Using GIS to Reevaluate Beaver Dam Effects on Local Environments in Northern Wisconsin Brook Trout Streams During the 1980s

Jon D. Popelars
Department of Resource Analysis, Saint Mary's University of Minnesota, Winona, MN 55987

Keywords: GIS, Aqueous Chemistry, Trout Populations, Beaver Dam Removal, Linear Regression, Water or Air Temperature, North Branch of Pemebonwon River

Abstract

Beavers have gone from nonexistent in most of the Midwest to reappearing in some of their historical ranges. This new surge in beaver population now requires re-analysis by many wildlife and fishery management organizations. The scale of the impact, because of the larger beaver population, and more importantly their dams, have on watersheds has only been studied in the last thirty years. During the 1980's the Wisconsin DNR (WIDNR) conducted a large scale study in the Pemebonwon River. This study is touted by many scientists and the results from the study are cited in many planning practices. Geographic Information Systems (GIS) can be used to further the study and its results. Updating the data collected into a database having spatial components will allow easier access to the data, incorporate new techniques in analysis, and allow visual results that the public can better understand. This study used the paper data from the Avery report and converted it into a database. The purpose of the database was to be queried and apply statistical tests. The second reason for including a GIS component was to allow the results from each point to be compared spatially, to see if additional understanding could be gained. The results involved looking at stream temperature, water conductivity, pH, turbidity, dissolved oxygen, and all were examined.

Introduction

The beaver (*Castor canadensis*), the largest rodent in North America, once made its home everywhere in North America except in southeastern swamps. Since European settlement, beaver populations plummeted, but now with regulations ruling beaver harvests, numbers are rebounding (Outwater, 1996). Concern now grows about what this population's effect will have on habitats of sensitive, more desirable species (McRae and Edwards, 1994). This has led to studies showing the beaver's impact on watersheds.

One such report, the Avery Report, finished in 1992, contained all the data from a study completed from 1982 – 1986. The study area was the North Branch of the Pemebonwon River, Wisconsin. It was chosen because it had a large beaver population and also contained brook trout (*Salvelinus fontinalis*). Many parameters were recorded in 1982 from stream and air temperature to twenty different aqueous chemical components. After collecting this data the WIDNR proceeded to remove all log jams and beaver dams. They maintained a free flowing water environment for six years and every two years collected data again.

Popelars, Jon. 2008. Using GIS to Reevaluate Beaver Dam Effects on Local Environments in Northern Wisconsin Brook Trout Streams During the 1980s. Volume 11, Papers in Resource Analysis. 12 pp. Saint Mary's University of Minnesota Central Services Press. Winona, MN. Retrieved (date) from http://www.gis.smumn.edu

Results from this report showed an improvement in trout population in the stream reaches where the impoundments were removed, but the river had a sharp decrease in trout population. A general water temperature decrease in all streams was noted following the removal of dams. The chemical parameters summarized in the report revealed minimal chemical impact from beaver dams on the system.

These results and findings were the founding of this investigation. This new study used GIS to look at locations and visually show improvements and degradation of stream elements in the study area over time. The initial part of the study evaluated physical and chemical data with statistical tests and, linear regressions to attempt to isolate important elements associated with beaver dam impoundments of trout waters. This study is hoped to be used by fishery planners and other wetland and watershed managers to assist in their decision making. There is a wealth of information contained in the Avery Report. This study investigated a few of the main points. The geodatabase development is important because it allows others to build on and develop inquires, not only into the trout population, but to also better understand beaver habitat.

Study Area

The study area is located in the northern part of Marinette County, Wisconsin. The county lists 623 miles of trout streams of which the study area was listed as a type II trout stream (WIDNR, 2008). The area was picked by the DNR because it was reputedly cited in the late 1970's and early 1980's as having a large beaver population (Avery, 1992). The specific part of the river and tributaries studied were between U.S. Highway 141 and High Line Road (Figure 1).

Marinette County had only 43,384 people noted in the 2000 census and had shown little change from the census going back two decades (Anonymous, 2008a). Land use in this northern part of Marinette County, where the study area was located, is primarily conifer forest and wooded wetlands. Urban areas are located in the southern area of the county as was most of the agriculture for the area. The county is heavily involved in the northern Wisconsin tourism business, using much of the public woodland and streams to attract outdoor enthusiasts. Because of these characteristics, this area was a good fit since one of the attractions to Marinette County is fishing opportunities (Anonymous, 2008b).

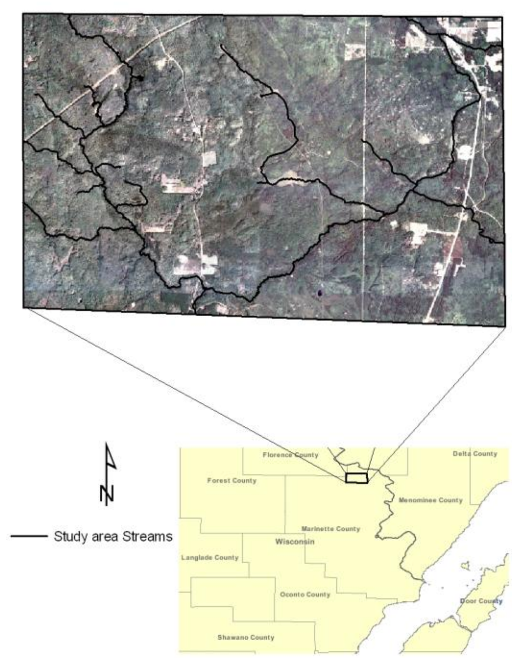

Figure 1. Study area location in Northern Wisconsin showing the selected study streams.

Methods

The analysis was divided into two phases; phase one was the development of a geodatabase. The second utilized the geodatabase to evaluate database elements statistically and spatially. The hope was to reaffirm trends originally noted and to formulate new ideas. All data were converted or created into a usable format for ArcGIS 9.2. The North American Datum (NAD) 1983 Universal Transverse Mercator (UTM) Zone 16N was the projection used.

Geodatabase Development

Georefrencing Sampling Points

Georefrencing original sampling points to spatially known features involved working with original field maps, which contained hand-drawn sampling marks (Figure 2) and a spatially referenced DOQQ from the United States Geological Survey (USGS). The USGS image was obtained from the national USGS map server (Anonymous, 2008c). A river stream layer was obtained from the WIDNR. The stream shapefile required minor editing to connect a stream to the river that was disconnected in the shapefile but was connected in the final Avery Report. Road intersections and railroad tracks were used to georeference the field map to the DOQQ. Occasionally stream road intersections or stream branches had to be used to assure a wide selection and dispersion of points. The goal was to have twelve points to allow the use of 3rd order polynomial transformation to achieve the best possible fit. The final RMS error was 1.59.

With a low RMS error, the points on the map were then digitized into a point shapefile. These points coincided well with the points on the old map.

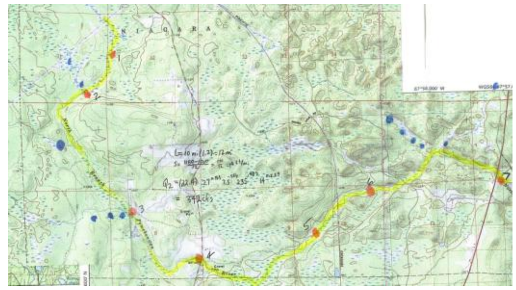

Figure 2. Hand marked points of sample point locations on a field map (From Wisconsin DNR Avery 1992 report).

Temperature points appeared on a map in the report and were not located near most of the hand marked points. Since these points were located elsewhere, an attempt was made to georeference the report map for temperature; unfortunately it did not work. The image warped when as few as five points were used. Further attempts to improve its RMS accuracy never yielded results below 120. In final action the points were placed where they appeared on the map next to trout sampling points following the recommendations of the Avery Report. It was there that, thermographs had been placed, at the outlet of the streams into the river. The four river sampling thermographs corresponded well with the trout population sampling points, allowing the same points to be used for both. No thermograph point was more then 340 meters from a stream mouth (Figures 3 and 4). All points, with the exception of thermograph F, were within 100 meters. The water sampling data also had a temperature component, but this was only recorded when water sampling occurred, twice per year as opposed to the thermographic data which was collected continuously throughout the year. The water sample points, also taken from the map shown in Figure 2, contained more points (Figure 4). Some of the water points had to be moved or adjusted to better align with that shown in the original Avery Report.

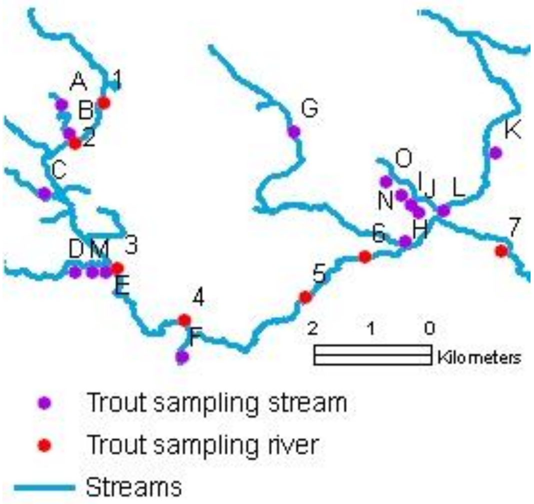

Figure 3. Trout sampling locations (scale 1:50,000).

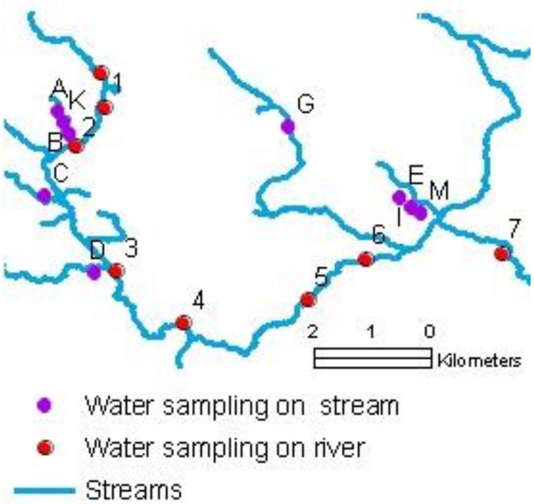

Figure 4. Water chemistry sampling locations (scale 1:50,000).

Data Entry of Avery's Results

Temperature Data

The first set of data entered into the database was the temperature data. The data in the report were in the form of a line graph, making a direct conversion of numbers difficult. To obtain as precise numeric results as possible, a ruler was used to measure the closest millimeter mark the line intersected. Using the measured number and knowledge that the gap for most of the chart divisions was 18.5 mm, a ratio was made to calculate the temperature data with two places after the decimal in degrees Celsius. This was done with each graph, recording the year, location, and highest and lowest temperature for each month. The graph recording the average air temperature for the three years sampled was included in this table for comparison. Some of the graphs had missing data, so the database also had missing data in the same places (Table 1).

Once extracted, the data was entered into an Excel spread sheet. Once the highs and lows were entered averages for each month were calculated and added to the table. Site names were added to the table to make it easier to locate data when the database is used. For results that did not have a value, the fields were left blank. The final formatted table had ten sample points plus the air average. The air recording site was a DNR station that was 25 milessouth of the study area. The data range from January 1982 through December 1986.

Trout Population

The trout population data had previously been compiled into Excel files by Olmsted County Environmental Services. The tables needed to be revised so that all data were on one sheet and formatted for importing into the geodatabase. Population data were recorded for twenty-one stations, for three months, over three separate years. The collection months were May, July,

Table 1. Excerpt of the table showing the site ID, site name and temperature (C°) lows for the first five months of 1982.

SiteID	Jan 82 low	Feb 82 low	Mar 82 low	Apr 82 low	May 82 low
1					12.97
2	0.81	0.68	0.68	0.68	11.62
3	1.22	0.81	0.81	0.81	11.35
4	0	0.27	0.27	0.41	11.35
D	0.13	0.14	0.14	0.27	8.51
F	0	0.14	0.14	0	14.05
H	0.13	0.14	0.14	0.27	13.78
A	0	0	0	1.35	12.16
B	0	0	0.27	0.27	6.35
C	0.41	0.41			12.02
Air	-4.19	-2.31	2.79	11.86	22.56

and October. The month of July had missing data, but was included for completeness (Table 2). In this table, blank spaces were also used to signify missing data. Zeros in the table signify sites that were sampled but no fish were observed.

Table 2. Excerpt of the table showing Site ID population sampling.

SiteID	MAY 82	MAY 84
1	108	221
2	34	82
3	257	279
4	305	614
5	232	403
6	304	196
7	77	20
a	0	0
b	0	5
c	17	24
d	0	3
e	20	14
f	7	14
g	0	0
h	70	15
i	0	0

Water Chemistry

Data for the water chemistry tables came from fourteen stream as well as eight river sampling points. There were twenty parameters recorded:

-Conductivity
-pH
-Dissolved O_2
-Temperature °C
-Hardness
-Calcium
-Magnesium
-Sodium
-Potassium
-Manganese
-Iron
-Sulfate
-Chloride
-Dissolved Ortho Phosphorus
-Total Phosphorus
-NH_3-N
-NO_3+NO_3-N
-Total Kjel-N
-Alkalinity
-Turbidity

The same practice of leaving blank spaces for missing data for water quality parameters was again used (Table 3). As part of its investigation, the Avery Report documented if the sample point was in a beaver dam or not. Samples were collected in February and August, of 1982, 1984, and 1986. A few sites were sampled in March instead of February due to accessibility. Two sites, M and N (Figure 4), on No Name Creek and Genricks Creek respectively, were only sampled in August and only had conductivity, pH, dissolved oxygen, water temperature and hardness measured. Another factor summarized in the Avery Report was the chemistry in the beaver dam area at the water surface and bottom. This was only done in 1982 while the beaver dams were present. The lower case b, next to some points' names, was used to record the readings taken off the bottom of a pond when surface and bottom readings were both recorded.

Combining Spatial Points and Tables

In Excel, linking the trout sampling data with the thermograph data required setting up a foreign key for the temperature data so tables could be joined. The joined trout population/thermograph data was further joined to trout sampling points in ArcMap. Water chemistry data was also joined to their appropriate water sampling locations in ArcMap.

In order to compare trout population, beaver dams, and water chemistry, a second foreign key was made to connect trout population data with a water chemistry point that existed within at least 100 meters. Most points occupied the same geographic point. Since more points were sampled for chemistry than were sampled for trout or temperature, there were some water chemistry points that did not have any trout or temperature data associated with them.

Statistical Analysis

Table 3. Part of the water chemistry table showing the first three parameters: beaver pond, and alkalinity in February 1982.

Water ID	Pond	Feb Alkalinity 82
1	N	130
2	Y	128
3	Y	131
4	N	130
5	Y	130
6	N	130
7	N	130
8	Y	
A	N	120
B	Y	130
Bb	Y	
L	Y	
Lb	Y	
C	N	
D	N	80
E	Y	80
Eb	Y	
F	Y	
Fb	Y	
G	N	150
H	N	150
I	N	150
J	Y	160
Jb	Y	
M	Y	
Mb	Y	
K	N	200

Means were calculated in Microsoft Excel. Coefficient of determination (R^2) analysis was performed in SPSS. The tests were performed using a regression calculation. Each physical chemical test was tested with its 1982 value against the 1982 trout data to try to find physical chemical results that related to trout habitat. Many of the test results returned a R^2 of less than .35 with most below .1. The physical chemical tests greater than .182 R^2 were: July low temperature, July high temperature, July average temperature, turbidity, dissolved O_2, conductivity, and pH. The number of points considered should have been sixteen, but due to missing data the number of points included in the analysis was substantially fewer. Since low R^2, values were noted; literature was used to identify important physical chemical tests with respect to trout population abundance.

The project data was extensive. Still, missing data in some months and years existed because data was not always collected. Also important, a two to three month difference between water chemistry data and trout population abundance and made comparisons difficult. Because of this offset, chemistry conditions when trout population data were collected could have been vastly different from that noted by chemistry sampling two months later. This offset of data collection could have contributed to the low coefficient of determination resulted noted earlier. To continue this study, a sub set of water chemistry tests was selected. Tests selected included stream temperature, air temperature, beaver ponds present, turbidity, pH, and conductivity. These selections were based on those deemed important by trout habitat research specifically that cited as of greatest importance in the Avery Report. Here, the selected water chemistry tests were analyzed in a regression to determine if a relationship existed between each water chemistry test and beaver dams. Also, GIS maps were developed to show change over time; of each parameter at each sampling point. At this point, the work of this study shifted from showing a direct connection between the trout abundance and beaver dams to showing the relationship, if any, of beaver dams to physical chemical tests deemed most important to the trout habitat.

Most articles cite water temperature as being critically important to trout survivability, specifically 10 - 23 °C. If water temperature exceeds 24 °C for more than a few hours, it causes trout to die (McRae and Edwards, 1994). The other water chemistry test cited was dissolved O_2. About 7 mg/l is recommended for a healthy trout water ecosystem. Trout can survive in a 5 mg/l environment, but this is inconsistent with good habitat (Deas and Orlob, 1999). Literature indicates that trout need a stream system with low turbidity during spawning, allowing gravel beds used for breeding to be silt free (Collen and Gibson, 2001). Since turbidity, conductivity, and pH all measure various floating particles in water, they were included in the final list of important trout habitat physical chemical tests. Turbidity is the best indicator of water clarity, but a balanced pH is also a good indicator of a healthy stream system.

Once the list of stream temperature, air temperature, beaver ponds presence, turbidity, pH, and conductivity was compiled for all sampled points, they were analyzed to see how beaver dams affected them. Since regression analysis could only be performed with numbers, yes and no for beaver dams present were switched to one and zero respectively to make all sampled data numeric. The first calculations involved temperature data. First an average water temperature was calculated for each month. Next a ratio calculation was used to bring all water temperatures in line with the 1982 air temperature by the formula.

$(X/Y) * Z = T$

where

T = new stream temperature if in 1982
X = average stream temperature for the month
Y = air temperature for that month and year
Z = air temperature in 1982 for that month

This equation was used to remove the difference of air temperature and find what the water temperature would have been had the existing water conditions occurred in 1982 (Table 4). Finally, the difference was found between other temperatures and the corresponding month in 1982. The recalculation was done because air temperature increased each year after 1982, and this made a direct comparison of water temperature difficult without adjustment. The removal of the variation from air temperature allowed beaver dam removal to be examined more effectively.

After average temperature for the sample sites and the whole watershed were determined, an attempt was made to establish a direct relationship between beaver dams and the subset of selected water chemistry tests with linear regression. First stream temperature was the dependent variable. The independent variables were: beaver ponds (present or absent), air temperature, conductivity, pH, dissolved O_2, and turbidity. Beaver dams and air temperature were the main focus of investigation, but others were undertaken to help validate the results. Each year did not need to be separated hence a larger sample size (n = 43) was formed. Only stream data points were included because turbidity was not collected on the river. However this should have little effect on the results as beaver dams were primarily located in the stream environment and this study's purpose was to improve this habitat. The reason air temperature was expected to be an important factor was because the McRae and Edwards' (1994) study revealed that site air temperature accounted for 63% (R^2 = .63) of the variability in stream temperature (McRae and Edwards, 1994). Avery (1992) states beaver dam removal lowers the stream temperature and increases dissolved O_2.

The same points were tested with each selected water chemistry test (dissolved O_2, turbidity, pH, and conductivity) serving as the dependent variable. The dependent variables were the remaining selected water chemistry test and beaver dams. The purpose of these analyses was to determine how these variables related to beaver dams.

Results

Some water chemistry tests showed a strong relationship to beaver dams while others had no relationship at all. For stream temperature, the coefficient of determination for beaver dams was .02 of the total R^2. The air temperature coefficient of determination was .94 R^2.

For conductivity, the only independent variable listed as a factor in the total R^2 with beaver ponds and had a .19 R^2. It is important to note the standard error of the estimate was 170.2. The large error means suggests the relationship between beaver ponds and conductivity is suspect at best.

pH produced a coefficient of determination of .51 R^2. For air temperature the R^2 with beaver ponds was .04. The regression coefficient was negative which indicated that as beaver ponds were removed, the pH increased and become more basic. Work also shows that beaver dam's presence or absence had little relationship to air temperature.

Turbidity results produced a coefficient of determination for beaver ponds of .37. The regression coefficient of the regression was positive indicating that beaver dams raised the water's turbidity. Other factors like dissolved O_2 and air temperature also contribute to the total R^2. Dissolved O_2 and turbidity show an inverse relationship, as one rises the other falls. This trend was probably due to silt, mud, and debris in the water utilizing O_2 available in the system.

Dissolved O_2 predictions, had turbidity as the largest contributor to the coefficient of determination at .27 R^2. If stream temperature is included, the two increase the total R^2 for dissolved oxygen to .71 with both showing an inverse relationship toO_2 content.

The observation of an inverse relationship between O_2 and turbidity is not surprising. In many streams, as stream temperature decrease in temperature, O_2, increases and this is particularly so in streams that have notable turbulence (Deas and Orlob, 1999).

Error in the regressions preformed for this study could also have occurred because physical chemical tests were only collected for one year with beaver dams. They were sampled again two years later but without the beaver dams present. If this occurred, it could have introduced some error in all the regressions with respect to beaver dams presence and possibly minimizing beaver dam importance in the total R^2.

Table 4. Table showing calculated results of stream temperature. Note negative values in the diff from 82 column shows warming while positive numbers show cooling.

Month	Stream	Air	If 1982	Diff from 82
Jan-82	0.39	-3.2	0.39	0
Feb-82	0.34	0.24	0.34	0
Mar-82	0.42	7.32	0.42	0
Apr-82	5.58	19.1	5.58	0
May-82	13.68	24.5	13.68	0
Jun-82	15.88	22.9	15.88	0
Jul-82	17.58	25.5	17.58	0
Aug-82	14.66	21.5	14.66	0
Sep-82	10.99	16.9	10.99	0
Oct-82	7.75	10.1	7.75	0
Feb-83	0.48	3.25	0.61	-0.26
Mar-83	1.04	7.79	0.98	-0.55
Apr-83	4.66	13.4	6.62	-1.04
May-83	9.43	21.6	10.70	2.97
Jun-83	15.13	29.3	11.82	4.05
Jul-83	19.47	30.7	16.23	1.35
Aug-83	17.49	26.8	14.01	0.65
Sep-83	14.13	19.8	12.07	-1.07
Oct-83	4.93	11.5	4.33	3.42
Jan-84	0.56	0.35	-5.29	5.69
Feb-84	0.55	3.72	0.03	0.31
Mar-84	1.24	8.37	1.08	-0.66
Apr-84	4.66	17.3	5.16	0.42
May-84	11.10	22.6	12.01	1.66
Jun-84	15.73	26.6	13.53	2.34
Jul-84	16.50	27.3	15.45	2.13
Aug-84	15.87	24.1	14.12	0.53
Sep-84	10.59	18.2	9.85	1.13
Oct-84	7.64	11.7	6.58	1.17
Jan-86	0.78	-2.32	1.09	-0.70
Feb-86	0.81	3.83	0.05	0.29
Mar-86	2.41	11.0	1.59	-1.17
Apr-86	8.10	19.8	7.82	-2.24
May-86	13.40	23.9	13.73	-0.05
Jun-86	15.26	26.5	13.18	2.69
Jul-86	17.91	26.7	17.14	0.44
Aug-86	15.02	23.2	13.89	0.76
Sep-86	12.14	18.2	11.28	-0.29
Oct-86	7.53	9.88	7.71	0.04

It is safe to say that this would only affect the beaver dam portion of the calculations and that the other independent variable should not have been affected.

Conclusion

Of the sub-set of physical chemical tests investigated with regression, only three had significant results. These, turbidity, dissolved O_2, and stream temperature is considered the primary components to trout survivability in a stream. Only turbidity has a significant relationship with beaver ponds. The beaver ponds alone make up .38 R^2 of the total R^2. Turbidity also showed a strong relationship with dissolved O_2 (.27 R^2).

The main reason cited for removing beaver dams is that it will decrease the stream temperature. In this study, air temperature had a stronger relationship with water temperature then it did to beaver dams. This could explain why the cooling expected to be found across the watershed was never observed. The Avery Report indicated that some places cooled up to 6° C others showed, no change or slight warming. Avery (1992) noted that 1984 and 1986 were warmer than 1982. Because of this, data in Table 4 shows what would happen if the air temperature from 1982 occurred 1983, 1984, and 1986. The results show a drastic temperature cooling in the summer months of May through August in 1983, right after the dams were removed. Instead of warming or remaining constant, the water remained cooler than pre-beaver levels by about 2.6°C.

The coefficient of determination for dissolved O_2 in the stream suggests turbidity and stream temperature with the closest relationship. Beaver ponds did not show a relationship to the amount of O_2 in the water. This was unexpected as beaver pond bottoms had the lowest dissolved O_2 found in the sample area. This could be due to the fact that the average was used each month, or it might be because the effects of beaver ponds were localized. Even if no relationship was found, there was a marked improvement of dissolved O_2 in the watershed after 1982. The largest improvement was seen in August of 1986 when the dissolved O_2 increased by 2.38 mg/l compared to August of 1982. Since the water temperature during 1986 was slightly higher than the water temperature in 1982, the difference could be related to a change in elements that consume oxygen.

Trying to establish relationships to trout abundance failed in the first phase of this study. Population abundance decreased in the river in 1986 sample and increased in the streams. In 2004, Avery released population numbers on the stream for that year. When compared to other years, the numbers in 2000 were greater than those found in 1986. The spring 2000 sample showed a 73% increase over 1982 and the fall of 2000 indicated a 24% improvement also over 1982.

Taking all of this into account, this study suggests a relationship between air temperature and water temperature. This relationship was stronger than that of beaver ponds to water temperature. Additionally, water temperature and turbidity suggested relationships to dissolved $O_{2.}$ Water temperature sets the 100% saturation level of O_2 in water, and turbidity is a major predictor of O_2 demand. Beaver ponds create localized areas of O_2 depletion, but as a whole, the river showed only about a 2 mg/l improvement of O_2 levels after beaver dam removal. Following dam removal, streams were quite varied from 1982 through 1986.

Based on the numbers found in this study, it would seem that air temperature was the most important element in controlling trout habitat and the removal of beaver dams only resulted in about a 2°C cooling across the study area. At no time during data collection did water temperature exceed 25°C. Only five locations had recorded temperatures in excess of 20°C in 1982. In 1983, eleven locations had recorded temperatures over 20°C and three locations in 1986 recorded similar findings. This supports this studies work, since in 1983 the summer months were the warmest recorded during the study, and in1984 and 1986 the temperature were slightly warmer than 1982.

Turbidity showed a significant beaver pond relationship. Beaver pond magnified inputs from the watershed as beaver ponds retain much of the sediment washed into the stream and prevents it from being moved throughout the stream. This causes low dissolved O_2 in the beaver pond but the benefit is that it should prevent the material from moving down stream and consuming O_2 there. If less sediment was put into the watershed, less would be retained in the beaver ponds.

This study left many areas to be further investigated. The turbidity dissolved O_2 relationship was not clearly revealed in this study. Another key point noted was trout population fluctuations that could not be directly linked to any of these physical/chemical results. The trout samples in the study were obtained almost three months before or after water conditions were sampled for physical and chemical characteristics. Water conditions can change drastically, even week to week. It was not safe to assume the conditions, when the population counts were made, were similar to the water quality characteristics at the time water samples were collected.

If a study of this scale was repeated, two major things could facilitate better understanding. First, prior to the beaver dam removal, the collection of water quality data should be collected for more than one year prior to establish a better baseline. Secondly collections of trout population abundance and water quality should occur at the same time, or at least within two weeks of each other, to more accurately gauge animal to habitat interaction.

A final point is that GIS can be used effectively to facilitate a better spatial model to mark sample points in beaver ponds and on streams. This would facilitate a better comparison of beaver pond to no beaver pond stream segments and more effectively document streams conditions with beavers present.

Acknowledgements

I would like to thank the many people involved in helping with this study. First thanks to Mr. Terry Lee from the Olmsted County Environmental Services for generating the idea and the need for the project. Also, he provided the information needed to gain an understanding and to grasp what needed to be done. I would like to thank the Saint Mary's Department of Resource Analysis staff: Dr. David McConville, Mr. John Ebert, and Mr. Patrick Thorsell; each for his help to finish the different elements of the project as well as encouraging me along the way. I would also like to thank Mr. Tex Hawkins for constant enthusiasm for the project and providing insight and contacts. I would like to thank the RA community of students who provided me with new ideas and encouragement to finish. Finally, I want to thank my family and friends who supported me and shared my frustrations and joys while working on this project.

References

Anonymous. 2008a. United States Census Bureau. Marinette County Census Data. Retrieved September, 2008 from http://www.census.gov/.

Anonymous. 2008b. Marinette County Government Website. Retrieved September, 2008 from www.marinettecounty.com.

Anonymous. 2008c. National Map Seamless Map Server. United States Geologic Service. Retrieved May, 2008 from http://seamless.usgs.gov/.

Avery, E. 1992. Effect of Removing BeaverDams Upon a Northern Wisconsin Brook Trout Stream. Bureau of Research Fish Research Section.

Avery, E. 2004. A Compendium of 58 Trout Stream Habitat Development Evaluations in Wisconsin–1985-2000. Bureau of Research Fish Research Section.

Collen, P. and Gibson, R. J. 2001. The general ecology of beavers, as related to their influence on stream ecosystems and riparian habitats, and the subsequent effects on fish – a review. *Review in Fish Biology and Fisheries vol. 10*. pp. 439 – 461.

Deas, M. L. and Orlob, G. T. 1999. Biological Oxygen Demand. Retrieved September, 2008 from www.krisweb.com/stream/do.htm.

McRae, G. and Edwards, C. 1994. Thermal Characteristics of Wisconsin Headwater Streams Occupied by Beaver: Implications for Brook Trout Habitat. *American Fisheries Society.* pp. 641-656.

Outwater, A. 1996. *Water a Natural History*. BasicBooks, 10 East 53rd Street, New York, NY, 10022-5299.

WIDNR. 2008. Wisconsin Department of Natural Resources. Wisconsin DNR Website. Retrieved September, 2008 from http://dnr.wi. gov/fish/.