POTENTIAL URBAN IMPACTS ON WATER QUALITY OF

THE RED RIVER OF THE NORTH

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The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of
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ABSTRACT

Ivashchenko, Anna, M.S., Natural Resource Management Department, North Dakota State University, September 2009. Potential Urban Impacts on Water Quality of the Red River of the North. Major Professor: Dr. Jay Leitch.

The Fargo-Moorhead (F-M) area, located along the Red River of the North (RR), is a rapidly developing metropolitan region. The water resources of the RR are intensively used for socio-economic and aesthetic purposes of residents. Although traditionally the RR is perceived to be clean, development of the metropolitan area may negatively impact the water quality. In order to assess this impact, analysis of the water quality parameters (including ammonia, conductivity, dissolved oxygen, fecal coliforms, nitrate-nitrite, phosphorus, salinity, total solids, transparency, and turbidity), taken at four sampling locations along the RR was made. Variation of the water quality measurements over sampling locations, potential human-induced water quality problem; and inter-connections between natural processes and water quality problems associated with the urban pollution were determined.

Based on the analysis of 15 parameters in the RR water upstream, within the city, and downstream from the F-M area, it is concluded that the urban area impacts the water quality of RR and potential sources that contributes to water quality differences over the monitoring sites vary. Significant variation of parameters over the sampling sites is found for conductivity, fecal coliform, phosphorus, salinity and TDS water quality measurements.

The result of this study is a broader understanding of the water quality problems, which will allow directing further efforts for more thorough study of the urban impact on the water quality of the RR utilizing monitoring data and other available data from different sources.

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1. INTRODUCTION

The Red River of the North (RR) has great value for the economic and community development in the Red River Valley where water resources are limited (Stoner et.al., 1998). In particular, the largest urban area, namely the Fargo-Moorhead area (the F-M area) is one of the few communities that obtain water directly from the river (Krenz and Leitch, 1993). Thus, water quality and quantity of the RR is a limiting factor for the F-M residents as an important socio-economic, recreational, and environmental resource.

Although traditionally the RR water is perceived to be clean, the rapid development of the metropolitan area may negatively impact the water quality. To investigate the potential affects, monitoring of water quality should be conducted. Water quality monitoring provides the understanding of the water quality problems associated with human activities; and this is the first step that should be taken in order to improve water quality of the water ecosystem (Lee et.al., 1982). Monitoring can provide valuable information about changes in water quality and may foster water quality improvement. Monitoring helps direct efforts of different stakeholders, including governmental and non-governmental agencies, industries, and communities and provides effective and efficient solutions to water quality problems.

In August 2001, River Keepers[1] started independent water quality monitoring of the RR. Since the main objective of this monitoring is to investigate potential urban impacts to the RR, three sampling locations along the river were chosen: upstream, within, and downstream from the F-M area (Holland, 2001).

[1] River Keepers is a non-profit non-governmental organization established in 1990 to protect and preserve the integrity and natural environment of the Red River of the North in the Fargo.

An analysis of the data provided by River Keepers may help understand potential impacts to the quality of the water as this water travels through the urban area. This analysis could provide insights into the relationships among seasons, urban land use, storm water runoff, and aquatic ecosystems. Furthermore, these insights could assist decision makers in management changes that could enhance the benefits from the RR.

Need for Study: The goal of this study is to provide a broad understanding of the water quality of the RR and to address changes in water quality as this water travels through the F-M area. Among the study objectives are: analyses of the in-field and lab monitoring data, identification of variation of the water quality measurements over sampling locations, assessing potential human-induced water quality problems; and finding out inter-connections between natural processes and water quality problems associated with the urban pollution.

Scope of Study: The study includes analyses of 15 water quality parameters taken from four sampling locations along the RR from August, 2001 through November, 2008. Data are provided by River Keepers.

2. BACKGROUND

2.1. Description of the Red River of the North

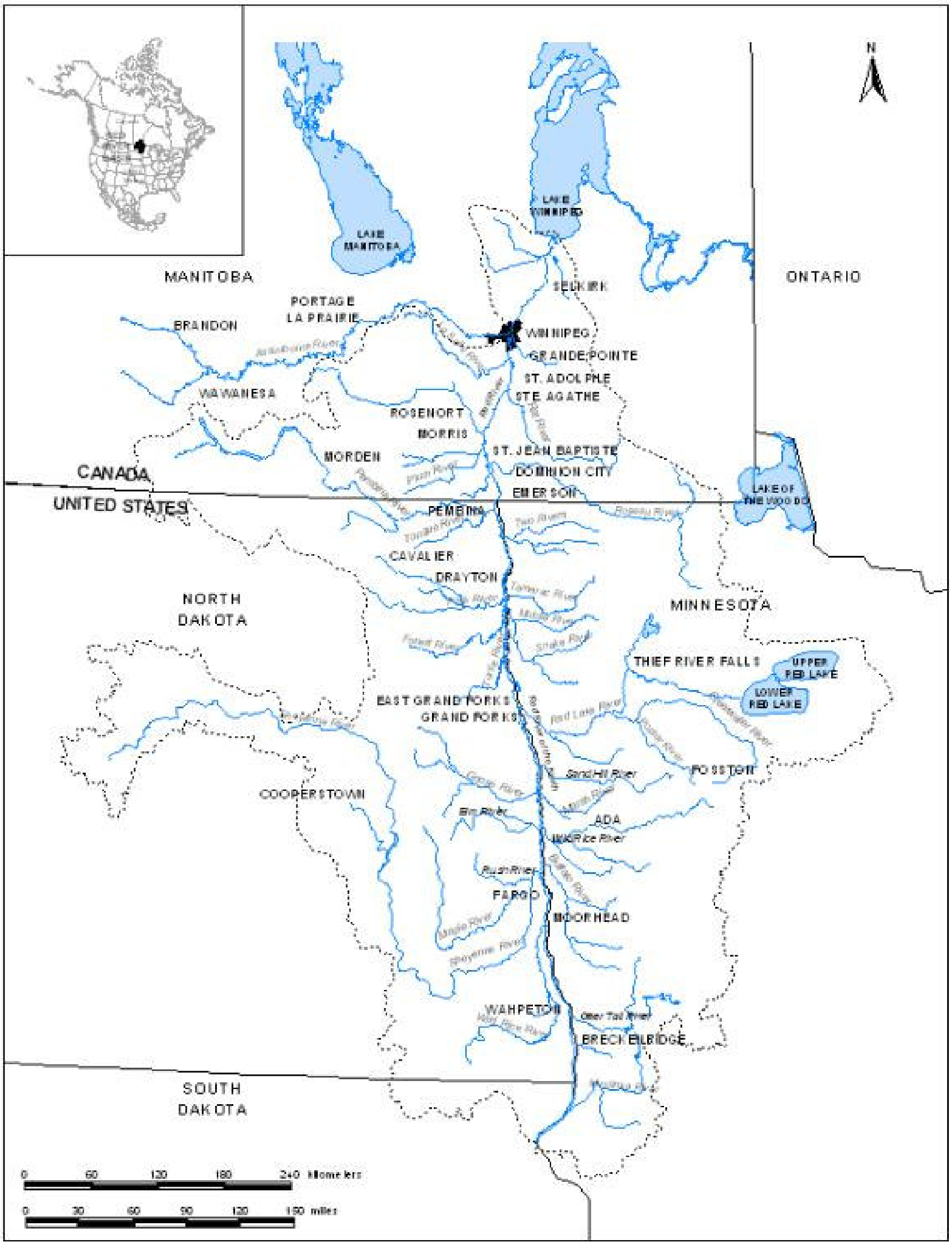
The RR is located in the north-central plains of the United States. It begins at the junction of the Otter Tail and Bois de Sioux rivers at Breckenridge, Minnesota and flows northward 885 kilometers (550 miles) to Lake Winnipeg in Canada (Benke, 2005). The distance from Breckenridge, Minnesota to the United States-Canada border is 635 kilometers (394 miles) where the RR forms most of the border between Minnesota and North Dakota (Emerson, 2005).

The Red River Basin (Figure 2.1) is an area of approximately 116,550 square kilometers (45,000 square miles) (Krenz and Leitch, 1993). Parts of South Dakota, North Dakota, and Minnesota in the United States, and parts of Saskatchewan and Manitoba in Canada are drained by the RR. The flat portions of the Red River Basin called the Red River Valley are located in the center of the region and were caused by sediment deposition from an ancient glacial lake, Lake Agassiz, that existed 7,000 to 12,000 years ago (Macek-Rowland and Dessler, 2002).

The RR is among few rivers in the United States that flow directly north. The headwater of the river is relatively flat and the river channel is shallow (Macek-Rowland, 2001). The unique topography and shallow river channel contributes to the frequently experienced flooding problems (Macek-Rowland, 2001, Red River Basin, 2009).

The streamflow of the RR is composed from ground water seepage and runoff from within the Red River Basin (Macek-Rowland and Dessler, 2002, p. 5). Flow varies over seasons and along the river. The RR daily average discharge at Fargo, ND, ranges from 0 cubic feet per second (cfs) in August-October months of 1933-1937 to 27,800 cfs in April, 1997 and 29,200 cfs in April, 2009 (based on Emerson and Dressler, 2002 and USGS, 2009 data).

Figure 2.1 Red River Basin Map (at NWRDC, 2009)



The RR, because of the predominantly clay soils, has a turbid appearance. Visibility of the water in the RR increases in the winter period (MN DNR, 2009). The climate of the RR is continental and characterized by short summers (mean air temperature is 20 ^{o}C (68 F) in July) and long winters (mean air temperature -18 ^{o}C (0 F) in January) (Benke, 2005). Mean annual precipitation ranges from 43 centimeters (17 inches) in the western part of the basin (Figure 2.1) to 65 centimeters (26 inches) in the east (Stoner, et al., 1993).

The RR plays a crucial role in population growth and economic development and is an important hydrologic resource in the region where the water resources are valuable for the region's economic and agricultural development (Stoner et.al., 1998). For the community development, the RR provides access to water and recreational resources. For this reason the quantity and quality of the water is an important factor for the population that resides along the RR. In addition, as an international and multi-jurisdictional river (Krenz and Leitch, 1993), water quality of the RR is also of international value and concern.

2.2. Water Quality and Urban Impact

Over 80% of the surrounding land in its basin is used for agricultural production (Lorenz and Stoner, 1996). Although water runoff from agricultural land into the RR is an issue of great concern, urban sprawl is also becoming an acute problem for the river's water quality.

Urbanization encompasses diverse changes of the stream that influence its physical, chemical, and biological characteristics (Booth and Bledsoe, 2009). So called "urban stream syndrome" (Walsh et.al., 2005) can promote changes in hydrology, water chemistry, channel morphology, organic matter, fishes, inverterbrates, and algae. The combination of different urban imposed alterations affects water quality of the stream ecosystem.

However, the status of water quality in the river is difficult to assess because of the complexity of pollution from a combination of point and non-point sources of pollution (Duda et al., 1982). Among point sources are treated effluents discharged from sewage treatment plants and industrial plant discharges (Pollution Issues, 2007). Nonpoint sources of pollution are: untreated effluents that bypass sewage treatment plants, runoff from storms in urban areas, combined sewer overflows that carry a mixture of untreated sewage and storm water, erosion of soil from construction sites, and ground water discharges to adjacent receiving waters (Sartor et. al., 1974; The Impact of Urban Development on Water Quality, 2009, Baker, 2009).

The RR flows through several urban areas along its path including the cities of Fargo, North Dakota and Moorhead, Minnesota (the F-M area). Based on the total population, the F-M area is the second rated residential area along the river and is the largest and most rapidly developing urban area in the Red River Valley (Stoner et.al., 1998). According to Census (2009), the estimated population in the F-M area was 195,685 people in July, 2008, an increase of 11% from 2000.

Increasing urban development also means an increase in the use of water resources. The F-M area is one of the few municipalities that obtain water directly from the river; most other cities retrieve water from groundwater sources (Krenz and Leitch, 1993). However, urban impacts are not only limited to water use, but also may decrease stream water quality. Thus, the expansion of the F-M area may negatively effect water quality of the RR. The potential point and non-point sources of pollution in the F-M area are water and wastewater treatment plants of Fargo, ND and Moorhead, MN, runoffs from residential areas, animal manures and others. However, traditionally the water of the RR is considered relatively clean. As reported by Hickel (1969), the water quality in the RR varies from good to excellent (p.52). Main sources of pollution are municipal, industrial wastes and irrigation return flow; and in the east, drainage from farmland and feedlots are an acute problem of water pollution (Hickel, 1969). In 1988, USGS stated that the RR was one of the cleanest rivers in the nation, based on the relatively low levels of surface pollutants.

Based on the assessment of water quality conditions in 1992-1995, the USGS report of 1998 (Stoner et.al., pp.3-7) concluded that water in the RR was generally safe to drink when unaffected by human activities. Concentrations of all the pollutants, including pesticides and nutrients, did not exceed U.S. EPA standards. According to the USGS report (1998), municipal wastewaters have a minimal effect on the river's quality (Stoner et.al., 1998, pp.3). However, ammonia concentrations were slightly increased downstream from the F-M area, but were diluted by river and tributary flows.

Despite the reported relatively high water quality of the RR, the Lake Winnipeg Implementation Committee (2005) states that the RR flood in 1997 resulted in the highest recorded nutrient levels in Lake Winnipeg to date. The Manitoba Water Stewardship Board (2006) associates nutrient pollution of Lake Winnipeg with increasing phosphorus and nitrogen levels in the RR. Although the causes of increased concentrations of nutrients need to be identified, the increases may be the result of increasing urban development and thus increased runoff from urban areas along the RR.

2.3. Monitoring of Stream Water Quality

Regular and periodic monitoring of water quality helps to understand changes and problems in the river's water and is essential in developing effective and efficient water management plans. According to Ellis and Lacey (1980) (in Parr, 1994), some objectives of water quality monitoring are: (1) identification of abnormal concentrations and defining peaks; (2) estimation of mean concentration; (3) investigation of trend or change; (4) monitoring of compliance; and (5) building up the picture of the process, and others.

In the United States, water monitoring is conducted by state, federal, and local agencies, universities, dischargers, and volunteers (EPA, 2009). Water quality parameters that are measured vary depending on the currently obtained water monitoring strategy. However, to achieve a comprehensive study of stream water quality, physical, chemical, and biological parameters have to be determined. As U.S. EPA (1997) states, the combination of these measurements is the "beginning to understanding how land uses in a watershed influence the health of its waterways".

As for the RR, city water treatment plants, wastewater treatment plants, state health departments, and others monitor some of the parameters. However, coordinated monitoring efforts are needed in order to learn about the water quality of the RR. Thus, River Keepers, which is a non-profit organization, started water quality monitoring in October 2001. One of the primary objectives of the River Keeper's river monitoring is to determine changes in conditions of the RR and as a result of the F-M community (River Keepers, 2005).

Essential Water Quality Parameters

The following major characteristics of water quality are useful in the identification of emerging issues as a result of urban impact: ammonia, conductivity, dissolved oxygen (DO) and DO%, fecal coliforms, nitrate-nitrite, pH, phosphorus, salinity, total dissolved solids (TDS), total suspended solids (TSS), water temperature, transparency, and turbidity. Assessing these parameters provides information on the general conditions of the stream and helps to determine if water quality is adequate for aquatic life, drinking, recreation, irrigation and other uses (Murphy, 2007).

Ammonia: Ammonia (NH_3-N) is a colorless gas with a strong odor. It is easily liquefied and solidified and is very soluble in water (Kentuky Water Watch, 2009). Sources of ammonia in water can be natural or anthropogenic, point and nonpoint. Low-level ammonia nitrogen may be present in water naturally as a result of the biological decay of plant and animal matter. Ammonia is also excreted by fish and animals, including humans (FishDoc, 1999-2004). Among anthropogenic sources of ammonia are raw sewage, urban and agricultural runoffs and others (Sawyer, 2008). Ammonia (NH_3-N) is a highly toxic element. However, when dissolved in water, ammonia reacts to form ammonium (NH_4^+) which is less toxic. The dilution of ammonia in water depends on pH levels and water temperature. Ammonia levels increase as pH decreases and as temperature decreases (Wurts, 2009). While plants are more tolerant to ammonia concentrations, even low levels are a threat to fish health (Murphy, 2007)

Conductivity and Specific Conductivity: Conductivity is a measure of the ability of water to pass an electrical current and is an indicator of the purity of water or the concentration of ionized chemicals in water. Specific conductivity adjusts the conductivity to what it would be if the water temperature were 25^0C (Nexsen, 2000-2009). Conductivity depends on many factors, including geology, precipitation, surface runoff, and evaporation (Michaud, 1991). Increasing conductivity indicates increased concentration of total dissolved solids and salinity, namely inorganic matter in the stream (EPA, 2009). Moreover, as conductivity increases, the potential of water to hold oxygen decreases.

Dissolved Oxygen and DO%: Dissolved oxygen (DO) is the measurement of the amount of gaseous oxygen (O_2) dissolved in the water, and DO% is the ratio of the dissolved oxygen content to the potential capacity of the water to hold oxygen. The stream ecosystem both produces and consumes oxygen (Addy and Green, 1997). Water gains oxygen from the atmosphere and aquatic plants. Decrease of DO can be a natural or man-induced process. In water ecosystems, DO is also decreased when there is a biological demand for oxygen (BOD), such as for the decomposition of grass clippings or leaves in the water. There is also a direct, inverse relationship between water temperature and gas saturation—cold water can hold more of any gas, including oxygen (Water on the Web, 2007). Human imposed decrease in DO levels may include additions of wastewater from sewage treatment plants, and oxygen consuming wastes from water runoff from farmland, urban streets, and feedlots (EPA, 2009). Oxygen is needed by all algae and other aquatic dwellers for many chemical reactions that are important to water ecosystem functioning. Lowered DO concentrations in water may induce fish kills.

Fecal Coliform: Coliform bacteria are mostly harmless bacteria that live in soil, water, and the digestive system of animals (WSDOH, 2007). Fecal coliform (FC), which belong to the family *enterobacteriaceae*, are present in large numbers in the feces and intestinal tracts of humans and other warm-blooded animals, and can enter water bodies from human and animal waste (Murphy, 2007). There are both point and non-point sources of FCs in surface water. Human sources of fecal contamination are municipal wastewater, septic systems, domestic animal manure, and storm runoff from urban and suburban areas. Wild animals, such as geese, deer, and turkeys, may contribute to FC levels (EPA, n.d). If a large number of fecal coliform bacteria (over 200 colonies/100 milliliters (ml) of water sample) are found in water, it is possible that pathogenic organisms are also present in the water (Murphy, 2007). Fecal coliform by themselves are usually not pathogenic; they are indicator organisms, which means they may indicate the presence of other pathogenic bacteria (WSDOH, 2007). Besides indication of the presence of other pathogenic microorganisms, FCs cause cloudy water, an unpleasant odor, and lower DO levels (Murphy, 2007).

Nitrogen and Phosphorus: Phosphorus and nitrogen are essential nutrients for plants and animals but their excess concentration could also be harmful for the ecosystem (EPA, Water Quality Criteria for Nitrogen and Phosphorus Pollution, 2009). There are both natural human, point, and non-point sources of phosphorus and nitrogen pollution. However, Bogestrand (2003) states that urban wastewater is one of the most important contributors to phosphorus discharges and to a lesser extent nitrogen. Among other sources of these nutrients are runoff from excessive cropland and residential fertilizer applications, runoff from animal feedlot or manure storage areas, and discharges from water treatment plants (Howarth et.al., 2000). U.S. EPA (2009) reports that nutrient pollution, especially from nitrogen and phosphorus, is one of the top causes of U.S. water degradation. Excessive nutrients may results in algal bloom, hypoxia, and decrease of wildlife habitat.

pH: pH indicates a sample's acidity, but is actually a measurement of the potential activity of hydrogen ions ($H+$) in a sample. It is presented on a scale from 0 to 14 and is one of the most important indicators that determine patterns of chemical and biological processes in the water (Why pH Is Important, 2009). pH changes can be caused with urban run-offs, acidic precipitation, agricultural run-offs, wastewater discharge or types of soil and ground waters (Mesner, N. and Geiger J., 2005). Optimal range of pH for most of the aquatic animals is from 6.5 to 8.0 (EPA, Monitoring and Assessing Water Quality, n.d) and even slight changes in pH could affect normal development of the stream. Depending on the pH level, chemical processes and toxicity of water may change (Sharpe, 2009). If acidity increases (pH decreases), water ecosystem experiences chemical and biological alterations, including decrease of biodiversity, fish kills and other. Increased alkalinity (pH increase) may cause release of metals from the stream sediments (Murphy, 2007).

Total Dissolved Solids and Salinity: The concentration of total dissolved solids (TDS) is a measure of the amount of organic or inorganic particulate matters that do not pass through 0.45 μm filter (Weiner, 2008). This material can include organic salts and inorganic salts such as carbonate, bicarbonate, chloride, sulfate and other (Murphy, 2007). On the contrary, salinity is an estimation of inorganic salts in water (AppsLaboritories, 2009). Sources of TDS and increased salinity include sewage, urban run-off, industrial wastewater, and chemicals used in the water treatment process. There are also natural sources that cause TDS/salinity increase such as the release of ions from rocks and soils (Murphy, 2007).

The presence of TDS in the water is necessary for the water balance in the cells of aquatic organisms (EPA, Monitoring and Assessing Water Quality, n.d). However, excessive concentrations may also negatively influence the development of the water ecosystem in general. Increases of both TDS and salinity usually increase conductivity. Other impacts of increased salinity and TDS are a decrease in water clarity which may lead to slowing of photosynthesis by aquatic plants and an increase in water temperature which may result in a decrease of DO in the water.

Water Temperature: Water temperature is a common and widely used physical characteristic of water quality that governs the types of aquatic life found in bodies of water (WQI, 2009). The temperature of water controls the rate of metabolic and reproductive activities, and determines which aquatic species can survive (Murphy, 2007). Temperature also affects the concentration of dissolved oxygen and can influence the activity of bacteria and toxic chemicals in water (Weiner, 2008). Variations in stream temperature can occur because of changing air temperature and natural or human-induced alterations in physical, biological, and chemical processes in the water (Water Encyclopedia, 2007).

Total Suspended Solids, Turbidity, and Transparency Tube: Total suspended solids (TSS) are solids in water that can be trapped by a 0.45 μm filter (Weiner, 2008). Total suspended solids can include a wide variety of material, such as silt, decaying plant and animal matter, industrial wastes, and sewage (Murphy, 2007). TSS together with TDS influence the clarity of water which is measured by either turbidity or transparency (Weiner, 2008). Turbidity is a measure of water clarity affecting water color and influencing water temperature. On the contrary, transparency is an inverse relationship to turbidity and is another indicator of water clarity (Sovell, 2009).

High levels of turbidity (low transparency) negatively affect aquatic organisms as depth of sunlight is restricted. Chronically high turbidity levels may cause fish kills (Murphy, 2007). Higher turbidity/low transparency also causes an increase of water temperature because of the higher potential of water to absorb solar energy. As a result, other physical, chemical, and biological changes may occur in a water ecosystem (based on EPA, 2009)

2.4. Water Quality Standards

Because of its international value, the RR Basin has a number of institutions involved in water management. According to Hearne (2007), the RR water management is represented by three sets of water law: (1) Minnesota's water law that is based upon riparian rights; (2) North Dakota's water law that is based upon prior appropriation, and (3) Manitoba system of water allocation that features provincial control. Water quality goals are set by the U.S. Environmental Protection Agency (U.S. EPA), Province of Manitoba water quality criteria regulations, and International RR Board (RRBC, 2009). In this study, the ND standards for water quality parameters for the class I streams were mainly used excluding standards for TDS and TSS (Table 2.1) (NDDOH, 2001).

Table 2.1 Water quality standards

Measurement	**ND Department of Health**
Ammonia	Is calculated depending on pH and season[1]
Conductivity and Specific Conductivity	–
DO	Not less 5 mg/L
Fecal Coliform	200 CFU/100ml
Phosphorus	0.1 mg/L
Nitrate-Nitrite	1 mg/L
pH	6.5-8.0
Salinity	–
TDS	500 mg/L for drinking water
Transparency Tube	–
TSS	100 mg/L limit of discharge
Turbidity	–

[1] Standards of quality for waters of the state. (2001). Published by ND Department of Health (p.11)

3. METHODS AND PROCEDURES

Water samples were collected approximately twice a month mainly during April-October between October of 2001 and October of 2008. These field measurements were taken by River Keepers and are available at the FM River Water Quality website: http://www.undeerc.org/watman/FMRiver/index.html (2009).

Water samples were collected at three locations (see Figure 3.1.): upstream from the F-M area (R1 site), within the city (R2), and downstream from the F-M area (R6). In order to investigate the potential impact of the tributaries on the main stream, the sampling of the Wild Rice River was made prior to its flow into the RR (T1) (Table 3.1).

Table 3.1 Monitoring site location (based on FM River, 2009)

Water Category	Monitoring Site	Location
River Water	R1	Bridge over the RR on Clay County Road 8
	R2	Bridge over the RR on 1^{st} Avenue North of the F-M area
	R6	Bridge over the RR on Clay County Road 22
Tributary Water	T1	Bridge over the Wild Rice River on Cass County Road 14

Water quality parameters and methods that were used for the sampling analysis are presented in Table 3.2 (based on Holland, n.d.). If not measured with the DO meter, analysis methods are approved by the U.S. EPA.

Figure 3.1 Monitoring site map

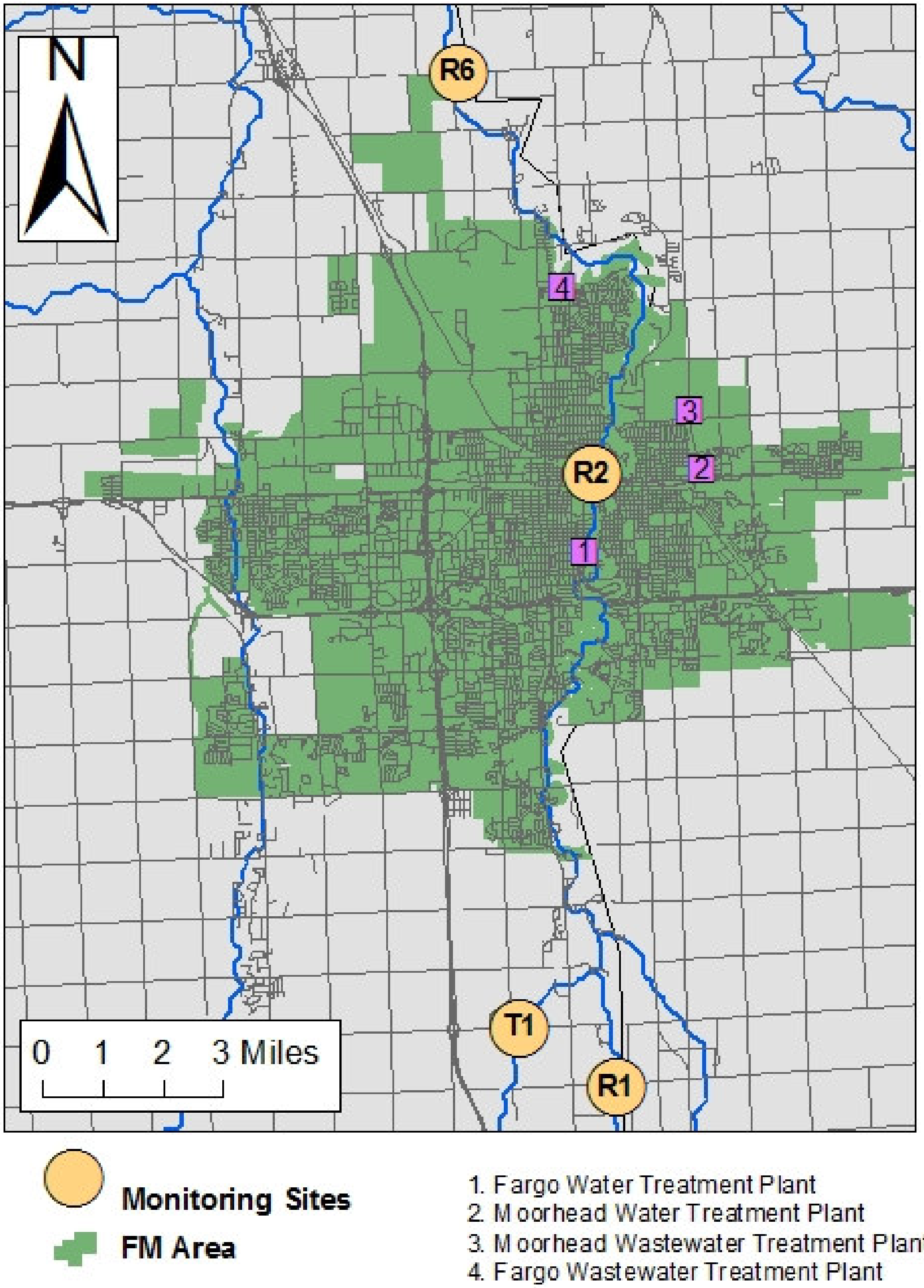


Table 3.2 Water quality parameter and sample analysis methods

#	Parameter	Units	Method[1]
1	Ammonia	mg/L NH3-N	SM 8038
2	Conductivity	µS/cm	SM 2510B
3	DO	mg/L	DO meter
4	DO%	%	DO meter
5	Fecal Coliform	CFU/100ml	SM 9222D
6	Nitrate-Nitrite	mg/L N	EPA 300.0
7	pH	pH	SM 4500-H B
8	Phosphorus	mg/L	Hach 8190
9	Salinity	ppt	DO meter
10	Specific Conductivity	µS/cm	DO meter
11	TDS Gravimetric	mg/L	SM 2540C
12	Water Temperature	ºC	DO meter
13	Transparency Tube	cm	Transparency Tube
14	TSS Gravimetric	mg/L	SM 2540D
15	Turbidity	NTU	EPA 180.1

[1] The DO meter is YSI 650 MDS Multi-Parameter Display System designated for field use

Additional necessary data such as discharge and other data were utilized from the USGS Water Quality Samples for North Dakota website:

http://nwis.waterdata.usgs.gov/nd/nwis/dv/?site_no=05054000&agency_cd=USGS&r

eferred_module=sw (2009). These data were identified and a suggestion is made for extending the present analysis using an expanded data set.

The objective of the study was to investigate if the F-M area impacts water quality. Data analyses were done to provide answers to six questions:

1. How have levels of the 15 measurements varied over 2001 to 2008?
2. Do water quality measurements differ over sampling locations, and how?
3. How do Wild Rice River in-flows affect the RR water quality?
4. What other water quality or quantity measurements are available?
5. Could River Keeper's water quality sampling protocol be enhanced and/or made more efficient?
6. Might any other water quality or quantity measurements help to explain notable variations in the 15 water quality measurements?

For comprehensive study of the water quality of the RR and potential urban impacts, the analysis includes:

- Descriptive statistics;
- Various data plots[2] displaying trends in data for each of the measurements independently;
- A t-test significance analysis between sampling sites;
- Correlation analysis and correlation matrices for the measurements; and
- Comparison with historical data.

[2] Trendlines that are depicted on the plots are built using Ms Excel program. No regression analysis was made. Type of the trendline is chosen based on R-squared coefficient which tells how closely trendline follows the data (MS Office online, 2009).

In the study, daily and average monthly data are analyzed. In case no apparent differences between daily and monthly data are determined, average monthly data results are used.

4. STUDY FINDINGS

In this chapter, some of the analyzed parameters are discussed together when they measure essentially the same phenomena, for example, dissolved oxygen and dissolved oxygen % and transparency tube and turbidity. Descriptive statistics of the used data is presented in Appendix A. Correlation analysis is incorporated in the text and the correlation matrices are presented in Appendices C1-C4.

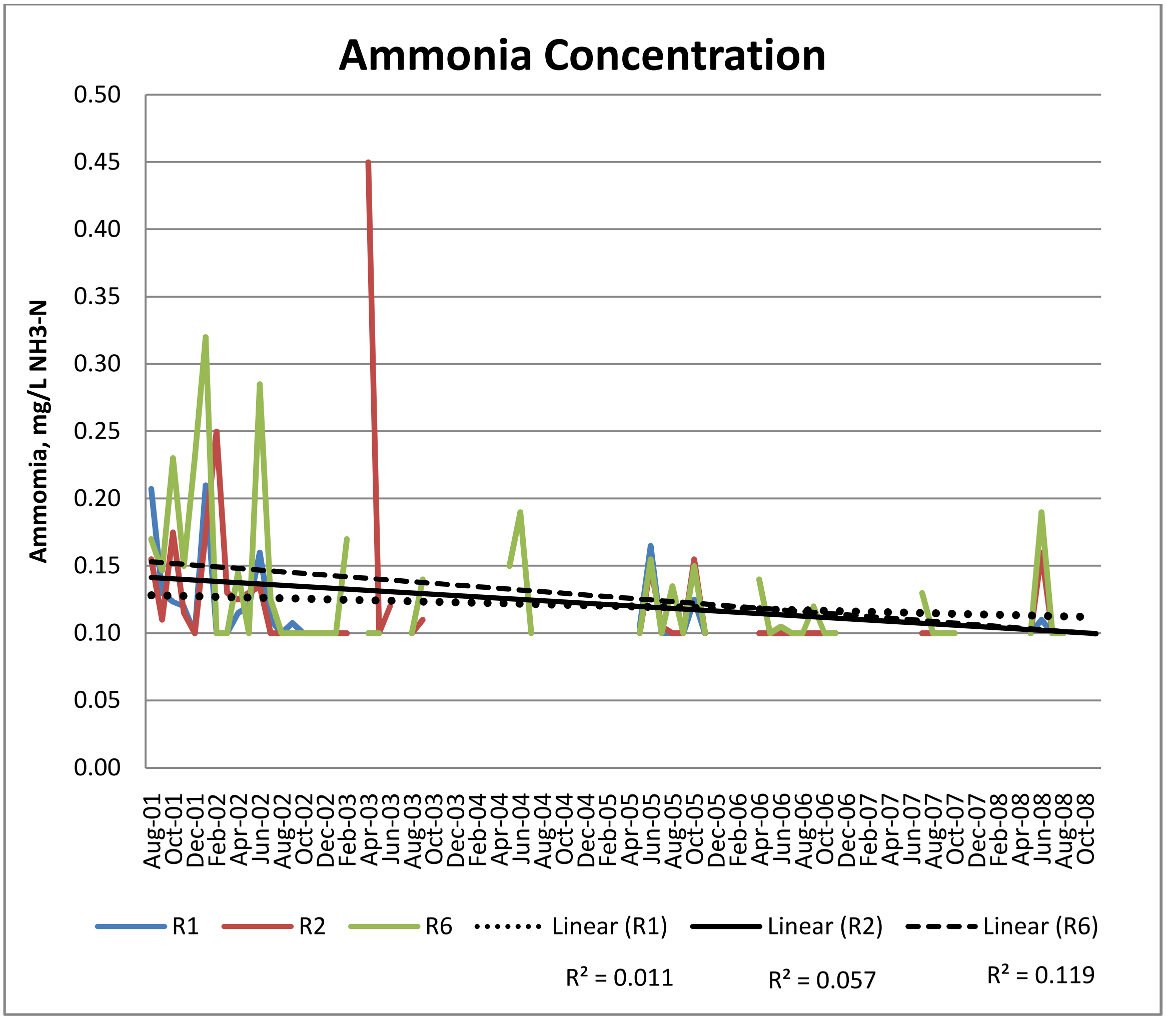
4.1. Main Stream and Urban Impact

Further, results are presented based on whether differences between measurements over sampling locations (Figure 3.1) are found. If difference in concentrations over sampling sites for any of the analyzed parameters was noticed, a t-test analysis of the difference was determined (Appendix B).

No Apparent Impact Found

Ammonia: Although differences in ammonia levels were observed, no repetitive trends of differences in ammonia levels among sites were found (Figure 4.1). Variation in the data may exist because of different possible sources of ammonia in the RR. Specifically, usage of cropland fertilizers may contribute to ammonia at R1, where ammonia concentrations are higher in June. Also, aquatic life and fish contribute to ammonia levels. Due to their mobility, this contribution to total ammonia cannot be easily monitored by location. Therefore, based on this initial analysis of the data on ammonia levels in three locations along the RR, it cannot be concluded that the urban area affects the concentration of ammonia in the RR.

Figure 4.1 Average monthly ammonia concentrations



<u>Dissolved Oxygen and DO%</u>: DO levels at three locations were similar, but they vary over time (Figure 4.2). In 67% of cases, DO concentration is higher at R1 compared to R6. In 58% of cases, DO concentration is higher at R1 compared to R2. However, these differences are not statistically significant. There is a strong correlation (Appendix D) between DO levels and water temperature, as expected, resulting in seasonal changes in DO levels. Winter DO levels are about twice as high as in the summer. There is no strong relationship between DO levels and phosphorus concentration (Figure 4.3) as well as between DO and discharge levels (Figure 4.4).

In general, the urban area does not impact DO levels in the RR. Even though a slight decrease of DO in the stream water can be observed at R1 and R6, there is no evidence on the direct impact of the F-M area on the concentration of DO in RR water. Seasonal decrease of DO levels is caused by water temperature rather than by phosphorus level. DO concentration in the RR water is higher than the North Dakota state water quality standard of not less than 5 mg/L. Even in summer seasons, DO concentration is more than 5 mg/L. However, warm water and low flow may contribute to considerable decrease of the DO levels as observed in June-July each year.

Figure 4.2 Average monthly DO concentrations

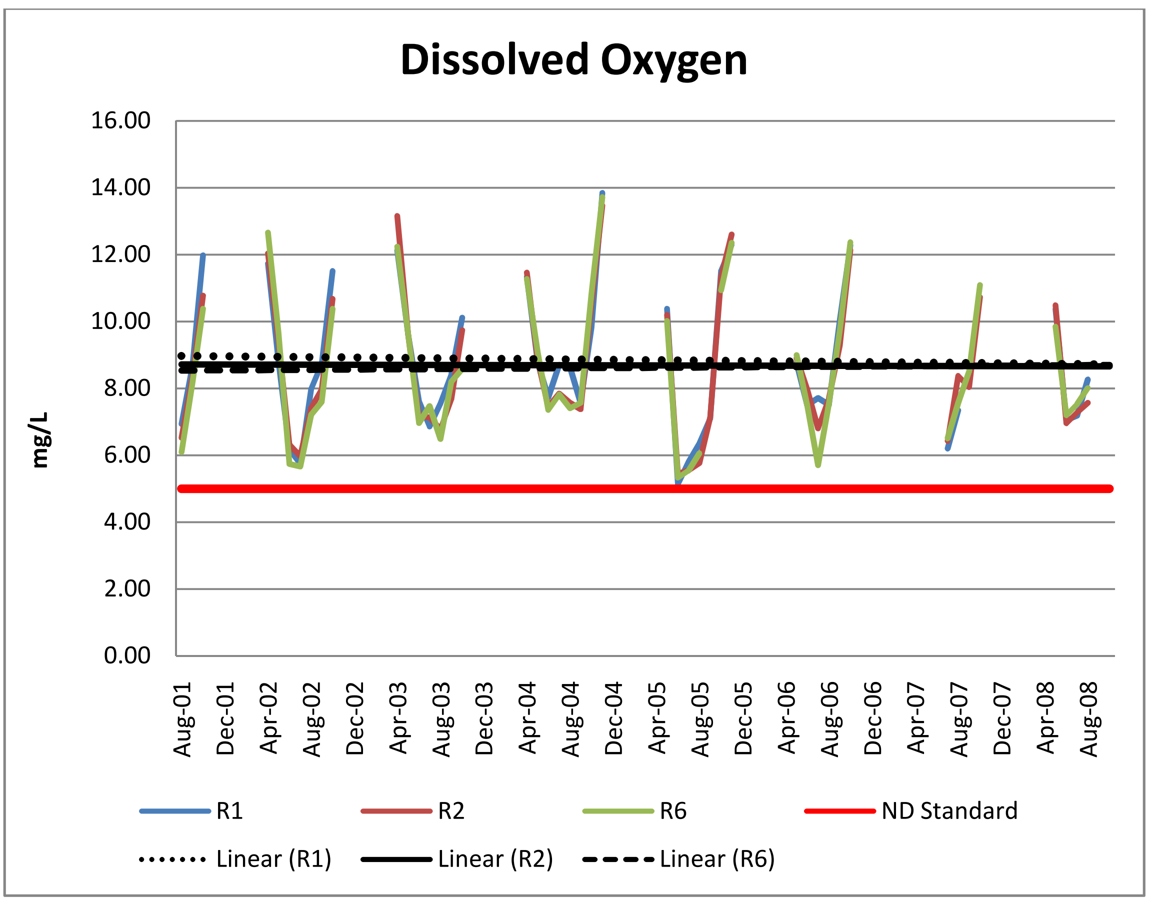


Figure 4.3 DO and phosphorus correlation

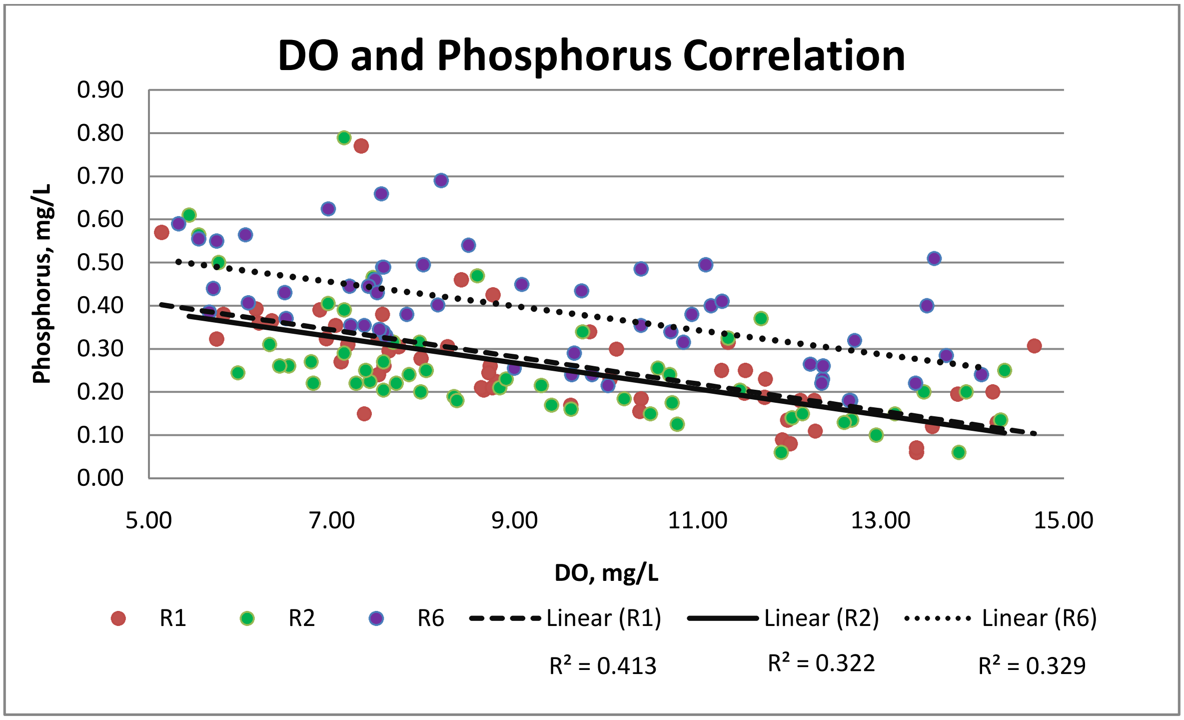
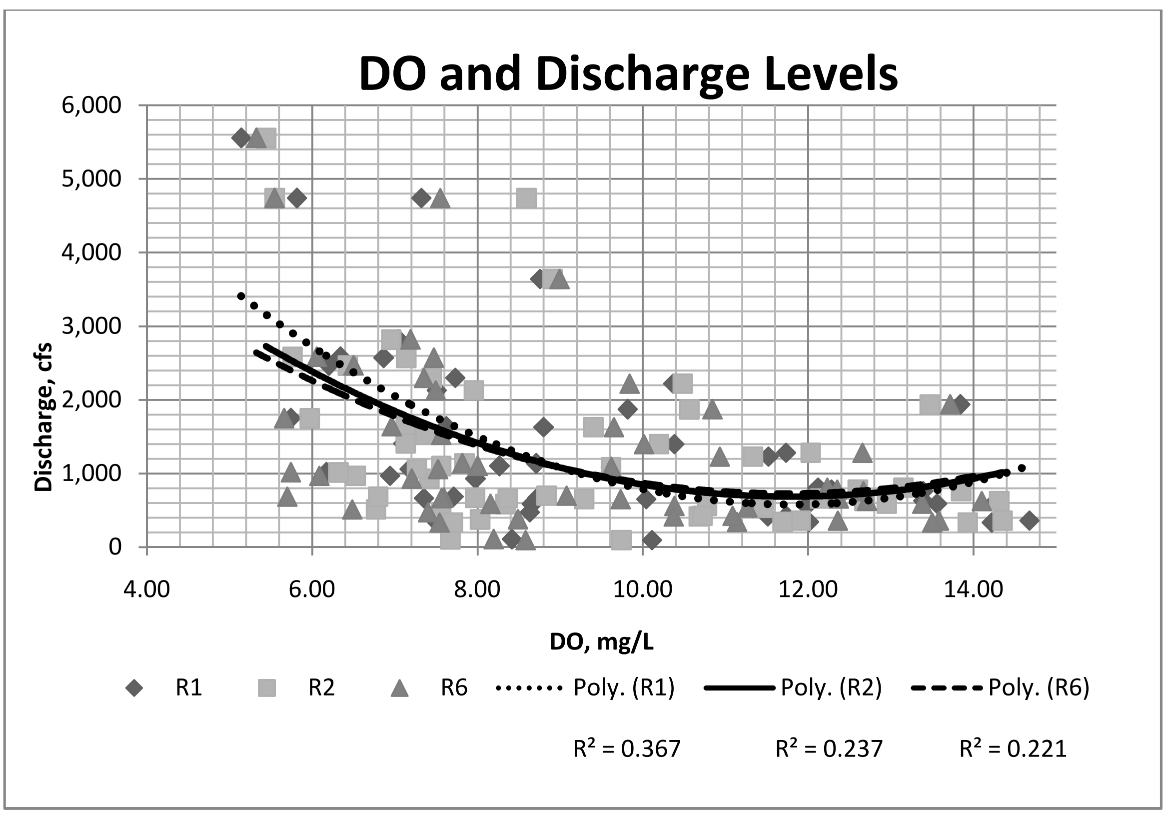


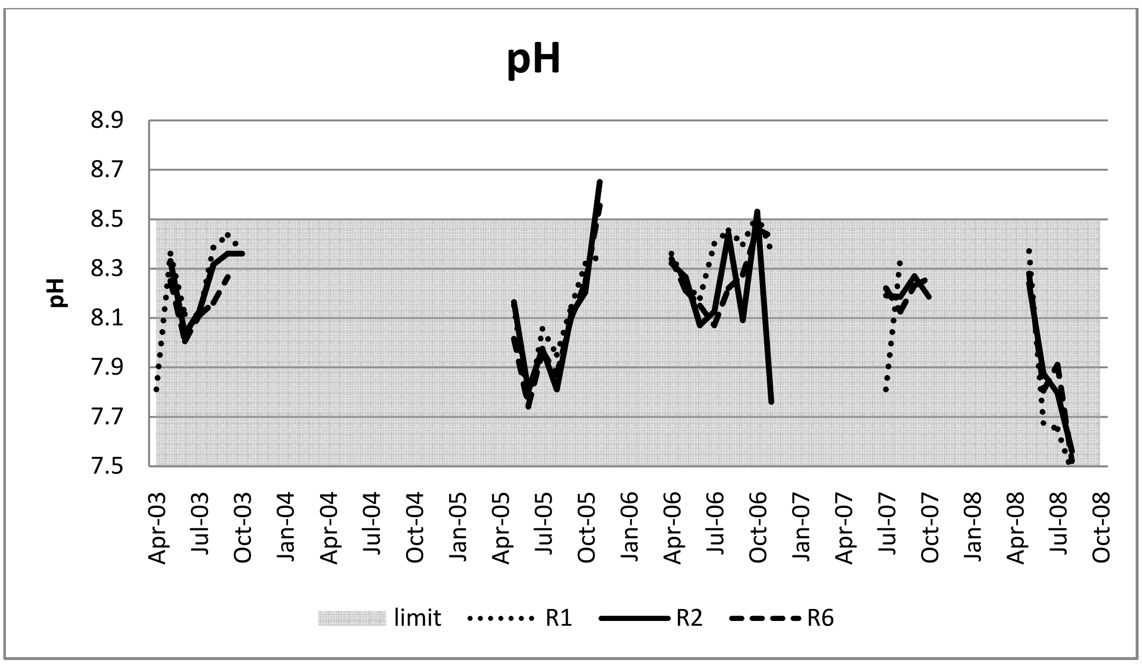
Figure 4.4 Correlation of DO and discharge levels



<u>pH</u>: No significant difference in pH between three sampling locations was determined (Figure 4.5). However, pH levels change seasonally and water becomes more acidic (lower pH) in summer months compared to winter months.

Regarding the difference in pH in each sampling location, the water was more alkaline at R1 and R2 locations compared to R6 site in 71% and 61% of measurements, respectively. pH is also higher at the R1 location compared to the R2 location in 65% of measurements. However, the difference in pH is not considerable and trendlines of pH changes almost coincide. Thus, there is not enough evidence to assume urban impact of the F-M area on pH levels in the RR.

Figure 4.5 Average monthly pH



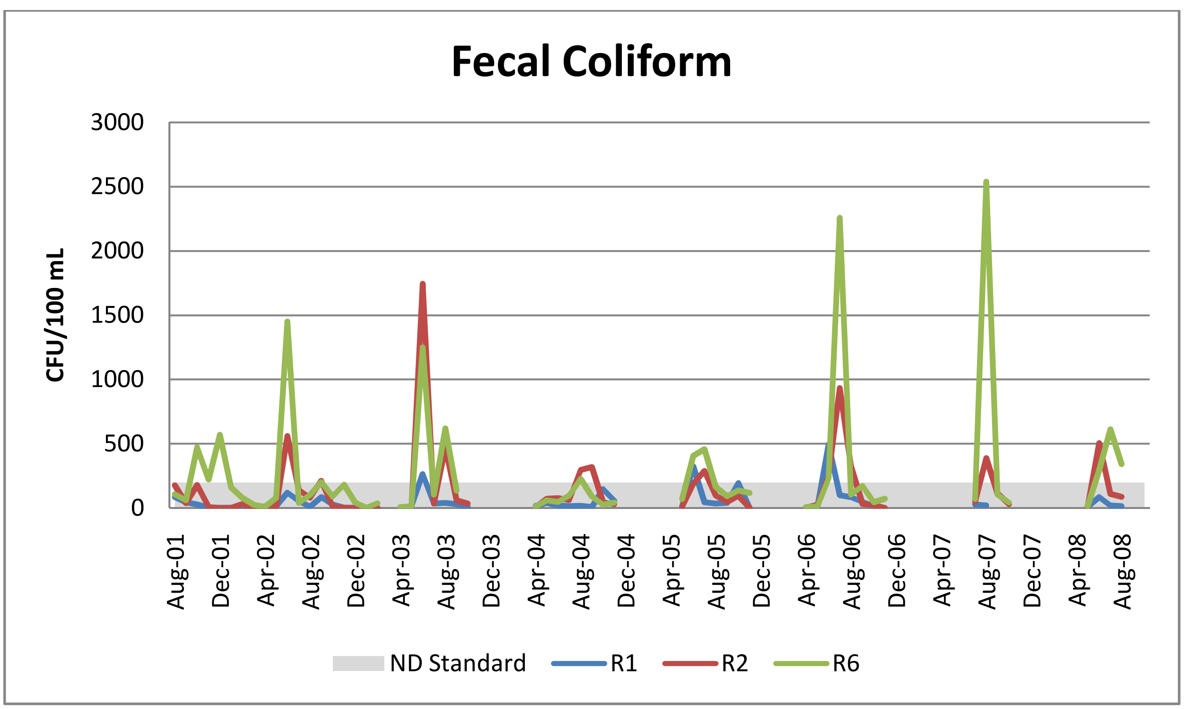
Apparent Urban Impact

For all the measurements where difference over sampling locations was found, a t-test statistical analysis was conducted ($\alpha=0.05$) (see Appendix B).

Fecal Coliform: Fecal coliform (FC) concentrations are considerably higher at R6 throughout the sampling period (see Figure 4.6). Spikes of FC concentrations at R2 also occur, however, they are infrequent. Comparing R1 and R2, R1 and R6, and R2 and R6, concentrations of FCs are higher in 64%, 86%, and 75% of measurements, respectively. According to the t-test, difference in FC levels between R1 and R2, and R1and R6 locations are significant (α=0.05). Therefore, the urban area significantly affects FC concentrations in the RR.

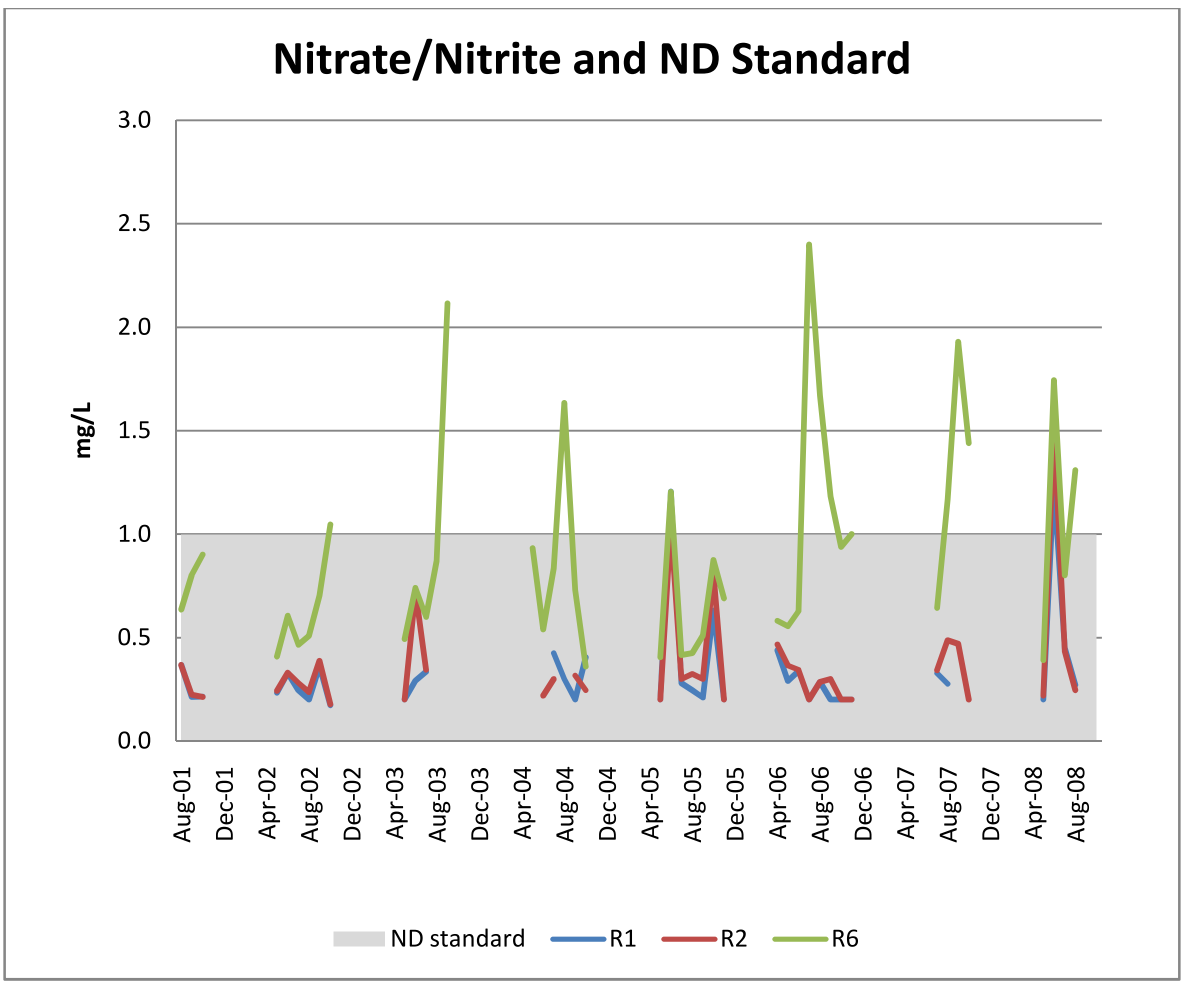
Fecal coliform concentrations vary seasonally, with significantly higher levels of FCs at R2 and R6 in the summer. Seasonal changes of FC concentrations are influenced by increased water temperature, making the aquatic environment more favorable for bacteria development. On average, FC concentrations are within the ND limits (200 CFU/mL) at R1. At R2, and more importantly at R6, the FC concentrations are significantly higher than the state standard.

Figure 4.6 Average monthly concentrations of fecal coliforms



Nitrate/Nitrite: Nitrate/nitrite concentrations differ at all three sampling sites. Levels are significantly higher at R6 than at R1 or R2 (Figure 4.7). However, nitrate/nitrite levels at R1 are higher in 78% of the sample cases than at R2. Most of the spikes in nitrate/nitrite concentration occur in the summer-autumn months. However, the t-test results show that the difference in nitrate/nitrite concentrations is statistically insignificant. Thus, no conclusions on the urban impact on nitrate/nitrite concentration can be made. Nitrate concentration in the RR is within the North Dakota limits (1 mg/L) at R1 and R2, but concentrations do exceed ND limits at R6.

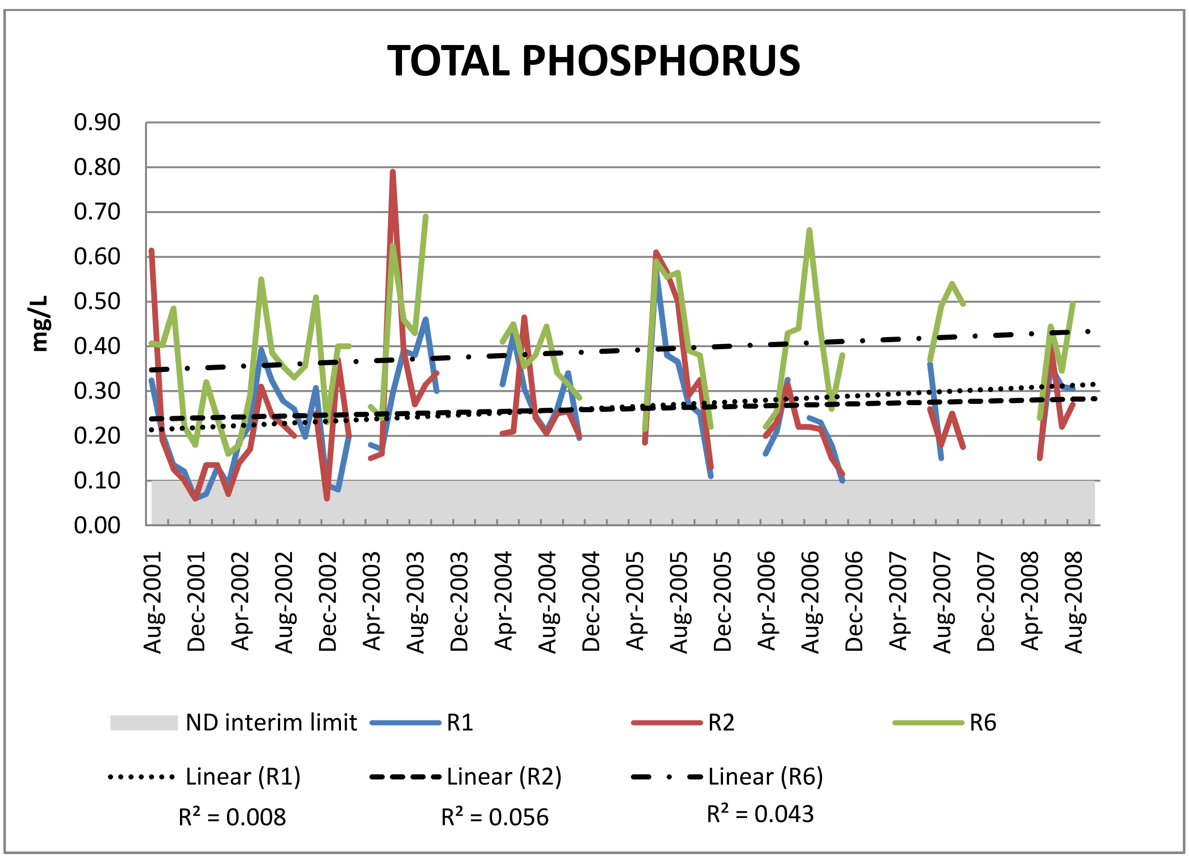
Figure 4.7 Average monthly concentrations of nitrate/nitrite



Phosphorus, total: Levels of phosphorus are significantly higher at R6 than at R1 or R2 (Figure 4.8) in 93% and 89% of measurements, respectively. Concentrations at R1 and R2 vary somewhat but the difference is not consistent. The-t-test result (Appendix B) also shows significance in difference of phosphorus level between R1 and R6, and R2 and R6 locations.

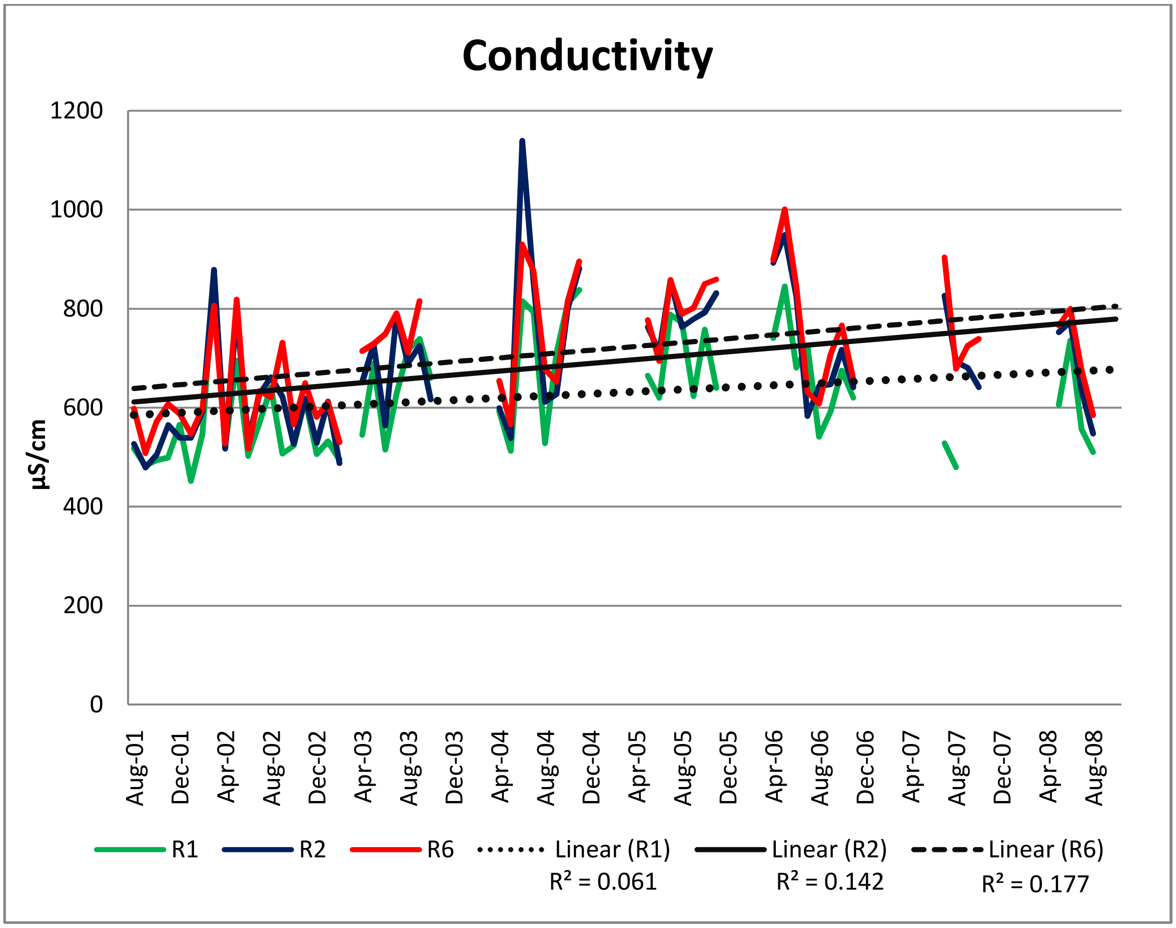
Phosphorus concentrations change seasonally, as expected, possibly due to fertilizer runoff in the summer. Therefore, levels are affected by the urban area, but to discern how and why will take more detailed sampling and analysis. For example, phosphorus was often lower at R2 than R1 (60% of measurements), which could be a result of the Wild Rice inflows. Phosphorus levels usually exceeded the ND Department of Health standard of 0.1 mg/l.

Figure 4.8 Average Monthly Concentrations of Phosphorus



<u>Conductivity/Specific Conductivity</u>: Conductivity is significantly lower at R1 and R2 than at R6 (90% and 83% of sampling cases, respectively) but there is no sustained and apparent difference in conductivity between R1 and R2 (Figure 4.9). However, a statistically significant difference is shown between R1 and R2, and R1 and R6 sites.

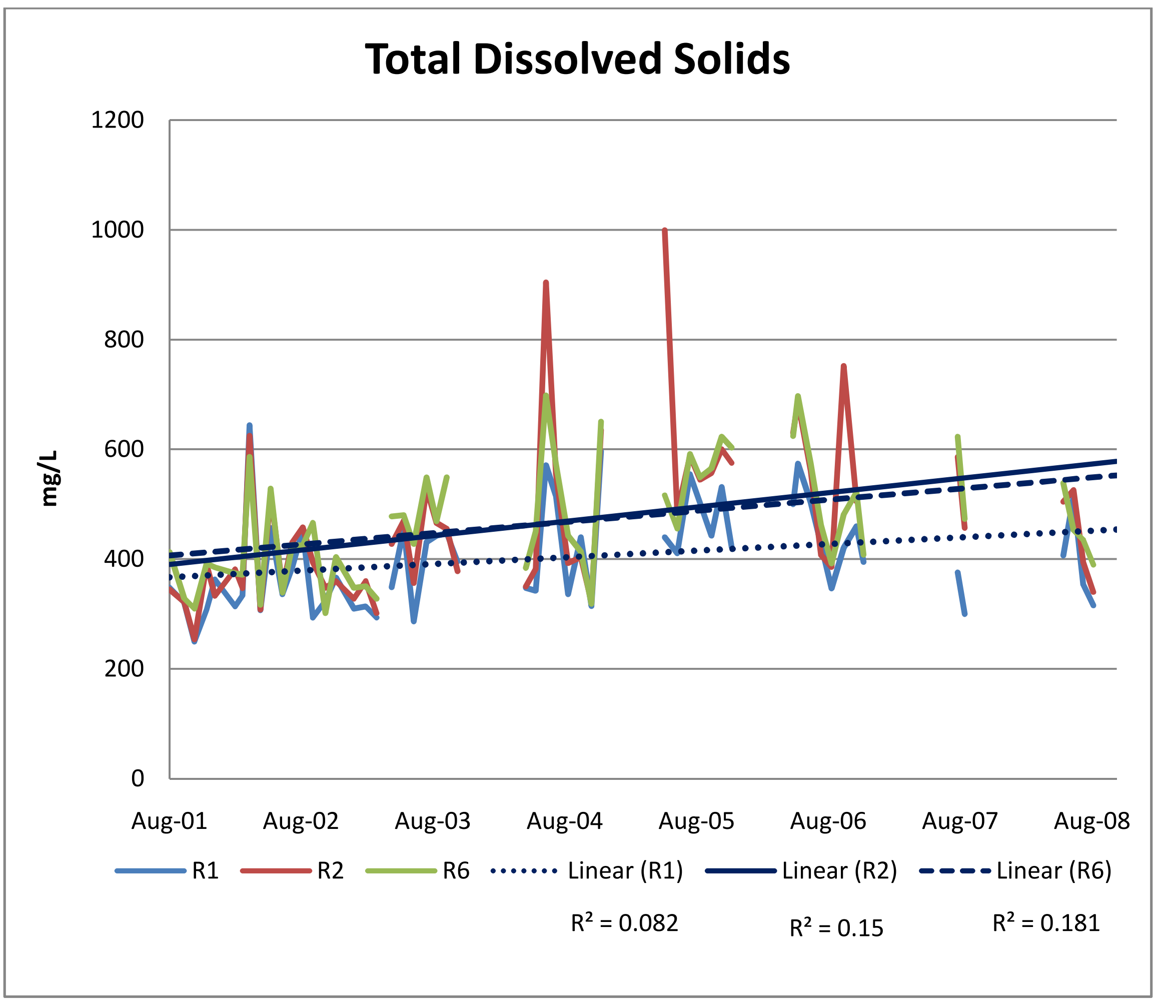
Figure 4.9 Average Monthly Changes in Conductivity



As expected, there is strong, positive correlation between conductivity, TDS, and salinity (Appendices E-G). Conductivity increases in dryer seasons, due to the concentration effect with lower flows. The urban area significantly influences conductivity in the RR. Conductivity is within the EPA standard for drinking water and was only higher than 900µS/cm in June 2004 and May 2006.

TDS/Salinity: TDS concentration and salinity are significantly higher at R2 and R6 than at R1 (Figure 4.10). There is strong, positive correlation between TDS and salinity and both influence conductivity. TDS concentration and salinity increase in summer seasons, perhaps due to increased concentrations as a result of lower flows. The t-test also indicates significant difference on both TDS and salinity levels between R1 and R2 locations and R1 and R6 locations. Therefore, the urban area significantly affects TDS and salinity in the River, primarily during dryer periods, and TDS and salinity may exceed the secondary water standard during low flows. Since the measurements of salinity and TDS are highly correlated (Appendix G), it may be adequate to collect measurements of only TDS.

Figure 4.10 Average monthly concentrations of TDS



Turbidity/TSS/Transparency Tube: While a difference between different locations of turbidity and TSS concentration was noted, no significant difference in transparency was found. In general, turbidity and TSS are higher at R6 than at R1 or R2 (Figure 4.11 and Figure 4.12, respectively) perhaps due to the influence of the low-head dams in the urban area. Turbidity and TSS levels increase somewhat in summer periods potentially due to more runoff and/or lower flows. Therefore, a significant, observable increase in turbidity and TSS levels occurs in the urban area. On the other hand, the t-test determines the only statistical difference in turbidity and TSS concentration between R2 and R6 sampling locations. Transparency of the RR water has decreased over the last 8 years (Figure 4.12). However, there is no evidence that the urban area impacts water transparency. A strong correlation between turbidity and TSS, and turbidity and transparency tube was determined as it was expected (Appendices H, I, and J).

Figure 4.11 Average monthly turbidity changes

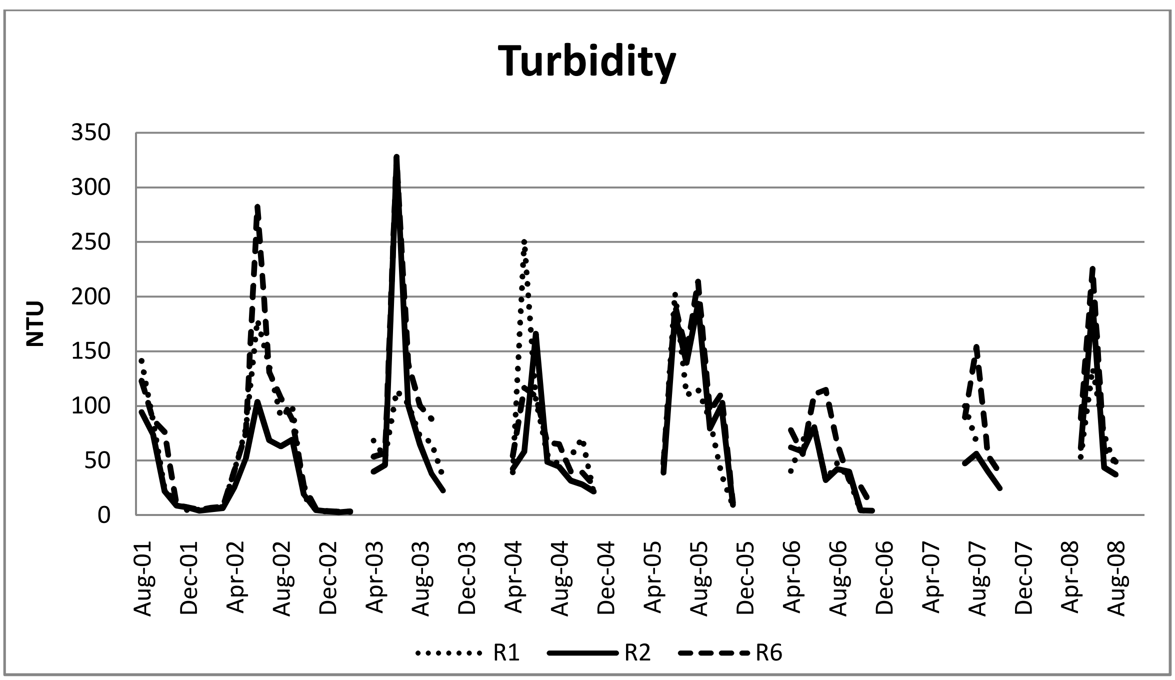
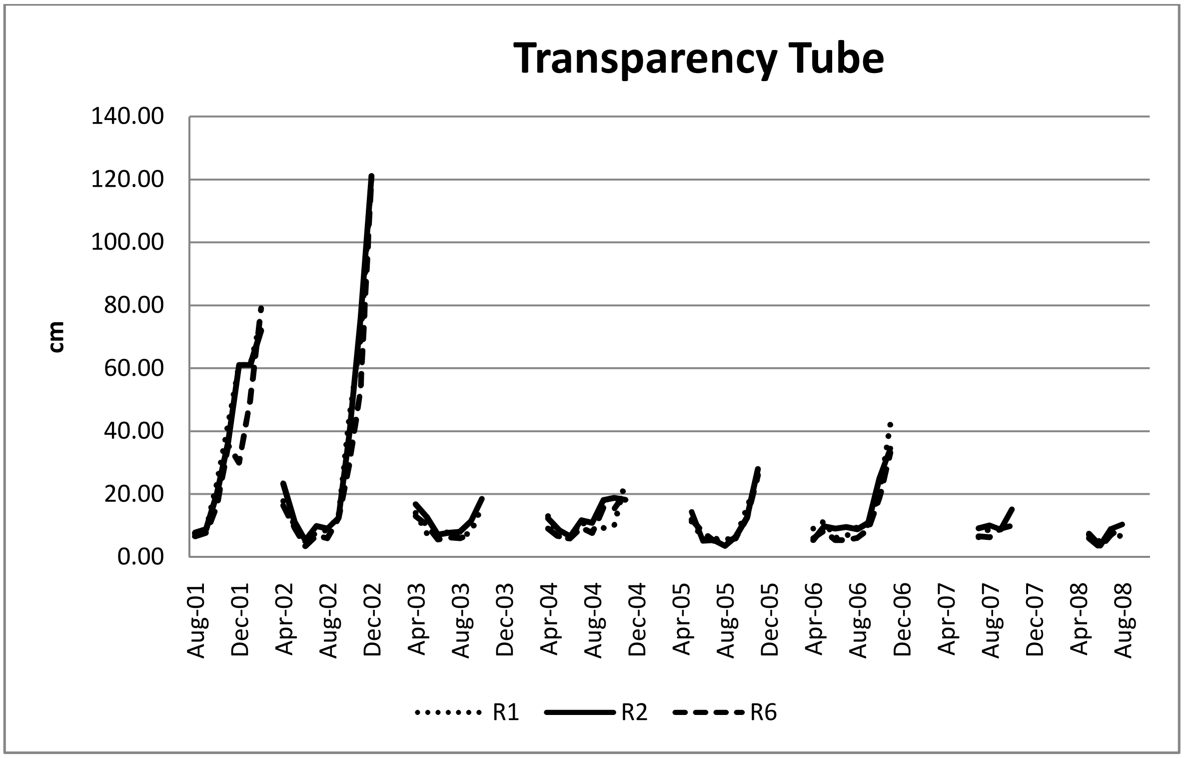


Figure 4.12 Average Monthly Transparency Tube Changes



Compared to MN chronic standard for class 2 streams, turbidity in the RR was significantly higher throughout the sampling period than Minnesota chronic standard for class 2 streams. Similarly, TSS concentrations are higher than the standard for discharge in Minnesota and North Dakota.

4.2. Tributary In-flow Impacts

In order to investigate the potential impact of the Wild Rice (T1), an analysis of the levels of the above mentioned parameters was conducted. The results show that there are no sustainable trends that signify the tributary (T1) influence (Appendices K1-K5). For example, analysis of the phosphorus concentration in 2008 shows that there is no direct evidence that explains the decreasing phosphorus levels at the R2 location because of T1 influence (Figure 4.13). Similarly, it can be concluded that TSS and nitrate/nitrite levels (Figure 4.14 and Figure 4.15, respectively) are not influenced by the Wild Rice in-flow.

Thus, there exists no confirmation that the Wild Rice in-flow impacts the water quality considerably. This may be explained with by the low discharge of the tributary which is only 5% of the main stream discharge (based on the USGS data from January 2001). The comparative plot of the discharge of the RR and the Wild Rice River is also presented in Appendix L.

Figure 4.13 Concentrations of phosphorus at R1, R2, and T1 locations

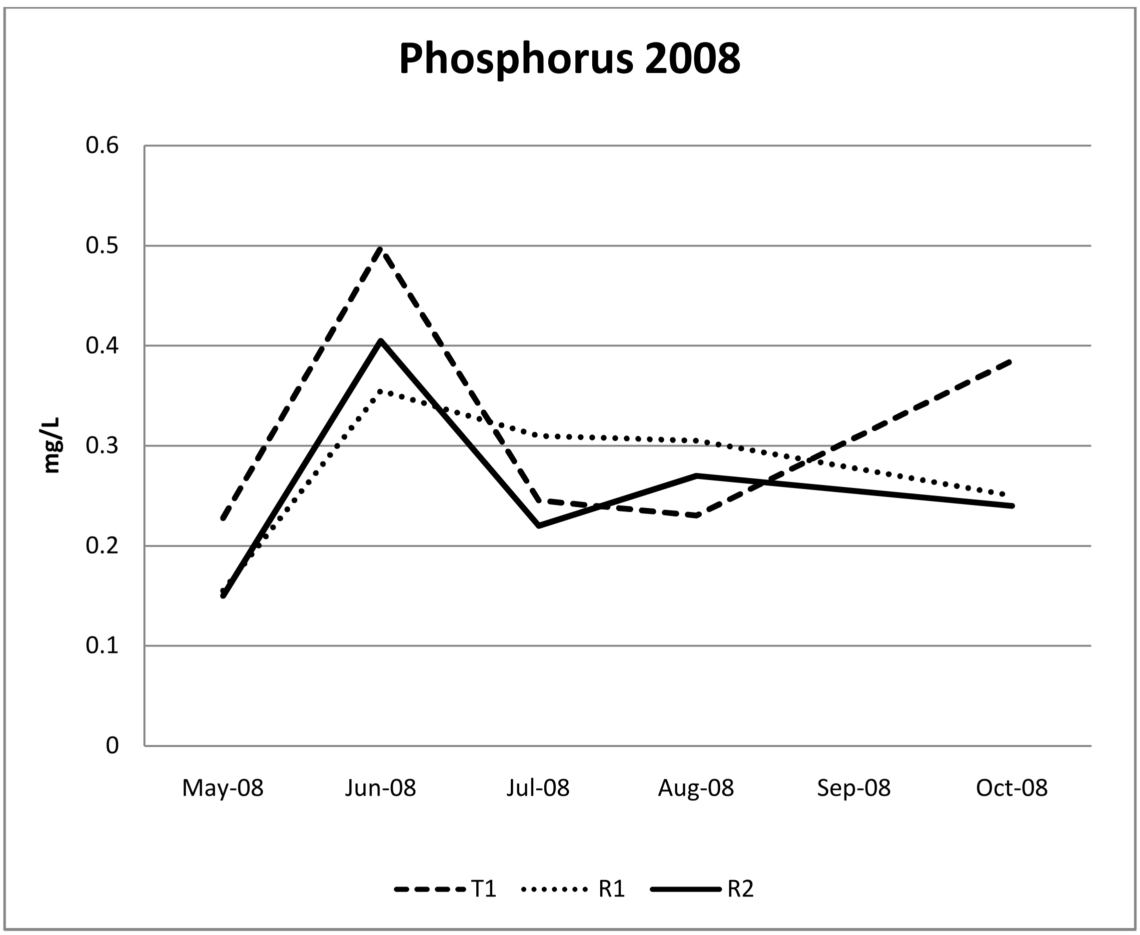


Figure 4.14 Concentrations of TSS at R1, R2, and T1 locations

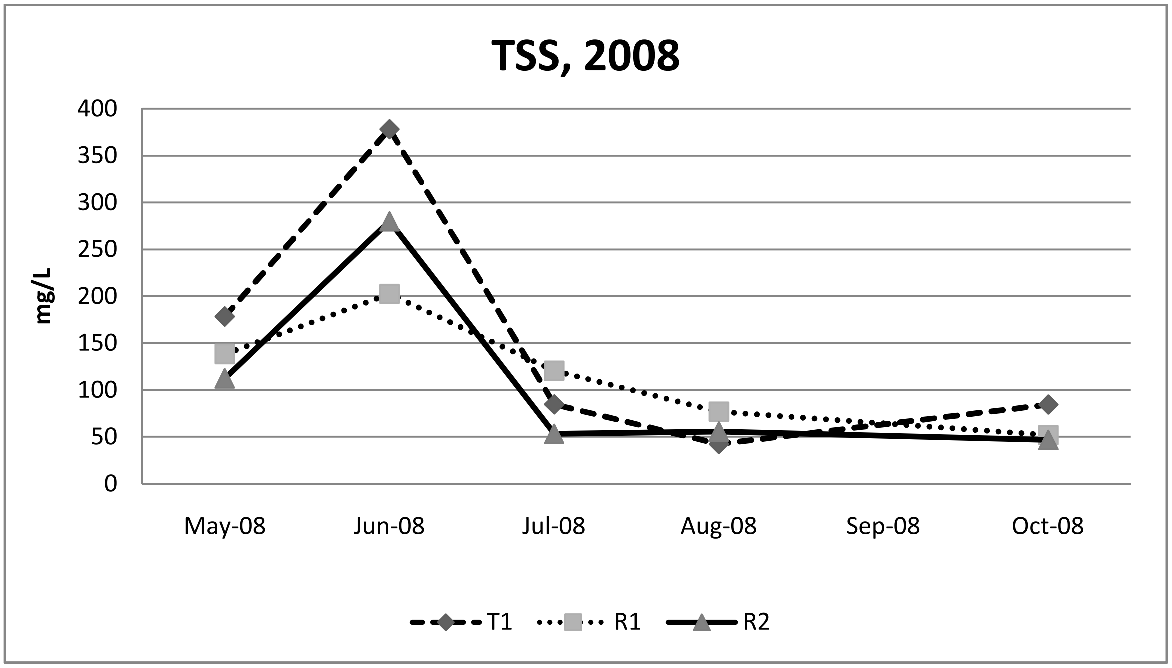
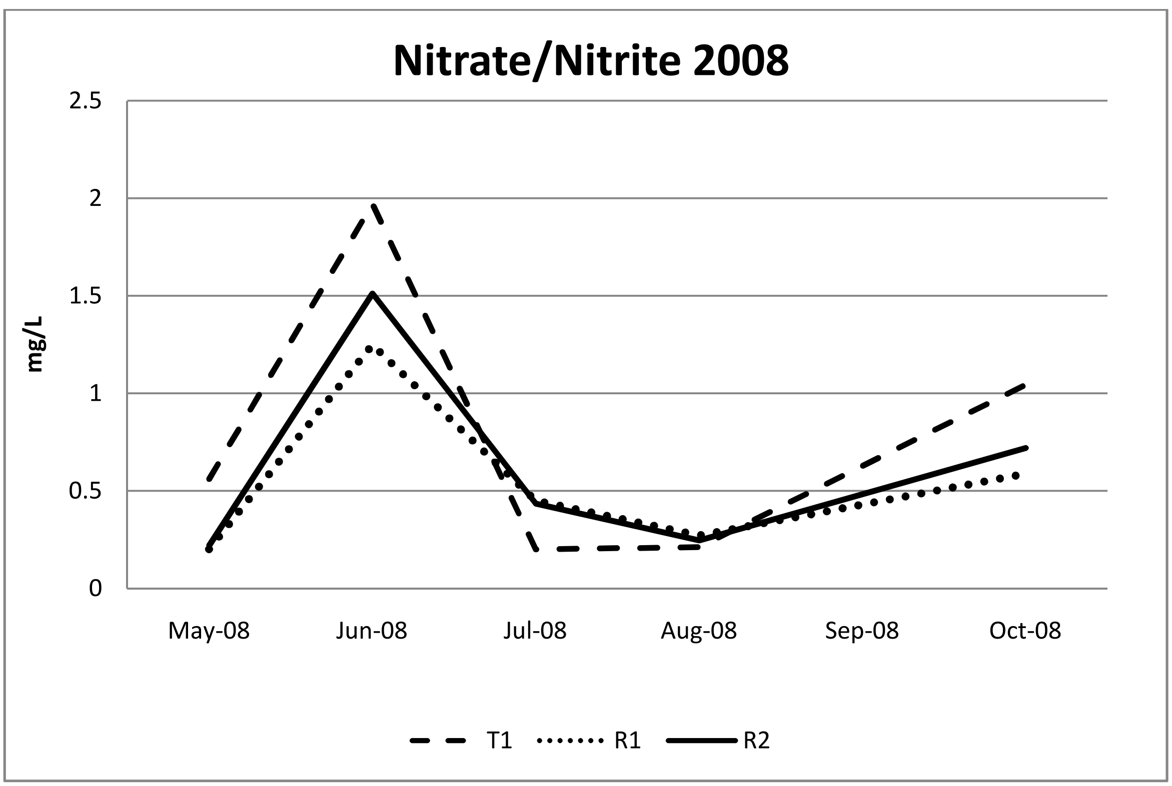


Figure 4.15 Concentrations of nitrate/nitrite at R1, R2, and T1 locations



4.3. Other Available Water Quality and Quantity Data

The USGS website[3] (2009) provides various data on water quality and quantity near the F-M area. The information that is available includes real-time data, daily data, monthly, and annual statistics, and field and lab measurements.

In this research, these data were used for:

1. Data comparison in order to test reliability of the data used in the research. Comparison plot of the USGS data and River Keeper's data on DO (Appendix M) shows that measurements are approximately the same.
2. Analysis of the discharge levels and their impact on the DO concentrations (Figure 4.4);
3. Comparison of discharge levels of the RR and the Wild Rice River (Appendix L);
4. Comparison with historical data.

Regarding the latter usage of USGS data, the comparison is provided in the Appendices N1-N5. Based on the available information, no significant conclusions on the water quality changes can be made. However, it can be noted that phosphorus and conductivity levels increased after 10 years. Other analyzed measurements, including DO, pH, nitrate/nitrite, and TSS vary in different years. A reasonable conclusion may connect the information to different discharge levels of the RR in dry and wet years.

4.4. Discussion

The analysis of the water quality data taken at three sampling locations along the RR (Figure 3.1) was done. This analysis allows assessing the impact of the F-M area on basic

[3] http://nwis.waterdata.usgs.gov/nd/nwis/dv/?site_no=05054000&agency_cd=USGS&referred_module=sw

water quality measurements (Table 3.2) during an eight-year period as well as changes of the analyzed parameters over time.

Primary findings of this research show that there are no apparent impacts of the urban area on ammonia, DO levels, pH and transparency. These measurements differ over time and location, but no general trends of these changes are noted. However, there is considerable difference between measurements taken upstream and downstream the F-M area (R1 and R6 sampling sites) for the following water quality parameters: fecal coliforms, nitrate/nitrite, phosphorus, conductivity, salinity, TDS, TSS, and turbidity.

Further t-test analysis confirms (α=0.05) that there is a statistically significant difference of conductivity, fecal coliform, phosphorus, salinity and TDS measurements taken at R1 and R6 locations (Appendix B). The t-test also confirms that measurements of conductivity, fecal coliform, salinity and TDS taken R1 and R2 differ significantly. These differences could signify the potential negative effects of the F-M area on the water quality of the RR.

Although the concentrations of DO, phosphorus, TSS, and pH are lower at R1 compared to R2, no evidence identifying the Wild Rice River as an influence on the main stream is found, this may be because of the relatively low discharge levels of this tributary. Thus, other causes of the phosphorus, TSS, and pH increases and DO decreases should be investigated. An assumption that dams that are located between R1 and R2 locations may contribute to these differences may be made, but more evidence is needed to confirm this hypothesis.

Considering the inter-connectedness of most physical, biological, and chemical processes in the stream ecosystem, correlation analysis was done and correlation matrices were developed (Appendices C1-C4). As expected, a strong correlation was found between DO and water temperature, between TDS, salinity and conductivity, between TSS, turbidity and transparency tube measurements, and between water temperature and TDS and TSS concentrations. These correlations have physical and chemical explanations.

Other analyzed USGS data include water discharge levels and historical data. Based on the analysis of this data, it can be concluded that discharge levels contribute to changes in water measurements although this impact cannot be considered to be important (Appendices K1-K5 and L). Moreover, the comparison of the available historical data only indicates an increase in phosphorus concentrations and conductivity over time. However, this conclusion cannot be considered significant as the comparison is limited because of minimal historical data (Appendices N1-N5).

5. CONCLUSIONS

Based on this study, the following conclusions on the urban impact of the F-M area on the water quality of the RR were made.

1. There is an impact of the F-M area on water quality of the RR. Potentially, the sources of urban water pollution are both point and non-point, including water and wastewater treatment plants, urban runoff from residential areas, runoff from animal manure, and others.
2. Analysis of the basic water quality measurements shows no apparent difference of the water quality prior to, in, and after the F-M area for: DO and DO%, pH, transparency, and ammonia.
3. Statistically significant variations of water quality between R1 and R6 monitoring location is verified for: conductivity, fecal coliform, phosphorus, salinity and TDS measurements. Furthermore, there is significant difference in the water quality measurement between R1 and R6 locations for conductivity, fecal coliform, salinity and TDS.
4. Currently the research indicates that due to relatively small discharge levels, the Wild Rice tributary does not contribute considerably to the water quality of the RR main stream.
5. All existing inter-relations of the water quality measurements could be explained by physical, chemical, and biologic processes. There were found no other unexpected correlations of the water quality parameters.

6. Additional available data that were utilized from the USGS website include: discharge levels of the RR and the Wild Rice River, historical data of the water quality parameters analyzed in the study, and current project time-framework data in order to investigate reliability of the water quality measurements provided by River Keepers.
7. The research found that some parameters that identify similar phenomena were measured such as DO and DO%, TDS and salinity, turbidity and transparency tube, conductivity and specific conductivity. In future studies, duplication of measurements would not be necessary which may save time and money.
8. In order to operate with more reliable data, the author recommends conducting water sampling at the same time at each sampling location. However, giving the limited resources of River Keepers and other non-profit organizations this suggestion may not be feasible.
9. Notes on the weather conditions prior to sampling may also be useful. For example, rains may cause the decrease of pH in the river`.

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