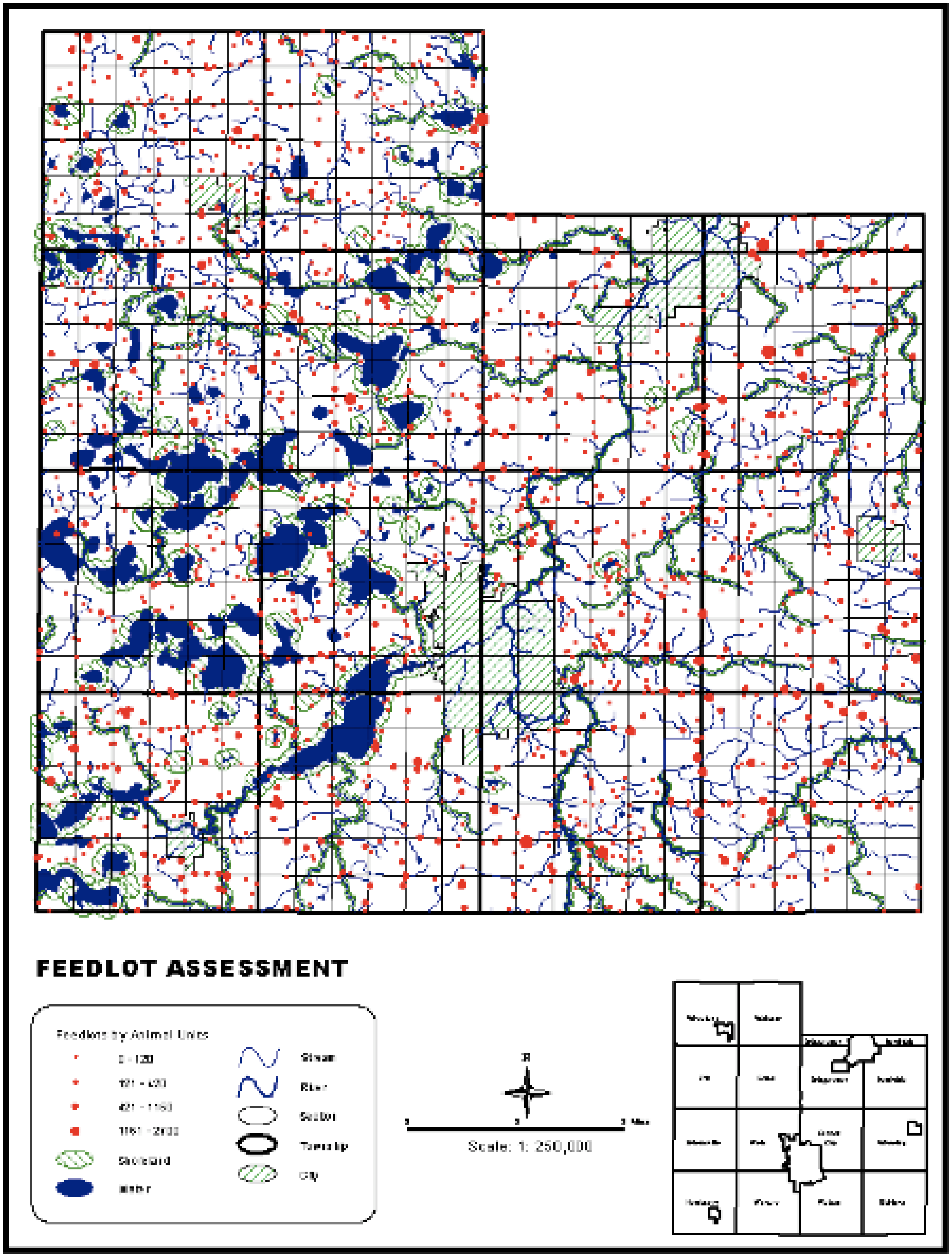


Figure 4: Feedlot Assessment (Minnesota Department of Natural Resources)

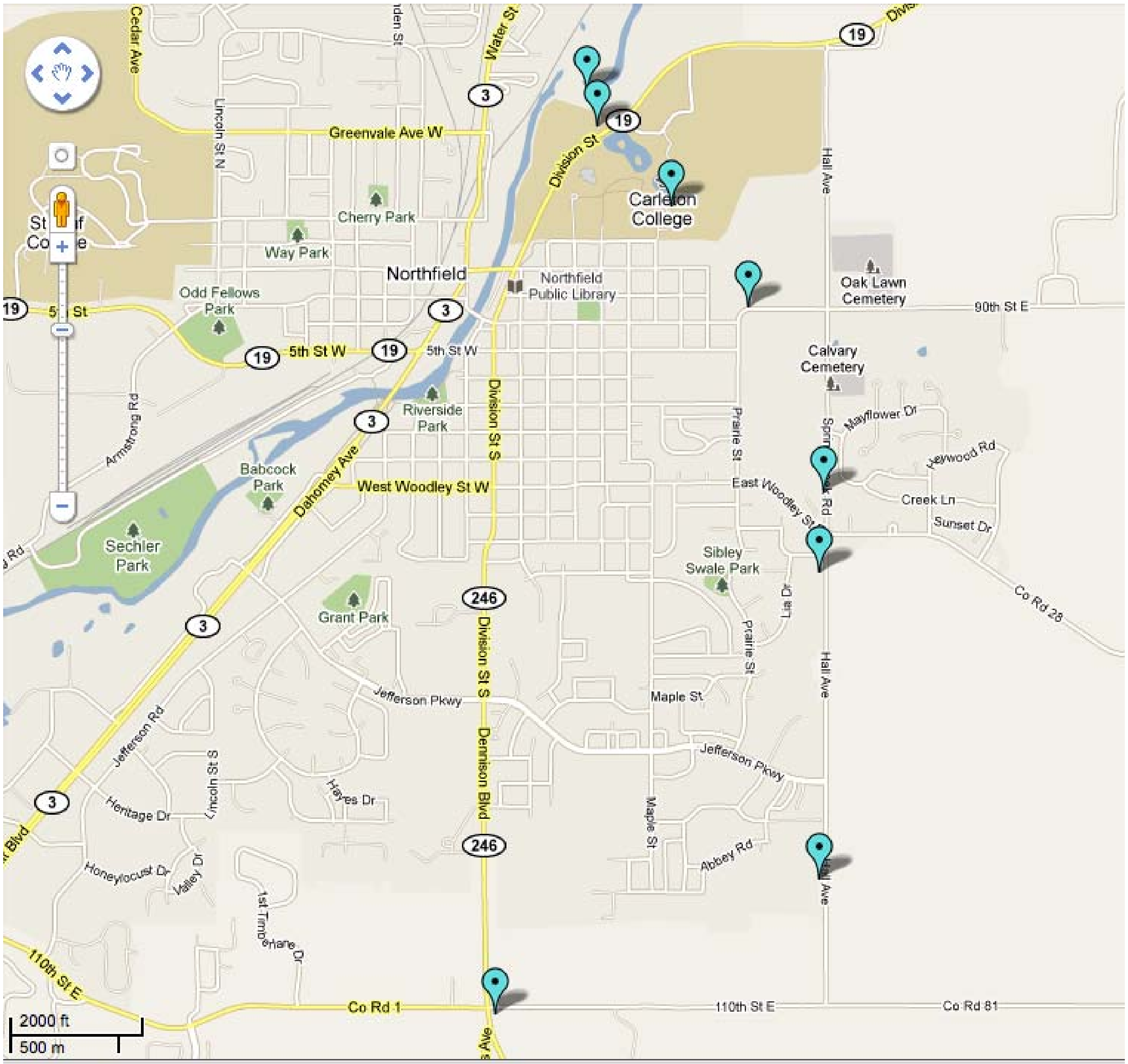
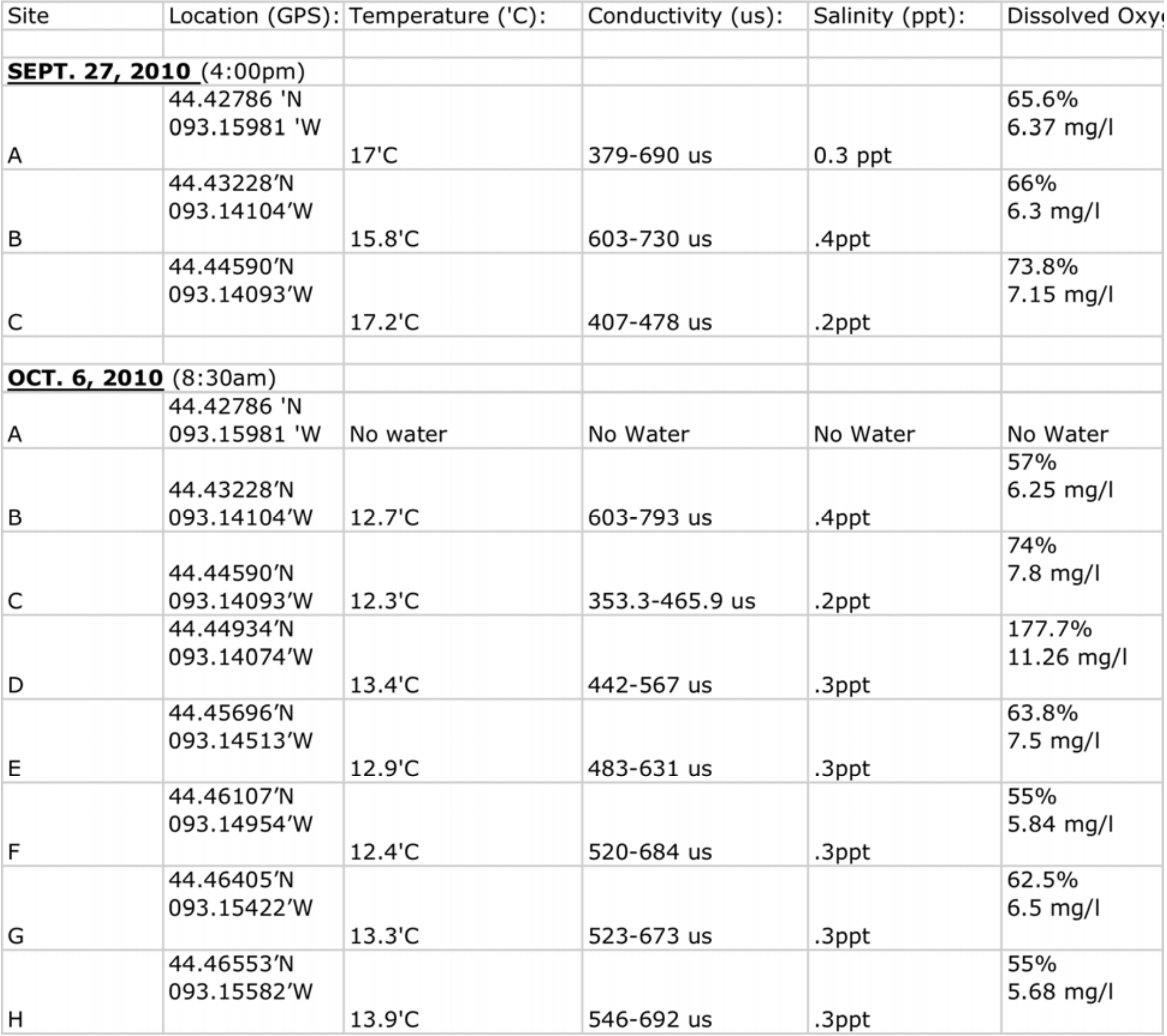


Figure 5: Map of Sample sites.



Site	Location (GPS):	Temperature ('C):	Conductivity (us):	Salinity (ppt):	Dissolved Oxy
SEPT. 27, 2010 (4:00pm)					
A	44.42786 'N 093.15981 'W	17'C	379-690 us	0.3 ppt	65.6% 6.37 mg/l
B	44.43228'N 093.14104'W	15.8'C	603-730 us	.4ppt	66% 6.3 mg/l
C	44.44590'N 093.14093'W	17.2'C	407-478 us	.2ppt	73.8% 7.15 mg/l
OCT. 6, 2010 (8:30am)					
A	44.42786 'N 093.15981 'W	No water	No Water	No Water	No Water
B	44.43228'N 093.14104'W	12.7'C	603-793 us	.4ppt	57% 6.25 mg/l
C	44.44590'N 093.14093'W	12.3'C	353.3-465.9 us	.2ppt	74% 7.8 mg/l
D	44.44934'N 093.14074'W	13.4'C	442-567 us	.3ppt	177.7% 11.26 mg/l
E	44.45696'N 093.14513'W	12.9'C	483-631 us	.3ppt	63.8% 7.5 mg/l
F	44.46107'N 093.14954'W	12.4'C	520-684 us	.3ppt	55% 5.84 mg/l
G	44.46405'N 093.15422'W	13.3'C	523-673 us	.3ppt	62.5% 6.5 mg/l
H	44.46553'N 093.15582'W	13.9'C	546-692 us	.3ppt	55% 5.68 mg/l

Table 1: Spring Creek Measurements

Site	Location (GPS):	Temperature ('C):	Conductivity (us):	Salinity (ppt):	Dissolved Oxy
OCT. 13, 2010					
A	44.42786 'N 093.15981 'W	No water	No water	No water	No water
B	44.43228’N 093.14104’W	11.4'C	816-606us	.4ppt	43.4% 4.2mg/l
C	44.44590’N 093.14093’W	11.9'C	515-385.8us	.3ppt	60.8% 6.55mg/l
D	44.44934’N 093.14074’W	15.1'C	559-452.7us	.3ppt	83.3% 8.37mg/l
E	44.45696’N 093.14513’W	12.6'C	643-488us	.3ppt	37.3% 3.9mg/l
F	44.46107’N 093.14954’W	11.4'C	677-503us	.3ppt	55.6% 6.00mg/l
G	44.46405’N 093.15422’W	14.4'C	667-533us	.3ppt	90.4% 9.22mg/l
H	44.46553’N 093.15582’W	13.9'C	542-688us	.3ppt	59.6% 6.14mg/l
OCT. 20, 2010					
A	44.42786 'N 093.15981 'W	No water	No water	No water	No Water
B	44.43228’N 093.14104’W	No water	No water	No water	No water
C	44.44934’N 093.14074’W	9.2'C	381.8-546us	.3ppt	61% 6.98mg/l
D	44.44934’N 093.14074’W	11.1'C	409.8-557us	.3ppt	78.2% 8.62mg/l
E	44.45696’N 093.14513’W	9.9'C	440.1-623us	.3ppt	64.7% 7.08mg/l
F	44.46107’N 093.14954’W	9.6'C	474-671us	.3ppt	77.7% 8.69mg/l
G	44.46405’N 093.15422’W	11.1'C	499-679us	.3ppt	78.4% 8.41mg/l
H	44.46553’N 093.15582’W	11'C	497-679us	.3ppt	72.3% 7.6mg/l

Table 1 (continued): Spring Creek Measurements

Site	Location (GPS):	Temperature ('C):	Conductivity (us):	Salinity (ppt):	Dissolved Oxy
OCT. 27, 2010					
A	44.42786 'N 093.15981 'W	No water	No water	No water	No water
B	44.43228′N 093.14104′W	8.1'C	398.7-589us	.3ppt	82% 9.58mg/l
C	44.44934′N 093.14074′W	6.3'C	353-548us	.3ppt	85% 10.46mg/l
D	44.44934′N 093.14074′W	8.4'C	371.4-544us	.3ppt	75% 8.7mg/l
E	44.45696′N 093.14513′W	8.2'C	390-575us	.3ppt	39% 4.55mg/l
F	44.46107′N 093.14954′W	7.8'C	421.7-628us	.3ppt	74.5% 8.8mg/l
G	44.46405′N 093.15422′W	9.5'C	448-636us	.3ppt	83% 8.8mg/l
H	44.46553′N 093.15582′W	9.1'C	449.9-647us	.3ppt	72.2% 8.3mg/l
NOV. 3, 2010					
A	44.42786 'N 093.15981 'W	No water	No water	No water	No water
B	44.43228′N 093.14104′W	6.9'C	477-729us	.3ppt	90.6% 10.83mg/l
C	44.44934′N 093.14074′W	5.7'C	373.1-590us	.3ppt	93.5% 11.67mg/l
D	44.44934′N 093.14074′W	7.1'C	396-601us	.3ppt	116.8% 14.1mg/l
E	44.45696′N 093.14513′W	7.7'C	447.2-669us	.3ppt	61.9% 7.29mg/l
F	44.46107′N 093.14954′W	8.0'C	471-698us	.3ppt	12% 1.36mg/l
G	44.46405′N 093.15422′W	7.6'C	434.2-650us	.3ppt	103.8% 12.38mg/l
H	44.46553′N 093.15582′W	7.9'C	449.7-668us	.3ppt	66.2% 7.87mg/l

Table 1 (continued): Spring Creek Measurements

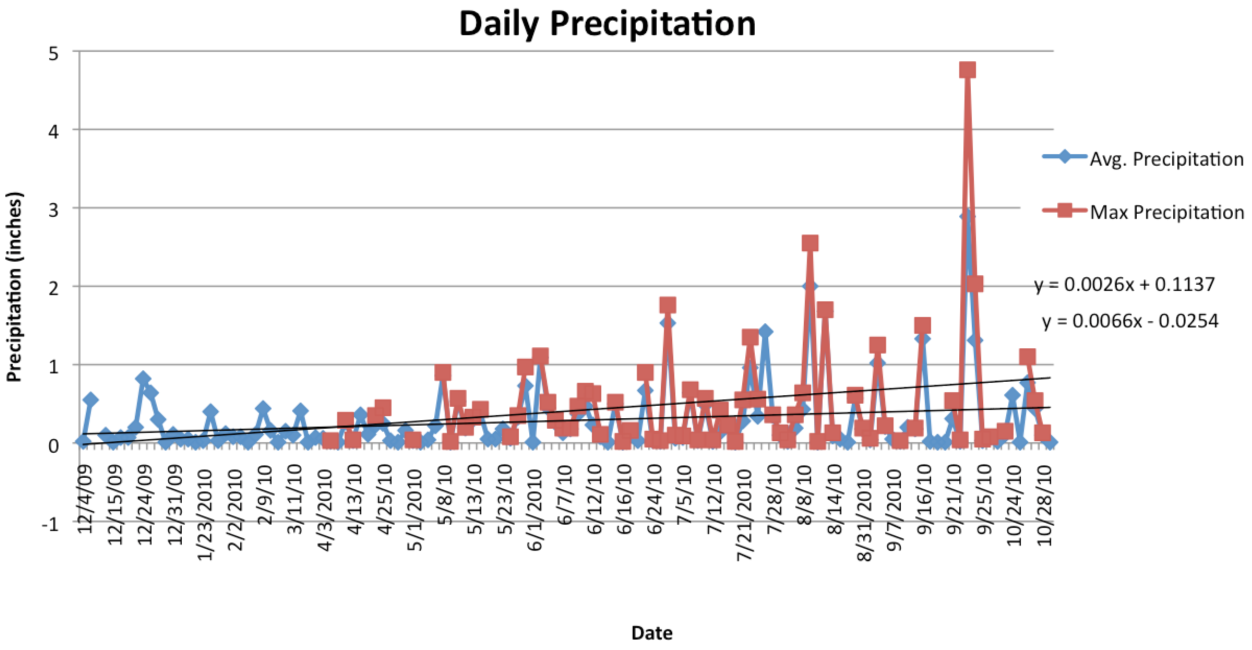
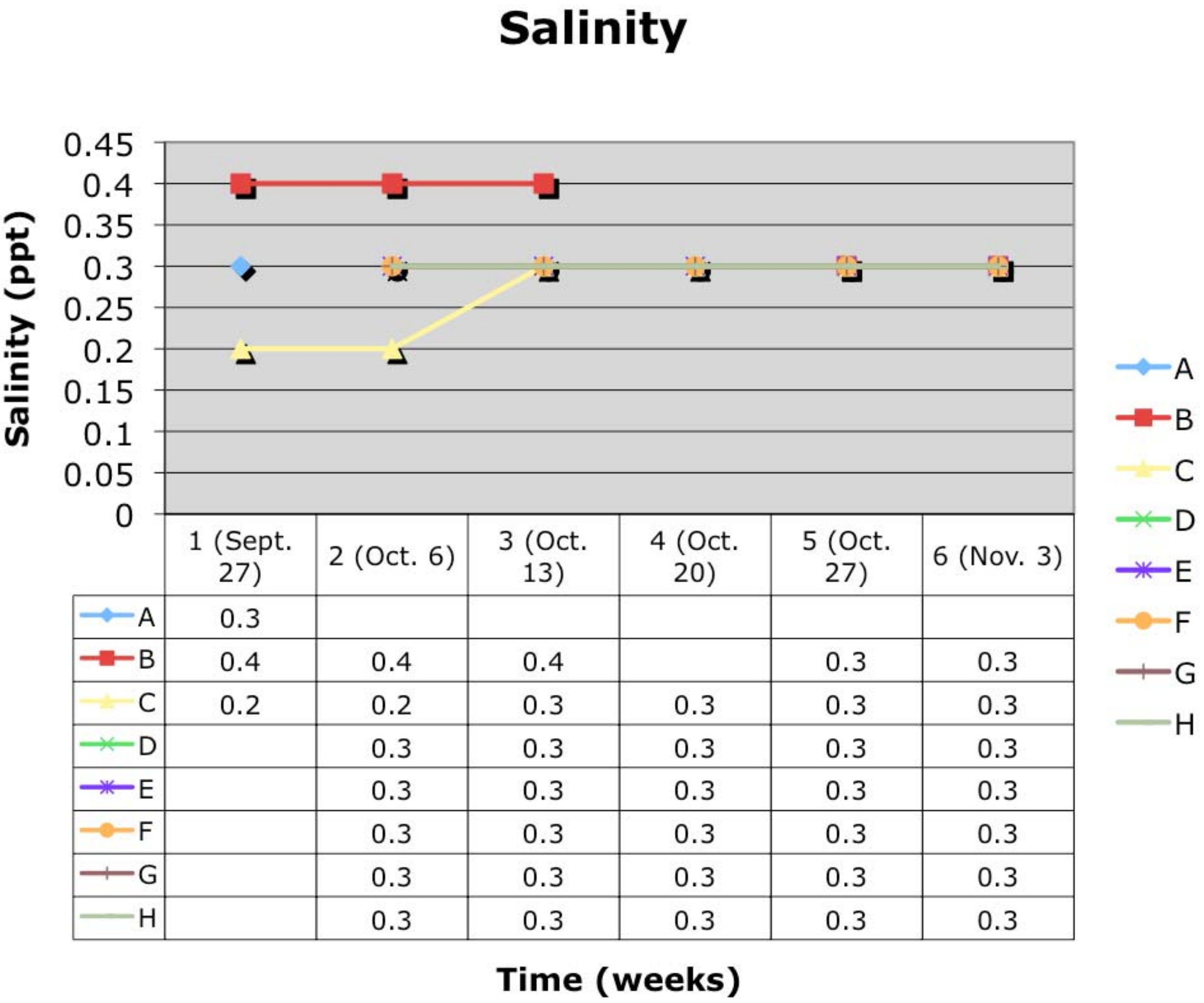


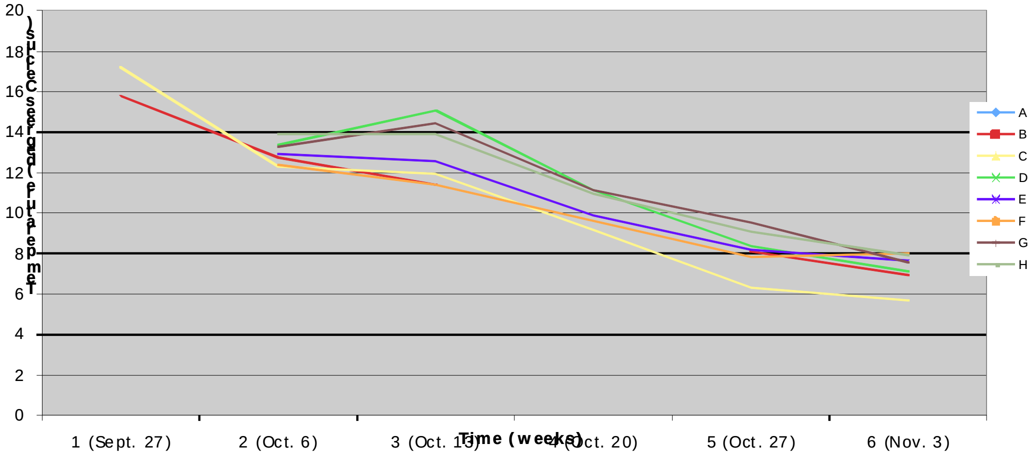
Figure 6: Daily Precipitation History, from Rainfall Group,
Intro Geology fall 2010



	1 (Sept. 27)	2 (Oct. 6)	3 (Oct. 13)	4 (Oct. 20)	5 (Oct. 27)	6 (Nov. 3)
A	0.3					
B	0.4	0.4	0.4		0.3	0.3
C	0.2	0.2	0.3	0.3	0.3	0.3
D		0.3	0.3	0.3	0.3	0.3
E		0.3	0.3	0.3	0.3	0.3
F		0.3	0.3	0.3	0.3	0.3
G		0.3	0.3	0.3	0.3	0.3
H		0.3	0.3	0.3	0.3	0.3

Figure 7: Salinity of Spring Creek

Figure 8: Temperature



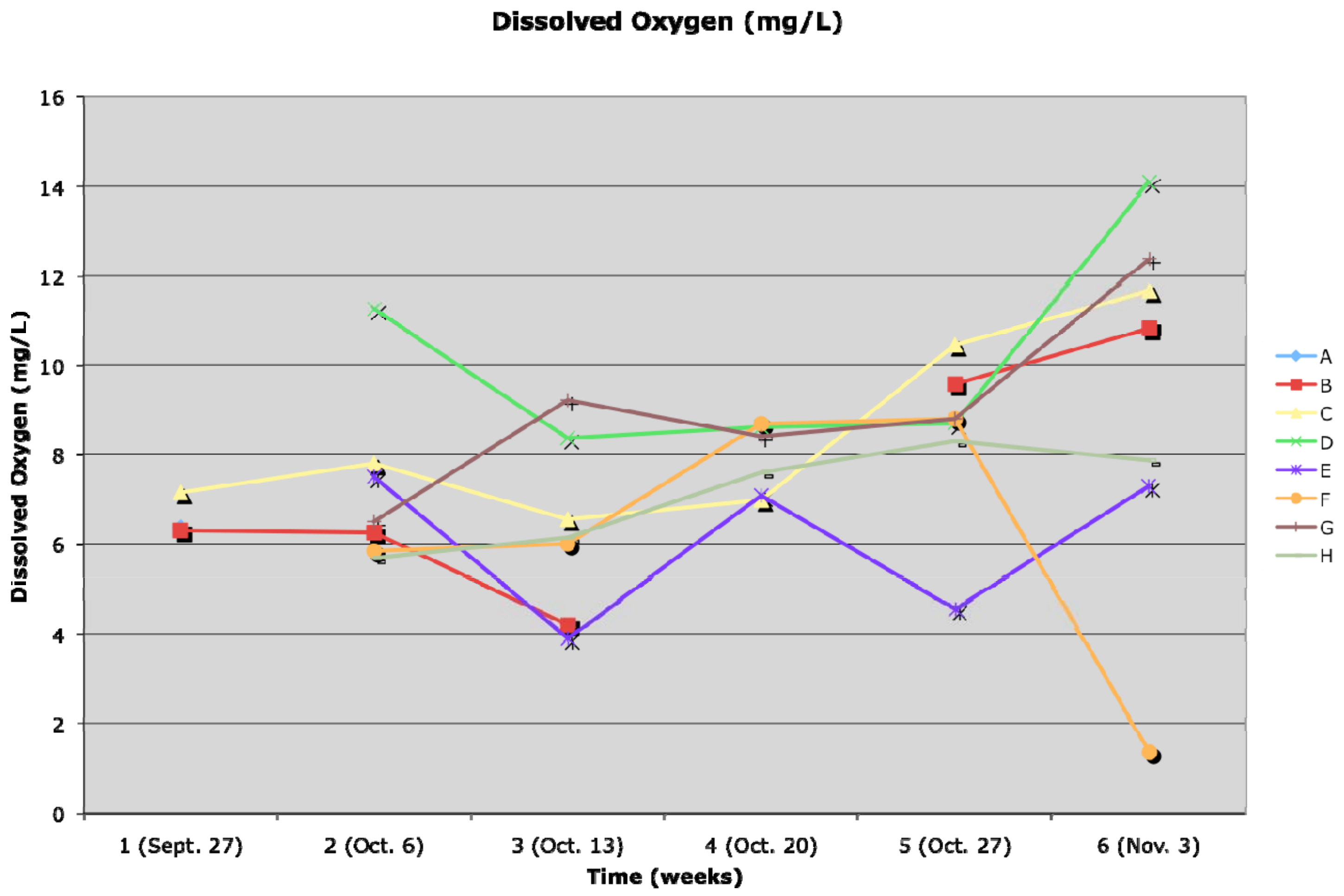


Figure 9: Dissolved Oxygen (percent)

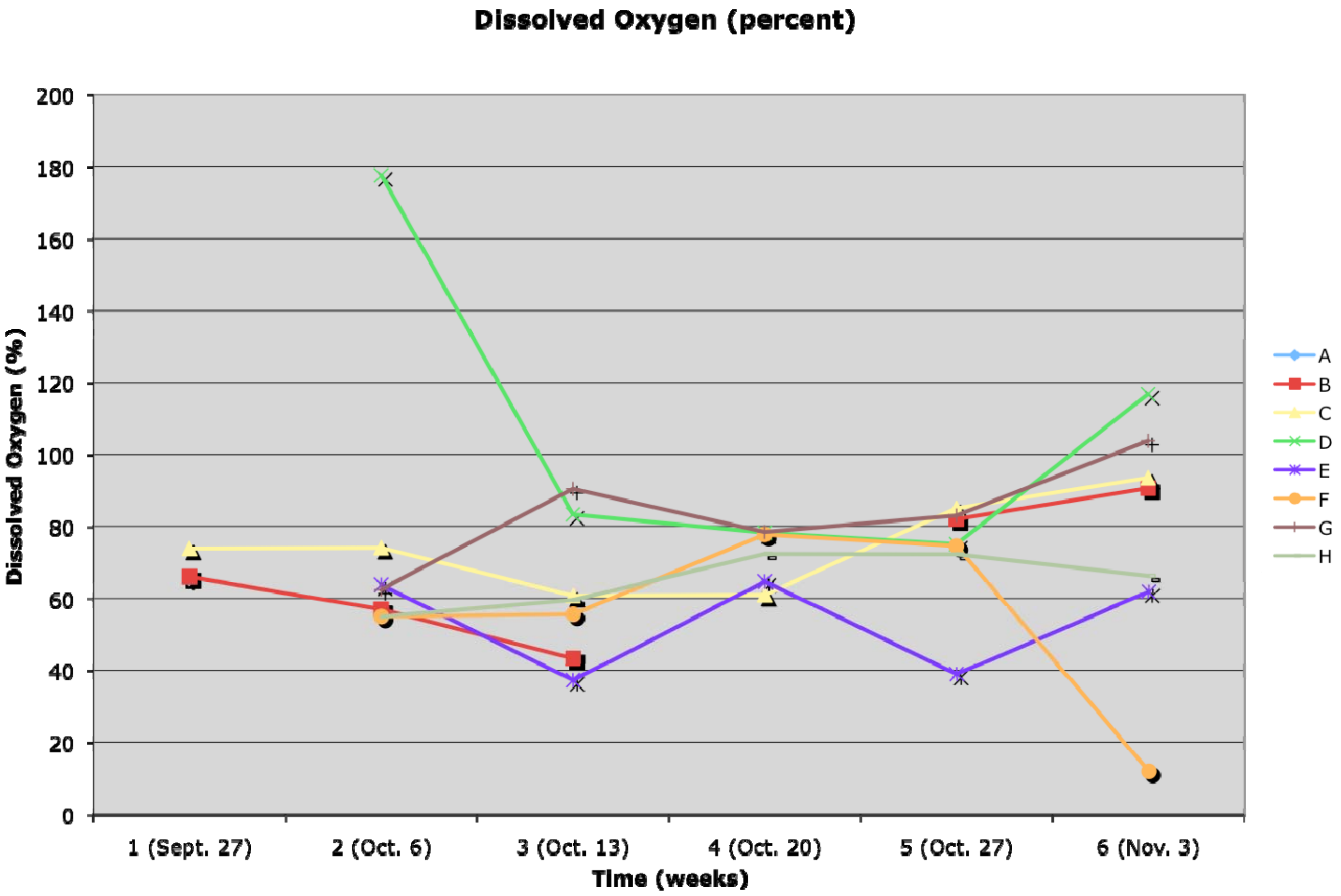


Figure 10: Dissolved Oxygen (percent)

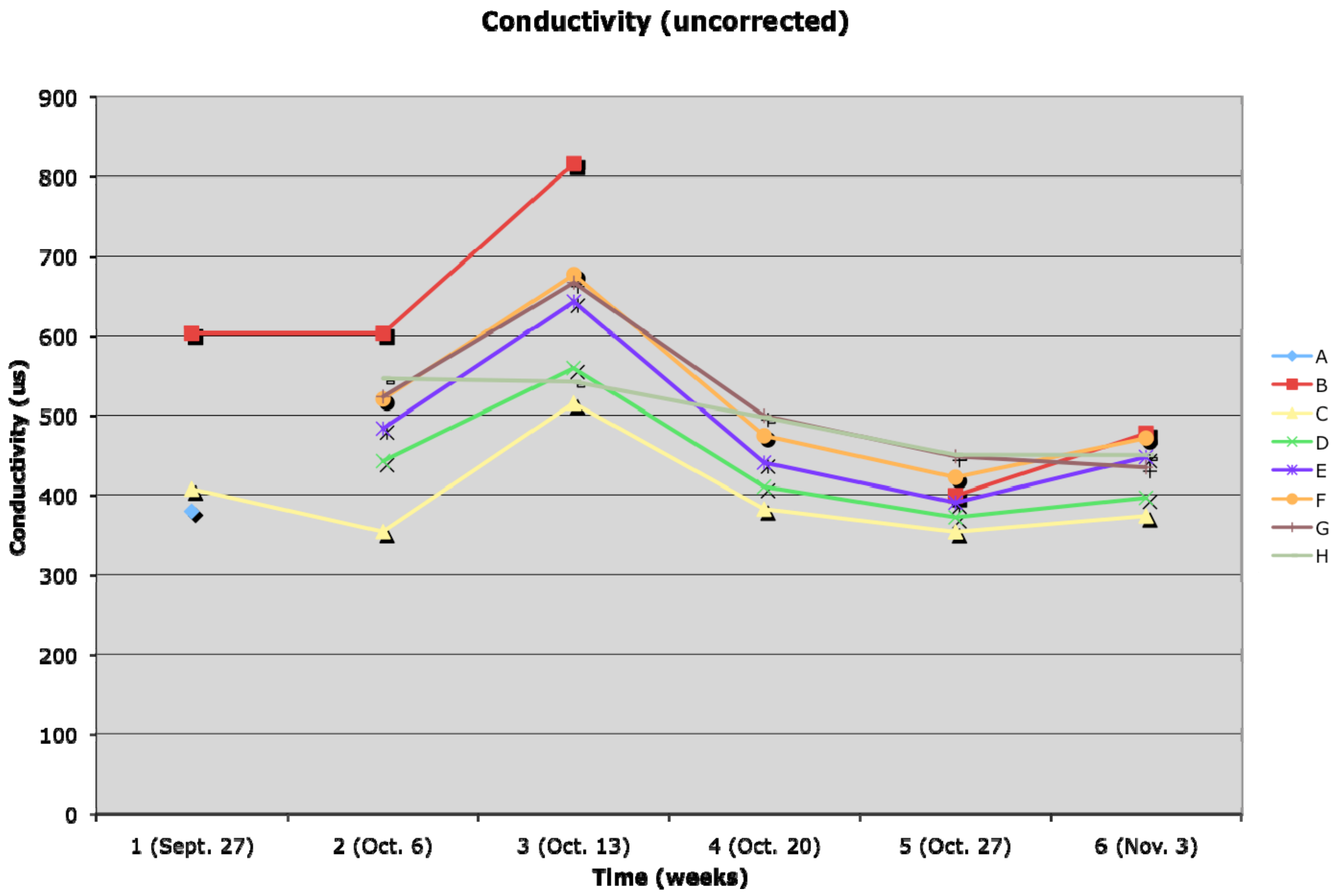


Figure 11: Conductivity (uncorrected)

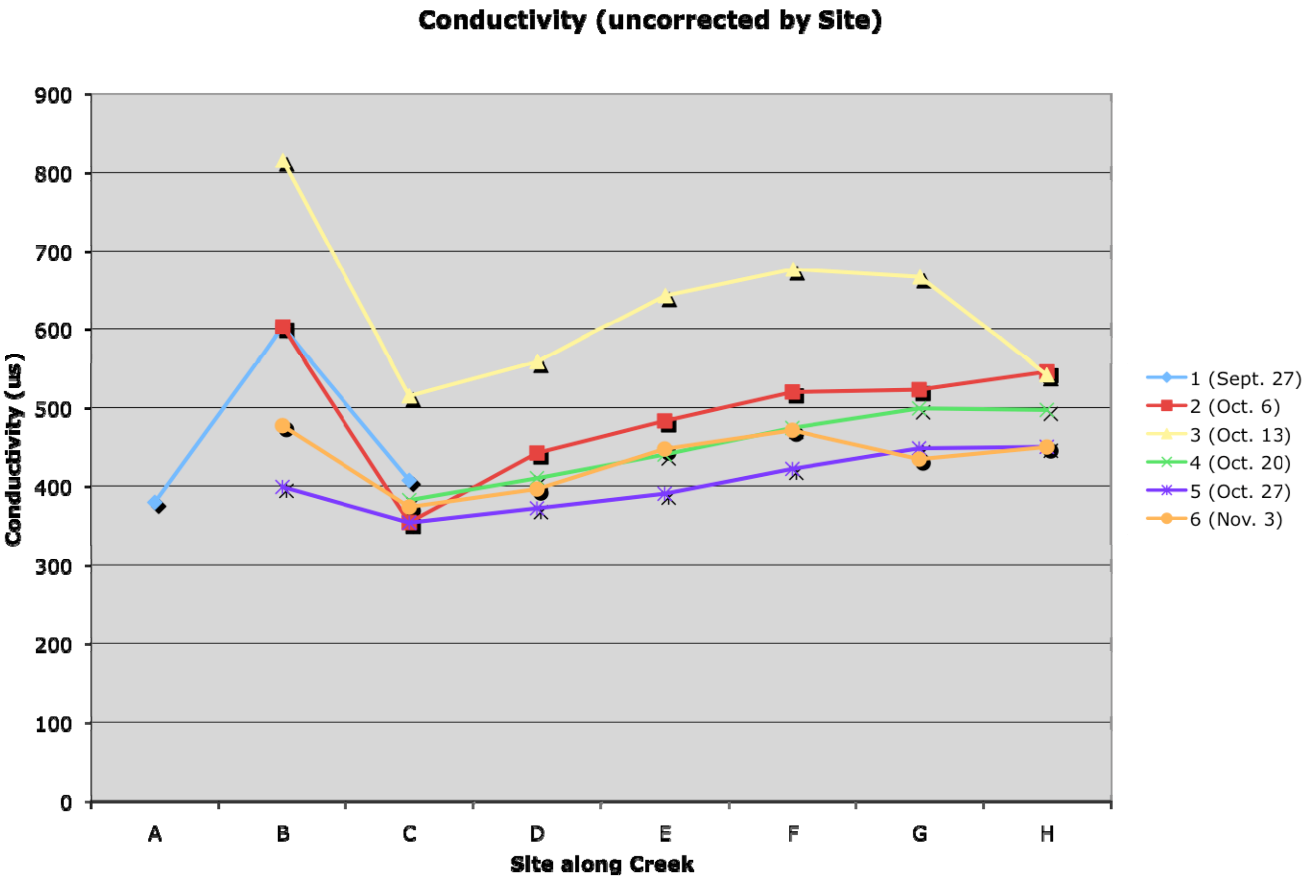
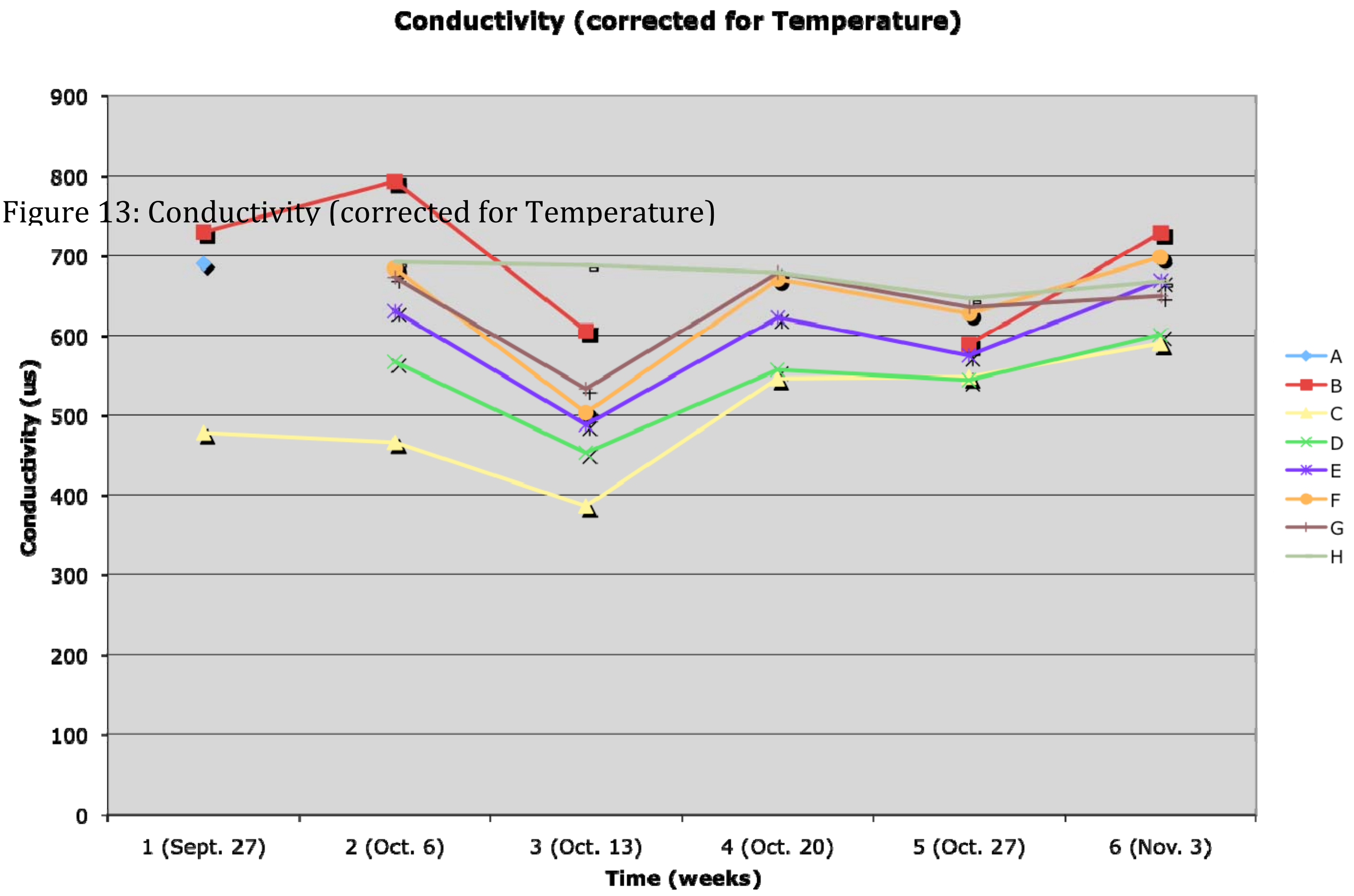


Figure 12: Conductivity (uncorrected by site)

Figure 13: Conductivity (corrected for Temperature)



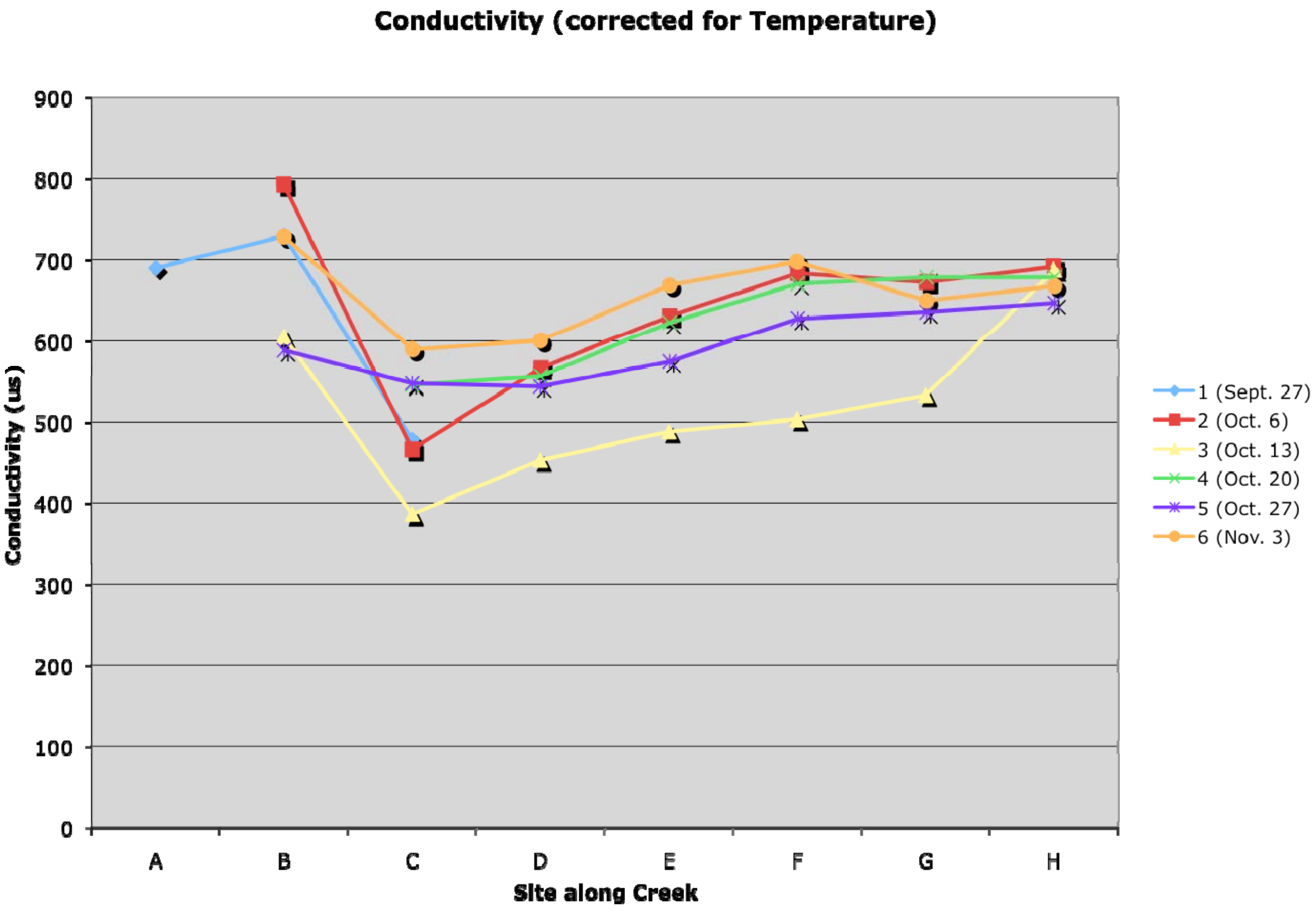


Figure 14: Conductivity by site (corrected for Temperature)

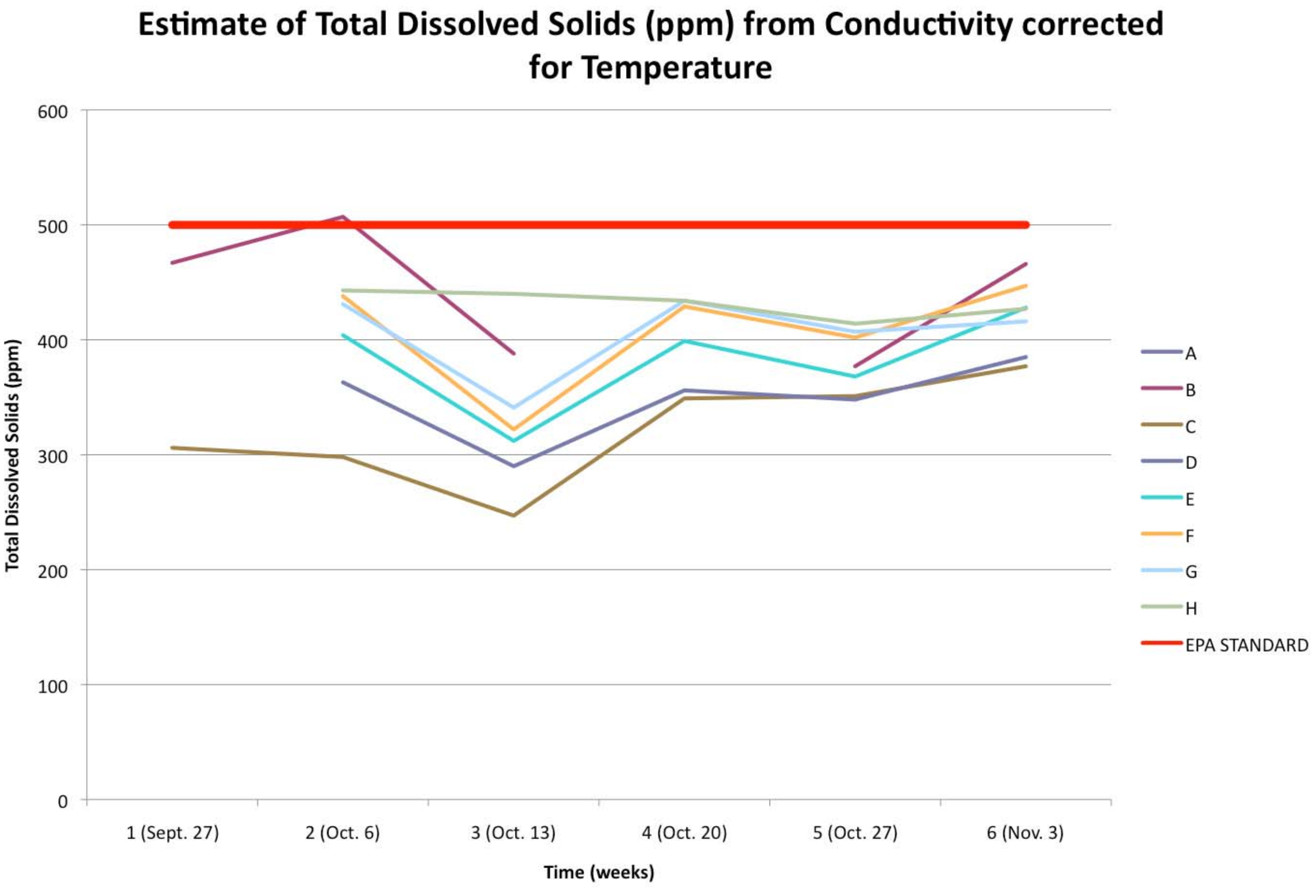


Figure 15: Estimate Total Dissolved Solids (ppm) from Conductivity corrected for Temperature

Figure 16: Aerial picture of city of Northfield, 2003 (above).
2003 Color Aerial Photos from 2010 Minnesota Department of Natural Resources.

Figure 17: Aerial picture of city of Northfield, 2008 (above).
2008 Color Aerial Photos from 2010 Minnesota Department of Natural Resources.

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