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A River Palimpsest: The Interdisciplinary Value of Water

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A River Palimpsest

The Interdisciplinary Value of Water:

Learning the Great Miami River Laterally through Ecology, Chemistry, Geography, Photography and History

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Honors Thesis
Katie Norris
Department: Biology
Advisor: Dr. Ryan W. McEwan
April 2010

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Abstract

Water is an invaluable natural resource to both human and ecological communities, and is currently threatened by global and local pollution and availability. Hypoxia, climate change and local issues all strain river systems to beyond repair. In light of this, communities and scientists must come together to understand the quality and value of natural resources, such as the Great Miami River, in order to inform policy, management and societal perceptions. The overall purpose of this thesis research project is to utilize interdisciplinary areas together to create a valuable, spatially lateral and chronological baseline picture of the Great Miami River. The intent is to track changes in water quality and nutrient loading variability along the rural-suburban-urban continuum of land use change. The research will set a baseline for the Great Miami River through a comprehensive overview and data collection during two five-day river trips, starting at the headwaters at Indian Lake down to the City of Dayton. By using a systems thinking framework within the context of an interdisciplinary approach, this study attempts to understand the relationships and interactions of the river/watershed/landshed system.

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Introduction

Freshwater is a vital natural resource necessary for life, and understanding and managing this resource is critical for the preservation and success of human and ecological communities. The total volume of water on Earth is both fixed and finite; it can neither increase nor decrease but is continually in motion through the stages of the water cycle (Clarke 2004). Historically, and currently, rivers play important roles in the development and distribution of human societies (Postel and Richter 2003). In the Ohio Miami Valley, rivers and streams have been a fundamental resource for humans, serving as transportation routes for Native Peoples, attracting early settlers, and serving as the foundation for cities, industrial activity and recreation. The Miami Valley is also enriched with a bountiful buried valley aquifer that provides fresh drinking water. Unfortunately, humans have polluted much of the available freshwater so that while the amount of water is not decreasing, humans are running out of unpolluted freshwater. In using and polluting more than half of the available freshwater runoff, humans are robbing other species and ecosystems of water needed to function (Barlow 2007). "Water is the foundation of every human enterprise, and if that foundation is insecure, everything built upon it will be insecure, too. As such, our stewardship of water will determine not only the quality but the staying power of human societies" (Postel 2008). Stewardship and management of water are not a selfless indulgence then, but instead necessities because hydrologic systems provide functions humans depend upon and cannot replicate (Postel and Richter 2003).

Two intertwining global change processes are the broadest obstacles to successful river management and repair; eutrophication-induced hypoxia, especially at the mouths of rivers, and climate change effects. With the introduction and implementation of water quality legislation in the 1970s and 1980s, problems of point source pollution in waterways almost disappeared, and issues of nonpoint source pollution rose to the forefront. The principal nonpoint source pollutants are excess nitrogen and phosphorus from agriculture fertilizer runoff (Gautier 2008). A surplus of nutrients such as these causes rapid growth of algae and vegetation, which then die off en masse and are decomposed by microbes that use oxygen, causing eutrophication and eventually hypoxia when the dissolved oxygen level falls below 2 mL of O_2/liter (Diaz 2008) Large hypoxic areas commonly occur where rivers flow into seas, oceans or gulfs and are known as dead zones because they cannot support aquatic life. The dead zone in the Gulf of Mexico experiences severe seasonal hypoxia and is directly influenced by the nutrient discharge from the Mississippi River, which carries large amounts of agricultural runoff from its watershed (Diaz 2008), including the Great Miami River. Global climate change is the second broad challenge and affects many areas of river management, including exacerbating hypoxia by further depleting oceanic oxygen through stratification, warming and increased discharge from greater rainfall patterns (Diaz 2008). Changing climate also increases the possibility and unpredictability of droughts and floods, threatens rivers and aquifers with saltwater intrusion from sea level rise, and strains fresh water availability for humans and ecosystems (Gautier 2008).

Too often, understanding of systems or problems is incomplete and de-contextualized or instead, overwhelming in scope, leading to solutions or management that address only part of the larger issue. This is especially true of restoration projects that focus on a piece of an ecosystem and assume that it will recover despite its larger context (Palmer 2009). Federal management agencies such as the EPA and USGS greatly add to our understanding of the watershed through large surveys every decade or so. Even so, I propose that the critical nature of the Miami Valley, and the complexity of the threats to it, argue for more frequent and community-based sampling. In my view, it is vitally important to draw connections between the water resources and all other aspects of society. In River Futures, the editors acknowledge that "Rivers are part of society's lifeblood. We live along these natural arteries of the landscape, and they provide fundamentally important services" (Brierley and Fryirs 2008). Acknowledging the significance and interconnectedness of the Great Miami River through an interdisciplinary approach will provide big picture understanding of the "strategic natural resource central to the communal, economic, aesthetic and ecological vitality of the region" (Rivers Institute mission statement). The water resources of the area literally and figuratively connect this region and must no longer be taken for granted as an un-spoilable natural resource. Bringing together many disciplines in order to focus on the big picture is part of the challenge of assessing the multi-facets of the river.

The idea of a palimpsest is important to understand because it provides an artistic, interdisciplinary, historical perspective for the understanding and research. A commonly accepted definition is that "a palimpsest may be anything having diverse layers or aspects apparent beneath its surface" (ArtLex). A palimpsest is "an object or image that reveals its history" and "any old objects…that show the effects of their past can be seen as palimpsests, relating information about their histories" (ArtLex). Rivers, including the Great Miami River, are examples of such 'old objects'. Rivers are palimpsests.

In this thesis research project, I seek to grow our understanding of the interconnectedness of the river by studying the threats to, and opportunities provided by, the Great Miami River as a whole, rather than as the sum of its parts. Working in the Laboratory of Environmental Ecology, at the University of Dayton (LEED: directed by Dr. Ryan McEwan), I conducted field research consisting of two, five-day long canoe trips with sampling transects from the mouth of the GMR at Indiana Lake, through several small cities, and ended up downstream in Dayton (Figure 1). Such trips were unique because the data collected forms a baseline, big-picture view of the upper GMR. The possibility for trends to emerge in the baseline is great due to the uninterrupted nature of the data sampling over the course of the five day trips. This project will also set a precedent to continually build the dataset and create an opportunity for future students to experience and practice interdisciplinary learning and research.

This project will test the following hypotheses:

- Water quality and river habitat along the stream continuum will reflect the agricultural-suburban-urban gradient present in the landshed that feeds the watershed.
- Nutrient loading of the river will be impacted by the accumulation of watershed drainage area and land use changes.

Additionally, the following disciplines are incorporated in this project:

- Chemistry – Water quality tests included pH, dissolved oxygen, temperature, nitrate, total phosphate, coliform bacteria and E.coli, biological oxygen demand after five days, and turbidity.

- Biology – Macroinvertebrate sampling was performed using kick nets and the collected specimens were identified to determine tolerance levels, which indicate stream health.
- Ecology – A Qualitative Habitat Evaluation Index was performed for each site, with additional riparian classification including invasive species abundance.
- Geography – GPS data points were recorded for sampling sites and were used for GIS mapping of the sites and data.
- Photography – Visual documentation of river and sampling sites was gathered to provide photographic aids and to record transition of rural-suburban-urban continuum.
- History – Research in these areas provides background information and context for the data gathered during the trips.

Because of the interdisciplinary nature of this project, the following document has been separated into three parts: Part I – The Historical Context, Part II – A River Journey, and Part III – The Scientific Manuscript.

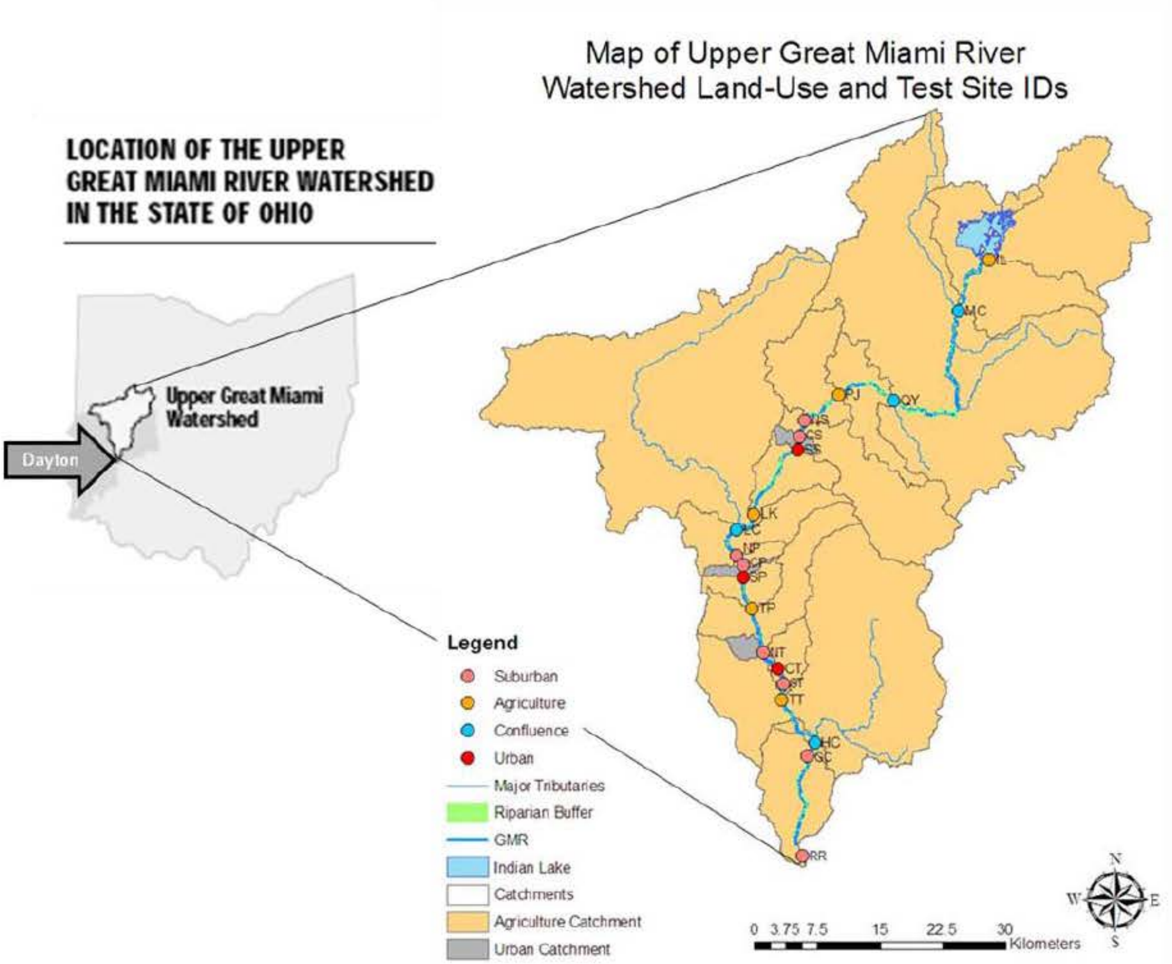


Fig. 1. Study area and sample sites

Part I. The Historical Context

Pre-settlement

Between ten and twenty thousand years ago the Wisconsin glacier re-shaped the current Miami Valley landscape and geology (Smith 1964). The massive force of this three hundred foot thick ice glacier reshaped existing rivers, scoured valleys and deposited moraine hills (Smith 1964). Old river valleys were filled in with gravel and debris by the Wisconsin glacier and became the vast Miami Valley aquifer (Smith 1964). The Wisconsin glacier also formed the Great Miami River and many of its tributaries (Smith 1964). Surrounding this in the west central section of Ohio are the glacial till plains, on top of which exists some of the best farming lands in Ohio (Smith 1964).

Populating the Region

Before European settlers arrived, Native Americans used the Miami Valley's rivers for travel and sustenance, including the Miami people, from whom the Great and Little Miami rivers received their names (Smith 1964). After much conflict in Ohio between the Native Americans and the European settlers, the Great Miami River valley north of Cincinnati began to develop, with Dayton officially surveyed in 1795 by Israel Ludlow (Smith 1964). The specific site of the city was chosen because of the confluence of the Great Miami and the Mad Rivers (Smith 1964). By 1820, Dayton's population was about 1,000, Cincinnati's was 9,642, and the growing Great Miami town had established a regular freight trade to Lake Erie through the Miami and Maumee rivers (Smith 1964).

Era of the Canals

The Mad River was harnessed to power many mills and later, in 1830, James Steele built a dam across the Great Miami north of town to run factories (Smith 1964). All of these dams and obstacles caused problems for river transportation though and roads were not a better option. These issues came to the forefront during the Canal Era in the U.S. and by 1822 public demand for the construction of a western Ohio canal system to transport goods resulted in the formation of a commission and a survey of possible routes (Carillon Park). In 1825 the Miami Canal was approved by the state legislature to run from Dayton to Cincinnati and construction began (Carillon Park). This canal became the Miami and Erie Canal when it was extended further north to Toledo, making it 248 miles long with 19 aqueducts, and 106 locks (Carillon Park). For a canal boat to go from Cincinnati to Toledo it traveled 512 feet above the level of the Ohio River to the summit of the canal, near Indian Lake, which is the headwaters of the Great Miami, and back down again to Lake Erie (Figure 2) (Carillon Park). The Miami and Erie Canal opened in 1827 and ran profitably until about 1856, when it was outcompeted by railroads (Carillon Park).

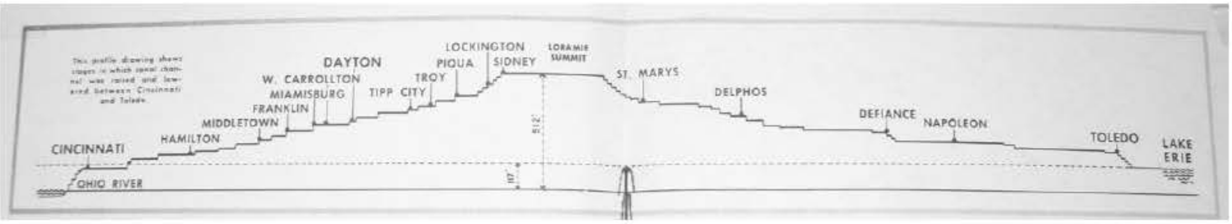


Fig. 2. This profile drawing shows stages in which the canal channel was raised and lowered between Cincinnati and Toledo.

Disaster Strikes

By 1913 the now unused canal running through Dayton was a source of controversy because the stagnant waters were causing property values to decrease, and others worried that it could get jammed with debris and exacerbate flooding (Bell 2008). Such fears were well founded because half of Dayton is on a floodplain and downtown is located near of the intersection of four rivers, the Great Miami, Stillwater, Mad, and Wolf Creek (Bell 2008). Thus, floods had occurred in Dayton before and in response levees had been built, which by 1913 were more than 20 feet high (Bell 2008). Additionally, the winter of 1913 in Ohio was unseasonably wet and warm, thus saturating the clay-like soils of the Dayton area (Bell 2008). The stage was set then for a devastating flood, all that was needed was excessive precipitation, which came in March of 1913 (Bell 2008).

From Easter Sunday, March 23 to Thursday, March 27, the entire Miami Valley watershed, drained by those four rivers, received between 7 and 11 inches of rainfall, which is about three months of normal rainfall (Bell 2008). On Tuesday March 25th the Great Miami River reached over 15 feet deep nearing the top of the levees, several of which broke later that day (Bell 2008). By that night the river had crested at 29.3 feet, which was 6.5 feet higher than any prior flood (Bell 2008). To make matters worse, high winds and ice the week before had downed hundreds of telephone and telegraph poles across the Midwest, making communication and weather warnings nearly impossible (Bell 2008).

Rapidly rising waters caused disaster for many homes (Figure 4), buildings (Figure 3), and bridges, and initiated fires caused by broken gas mains (Becker and Nolan 1988). People were forced to seek shelter in attics or on roofs while awaiting rescue by those with boats from higher ground, aided particularly by the efforts of NCR workers and resources (Becker and Nolan 1988 and Bell 2008). In Dayton 98 people died; the greatest number in any city affected by the flood (Bell 2008). Because Dayton was hit so hard by the flood, the Ohio legislature authorized the city to appoint an emergency commission to ensure long-term repair and reconstruction (Bell 2008). The city then incorporated this commission into a non-profit, the Dayton Citizen's Relief Commission, led John Patterson, head of NCR (Bell 2008). The commission sought to prevent future flood disasters and established a flood-prevention fund and raised more than $2 million in ten days (1913 dollars) (Bell 2008). Out of this came the creation of the Miami Conservancy District, charged with building a system of five earthen dams (Figure 5 & 6), which headed by Arthur E. Morgan, became the largest engineering project in the U.S. at the time (Bell 2008). Since then, the flood protection system has been tested many times by rain events, and it has proved effective each time (Becker and Nolan 1988).

Fig. 3. "Sudden torrents of water rushed through the main business district at up to 25 miles per hour. Three horses struggle against stiff current. This photograph was likely taken from the building of the Dayton Daily News at Ludlow and Fourth Streets" (Bell 2008).

Fig. 4. "An aerial view from Miami Valley Hospital looking due north over Apple Street toward downtown Dayton begins to reveal some of the destruction to homes in the city's southern sections due to the floodwaters' powerful currents. Several homes have been moved from their foundations and so sit at odd angles with respect to their neighbors, and floating debris is clearly visible between houses" (Bell 2008).

Fig. 5. Taylorsville Dam, taken 9/29/1920. View looking south, showing concrete in advanced stages (Miami Conservancy District).

Fig. 6. Taylorsville Dam, taken 1/16/1922. View of downstream side from point on east bank, with a good view of spillway and bridge (Miami Conservancy District).

A Brief History of Agriculture

Just as societies exhibit a progression in demographic and economic trends, so to is there an apparent sequence of different land-uses that societies appear to follow (Foley et al. 2005). This transition in land-use stages is demonstrated in Figure 7, and provides a framework understanding for the history of land-use in the U.S. and the Miami Valley of Ohio. Both agriculture and urban land-uses are important factors for understanding the inputs of watersheds because they have recently become significant portions of the landscape (Foley et al. 2005).

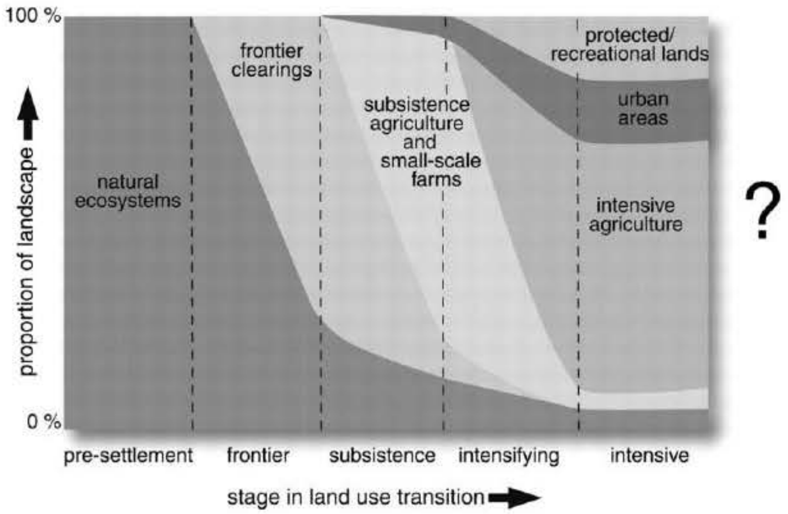


Fig. 7. "Land-use transitions. Transitions in land-use activities that may be experienced within a given region over time" (Foley et al. 2005).

In the early 19th century, farmers paid little attention to soil fertility because land was still fairly plentiful, thus depleting the soil resources of many areas (Blum 1992). Then in 1927 the world population reached 2 billion and land increasingly became a limiting factor so focus shifted to ways of increasing crop yields (McKenzie 2007). Following WWI, the newly developed nitrogen industry needed for the war found new applications in agriculture through the production of synthetic fertilizers (Blum 1992). Similarly, in the 1950s after WWII, an intensive chemical and technical approach to food production was taken because the materials produced in the war were pushed to be useful in other industries (Blum 1992). Combined with the mechanization of farming, this led to an expansion in the size of farms and a decrease in the number of farms (McKenzie 2007). This industrial method of food production, including monoculture crop farming and confined animal feeding operations (CAFOs), required high chemical and energy inputs, but also massive amounts of water through irrigation (McKenzie 2007). Such excessive inputs though are very inefficient though because on average crops can only absorb 1/3 to 1/2 of the nitrogen applied (McKenzie 2007). These excess nutrients can then run off land and enter waterways where they contribute to water pollution and can cause eutrophication of water bodies (Gautier 2008).

While these shifts in agricultural methods led to increased yields it was at the expense of high hidden costs (McKenzie 2007). Over the years, in response to this, there has been a fluctuating movement for sustainable agriculture, but this requires understanding complex interactions of soil, crops, climate, etc and so people have sought easy solutions (Blum 1992). Increasingly though there has been recognition of the hidden costs and a subsequent push for organic farming (Blum 1992), which could be a significant portion of the landscape in the future (Fig. 7).

Part II. A River Journey

Planning and executing the logistics of the two five day river trips was a unique task in and of itself. There are no parks or campsites along the Great Miami River, which made planning a continuous trip challenging. Because of this, and in keeping with efforts to promote regional cooperation, partnerships were made with the City of Sidney Wastewater Treatment Plant, City of Troy, and Five River MetroParks, who assisted in providing places to camp. The field team consisted of four individuals, along with two canoes, lots of testing equipment, plenty of food and two shuttle cars that were ferried downstream each day. Despite many obstacles, including huge downed-tree dams, sickness, low-dams, torrential rains, and exhaustion, the trips were a huge success. Not only was this possibly the first time people had paddled such an extensive portion of the river since the time of settlement, but it also brought the team closer to each other and to the river. It may be impossible to measure how important experiential learning is as a form of understanding the world, but it definitely increased my sense of place and connection to the river.

Below are excerpts from an interview of me discussing Dayton and water resources after the trips, followed by a photographic journey down the Great Miami River.

Dayton's relationship to the river

"I think right now Dayton's relationship to the river and its water resources, is very limited. There are some people in the region who see the river and the aquifer and understand its potential and want to utilize it in a positive way and also protect it. But I think as a general population, there really isn't much recognition at all. I think that the fear from the 1913 flood has kind of faded away and a lot of people who know about it, and remember it, use it as an excuse as to why we're not connected to the river, but I really feel that most people have forgotten about it. It's just there. When you drive over any of the bridges, you can't see the river from your car, and because of the levees, you can't see the river. So I think it's just a matter of the area not being aware of it."

Fostering a sense of place

"I think when people get outside, and when they have positive experiences outside their house and their work, they really feel connected and they appreciate where they live more and they establish that sense of place. And so key things like having great parks, and having recreational opportunities and having rivers that you can just go to and enjoy in many different ways, gives people a sense of identity, and in doing that they feel proud of where they live and they want to better it."

Ways to change perceptions

"Part of what Dayton can do is what they're already doing; it's a slow and steady thing. Raising awareness and getting people out there. Getting them to have those first experiences. Part of it is the aesthetics of the river, because in the city it's channelized and it's very flat and not flowing and it looks kind of boring, and maybe people would say ugly. And so changing that so there's variation in plants and artwork and trying to make it more interesting and accessible, could be something. And that's something that costs a lot of money; it's an investment in the river, in the city."

Water will bring people

"As much as Dayton is afraid that we don't have people and we don't have jobs, and we're this supposedly, quote unquote dying city, I think having water here, in the future is going to bring people. Because places like Los Angles and Las Vegas and the southwest, they just don't have the water to support those populations. So water is really important, you can't live without it and I think people are going to come here because of that."

A river city

"The other thing that's really awesome about paddling from north of Dayton is when you're on the Great Miami, you round that bend, and you see Dayton. And, it's just awesome. It's an amazing view because there's no other place from the area that you can see Dayton from that perspective. Seeing it from the river just really hits home that it is a river town. And I think we forget that a lot."

River reflections

"I also really like it when fish jump in your boat, when you're paddling along. It's just crazy, it's almost like the river just comes out and reminds you that there's life in it."

"It's just that sense of peace. You have a crazy week, doing whatever or doing homework and going to meetings, and then usually on Fridays, we just go out there and we paddle, and you take this big deep breath and you let everything go, and just soak in being outside, and it just always makes me smile."

Photography

Just downstream of the headwaters

One of many log-jams during the first day

Swampy section surrounded by agriculture

Kick-net sampling for macroinvertebrates

North of Sidney

A still natural section in "downtown" Sidney

Heavy rain on the third day

Downtown Piqua

Large dam near old Piqua power plant

Wide slow stretch of river

Camping in Troy

Downtown Troy

The team doing sampling

A pebbly run

Approaching Taylorsville Dam

Downstream of Taylorsville Dam looking north

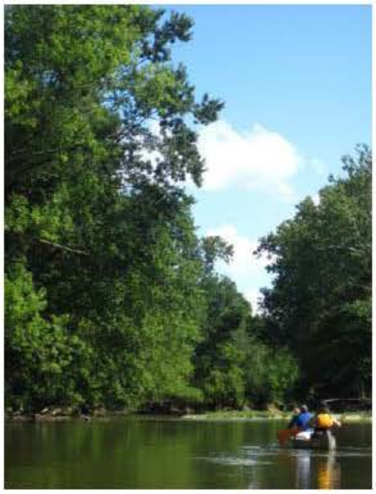
A forested site with great riffles

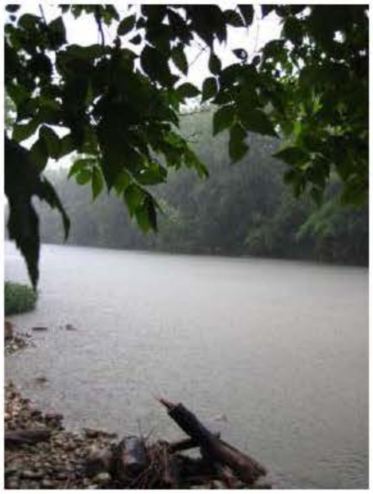
Unexpected construction on the river

Upstream of Dayton

The team after taking out at the end

A River Collage





Looking to the Future

In moving forward I believe that the citizens, governments and organizations of the Great Miami River watershed need to continue to think on a regional scale. Rivers do not recognize political boundaries, so in this case, people can't either. Embracing this mindset can help build relationships along the Great Miami River corridor, which will benefit not only the river ecosystem, but also the vitality and livability of the region Increasing river access and low-dam safety, through better signage, can help encourage people to use the river for recreation. All of this will foster cooperation within the watershed rather than competition.

Similarly, by using this study as a baseline, the region can begin to build an annual dataset that assists in tracking trends over time. This is valuable because it ensures that people are thinking about the river as well as providing real data that they can pull from to inform management. However, it is important to note that the time of year of testing is significant because to understand the nutrient influx from agriculture, sampling should be done in the spring, when fertilizers are being applied. Additionally, better ways should be sought to separate out distinct land-use influences from one another. This dataset and sampling could also be extended south to where the Great Miami River merges with the Ohio River to encompass the entire watershed. The rivers of this area are key assets, they have been around for a long time, and with care and consciousness, they will thrive long into the future.

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Part III.

Longitudinal Analysis of the Relationship between Land-Use and Biological Integrity of a Freshwater River System, Southwestern Ohio, USA

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Keywords

Great Miami River; watershed; land-use gradient; nutrient loading; ecological integrity

Abstract

Rivers in the Midwestern U.S. pass through landscapes that are often highly impacted by urbanization and agriculture. Factors that influence the biological integrity of the Great Miami River in southwestern Ohio, USA were examined to 1) track changes in water quality along a rural-suburban-urban continuum and 2) examine nutrient loading longitudinally. Water quality data, habitat evaluations and macroinvertebrate data were collected. The chemical data showed a negative correlation between water quality and distance from the headwaters. Similarly, nutrient loading of phosphates increased with distance from the headwaters and on average, the urban sites scored lower than non-urban sites. In summary, our data supports a 'river continuum' concept of accumulating impacts from the headwaters through an anthropogenically influenced landscape mosaic. Future work is needed to further understanding of regional dynamics. An integrated spatiotemporal understanding of water quality would assist regional communities in understanding and mitigating their impacts on rivers.

Introduction

Water is an invaluable natural resource for both human societies and natural ecosystems, but local and global pressures threaten the ecological integrity of many river systems (Brierley and Fryirs 2008). At the landscape level, there is increasing recognition that anthropogenic actions are the principle threat to the ecological integrity of river systems (Roth et el. 1996; Allan 2004). For example, changes in land-use impact the water quality, habitat and biota of rivers (Meyer et al. 1999; Allan 2004). Thus, research is needed to further the understanding of watersheds as socio-ecosystems that embody complex interactions between humans and environments (Walker et al. 2002; Palmer 2009).

Rivers and watersheds are increasingly being viewed as intricate mosaics of habitats and environmental gradients that exhibit high spatial complexity and connectivity (Ward et al. 2002; Allan 2004). Such gradients are partially produced by the patchy variation in land-use, comprised of urban, suburban and agriculture lands. While urban land use typically accounts for a small percentage of the total catchment area, it often imparts a disproportionately large negative influence (Paul and Meyer 2001; Allan 2004). Similarly, declines in water quality, habitat and biota are associated with increases in the percentage of agricultural land in a catchment (Roth et al. 1996; Wang et al. 1997; Allan 2004). Despite the understood ecological importance of a whole watershed perspective, few river restoration projects encompass large temporal and spatial scales based on landscape level inputs and large scale ecosystem processes (Palmer 2009).

In order to evaluate the necessity and extent of river rehabilitation efforts, it is essential that regional management organizations understand land-use and current river conditions. In southwestern Ohio, the Great Miami River (GMR) watershed drains 10,220 km^2 of land, including a mosaic of agricultural and urban (Miami Conservancy District 2009), making assessment and management challenging. Additionally, Ohio is one of the top nine states whose streams contribute the largest percentage of total nutrients (nitrogen and phosphorus) delivered to the Gulf of Mexico, which cause eutrophication induced hypoxia (Alexander et al. 2008). Management, protection and repair of the regional and national water resources are limited then by a lack of current understanding of the longitudinal connectivity of land-uses and rivers.

The upper section of the Great Miami River watershed is ideal then for beginning to understand complex land-use gradients because it contains mostly agriculture, interspersed with small urban areas. This dynamic allows for the repeated comparison of agricultural and urban influences, including the potential to observe subtle accumulations, without the overwhelming inputs from a major city like Dayton. Because of this, a continuous longitudinal and chronological baseline study of the upper Great Miami River was conducted north of Dayton. Sampling locations were selected based on four land use conditions: agriculture, urban/suburban, significant riparian and major confluence to address the following hypotheses:

- Nutrient loading will be impacted by the accumulation of drainage area and land use changes.
- Water quality and river habitat along the stream continuum will reflect the agricultural-suburban-urban gradient present in the watershed.

Methods

Study Area

The Great Miami River flows southwest for 273.6 km from its headwaters at the human-made Indian Lake to the Ohio River, west of Cincinnati. The total watershed drains 14,768.1 square km of land in Ohio and Indiana, and includes the Mad, Stillwater and Whitewater Rivers and Twin, Wolf, Loramie, and Honey Creeks (Miami Conservancy District 2002). For this study, only the upper portion north of Dayton, approximately 112 km of the GMR, was tested (Figure 1). Approximately 80 percent of the land use in the watershed is agricultural, comprised of row-crop corn, soybeans and wheat (Miami Conservancy District 2009). According to the 1995 Ohio EPA "Biosurvey of the Upper Great Miami River", all stretches of the GMR stream received either excellent or good biological health ratings (Miami Conservancy District 2002). Despite these positive results, many threats continue to pressure the water quality and ecologic integrity of the river including low dams, channelization, urban runoff and nutrient and pesticide runoff (Miami Conservancy District 2002; Rowe et al. 2004; Gautier 2008).

The climate of the region is temperate and includes a cycle of four seasons, with no significant dry period. The average annual air temperature of the region is 10.5-12.2°C and it receives approximately 88.9-109.2cm of precipitation annually and 50.8-76.2cm of snowfall per year (USGS 1997). The Great Miami River watershed geology is comprised of clay and silt-rich glacial sediments that lie on top of Ordovician- and Silurian-age bedrock. Due to these glacial deposits, the region has an extensive buried valley aquifer, which serves as the main source of drinking water (Miami Conservancy District 2009). The topographic gradient of the Miami Valley is from North to South and altitudes in the study unit range from 472.4m above sea level to 137.2m (USGS 1997).

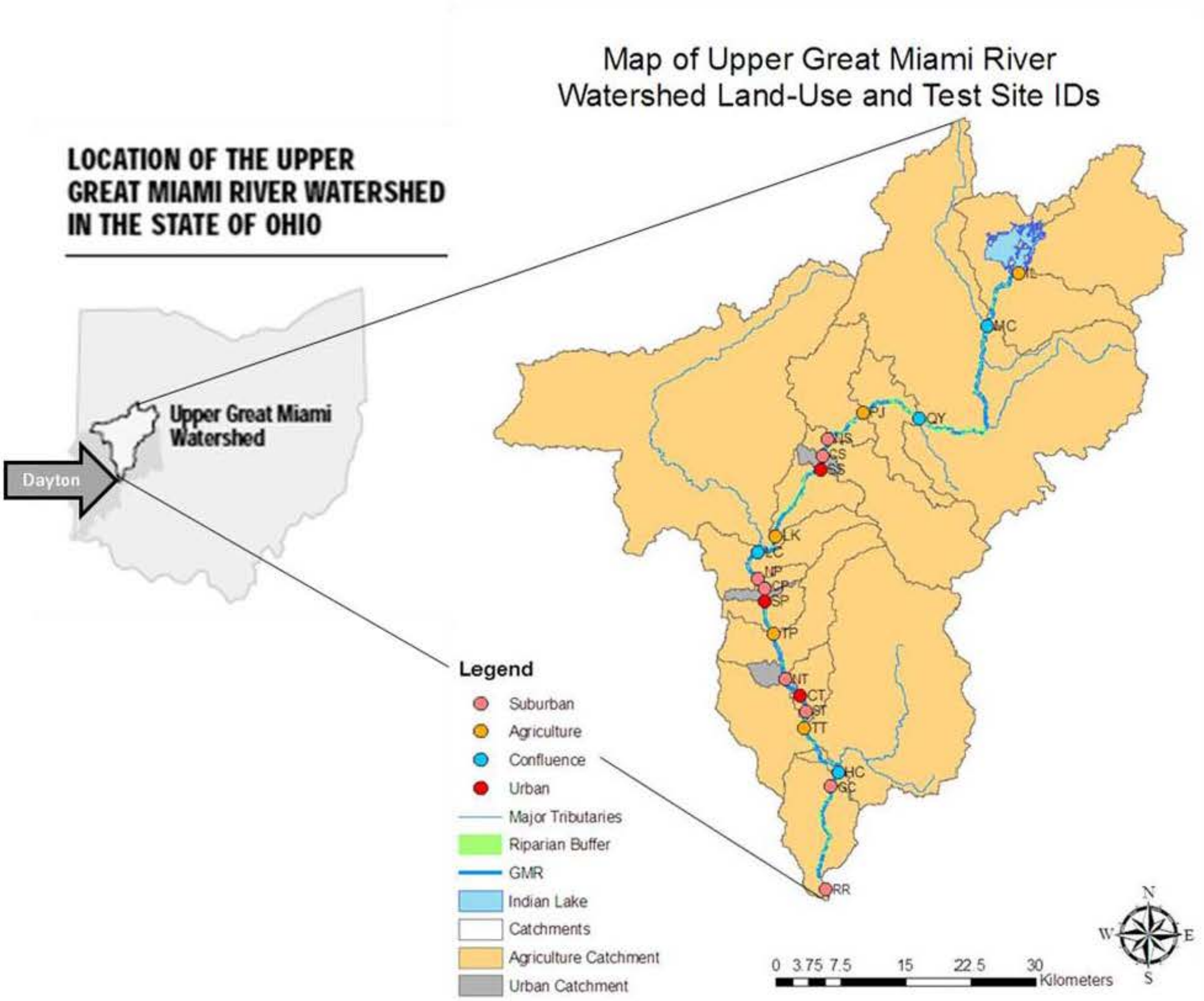

Fig. 1. Study site and sample locations along the upper Great Miami River in Ohio, USA. Site names are represented by two letter codes. Each site has a respective subwatershed catchment area that drains to it. These are shown by the grey lines that divide the study area. Sites are also color coordinated by their designated land-use category.

Site selection, data collection, lab methods

Data was collected during the course of two extended river trips starting from the headwaters of the Great Miami River at Indian Lake and ending north of Dayton. This stretch covers approximately 112 km of the river corridor that flows through the Ohio municipalities of Sidney, Piqua, Troy, Tipp City and Dayton. A variety of tests were conducted at predetermined sampling sites (n=20) during the trips to gather data (Figure 1). These tests were a modification of the stream team monitoring parameters, provided by the Miami Conservancy District (Hippensteel 2004). Testing was performed during July and August of 2009. The gradient hypothesis was tested by choosing sampling sites above, within and below the cities along the GMR, as well as sites influenced by agriculture land use. Nutrient loading was tested by taking nitrogen and phosphorus samples at the confluences of streams with the GMR.

A variety of aquatic and terrestrial variables were assessed at each sample location. Chemical water quality parameters were measured in the field, and samples were also collected for lab analysis. Tests were performed on samples from river left, center and right, giving each site triplicate replication. In each location the following tests were performed: pH using a Hach Pocket Pal™ handheld meter, dissolved oxygen using the YSI EcoSense® DO200 probe, temperature using a plastic-armored non-mercury thermometer, nitrates using the Hach NitraVer Test Kit, and turbidity using a homemade turbidity tube. This tube was constructed using a plastic one meter long tube, marked with cm increments, and had a black and white secchi symbol drawn on the inside of the bottom cap. A turbidity tube serves the same function as a secchi disk would in a lake, but because rivers can be very shallow, water is poured into the tube until the black and white symbol can no longer be seen and a measurement is recorded from the cm increments along the side of the tube.

Samples were also collected for lab analyses that could not be performed in the field. Biological oxygen demand (BOD5) samples were collected in opaque sample bottles and tested for dissolved oxygen after five days using the YSI EcoSense® DO200 probe. Additionally, samples of river water were collected and stored at 4°C until processed using the Hach PhosVer Total Phosphate Test to measure total phosphate. The amount of coliform bacteria and E.coli in the water was measured using Micrology Labs, Inc. Coliscan petri dishes and agar on which colonies were grown and then counted.

Macroinvertebrate sampling was performed using a seine kick net held by two wooden poles on either side (Plafkin 1989). Kicking, to disturb rocks and sediment, of the approximately one square meter riffle sampling area was performed for approximately two minutes (Plafkin 1989). The specimens collected on the net were transferred into a white bin, sorted, identified to family and genus, and recorded in the field.

A Qualitative Habitat Evaluation Index was performed for each site. This evaluation provides a measure of the stream habitat and riparian health that generally corresponds to physical factors affecting fish and other aquatic life. For each site, the same individual assessed and assigned scores for substrate structure, silting, land use, fish cover, sinuosity, erosion, depth, riffles and non-natural changes (Hippensteel 2004). For this study the habitat evaluation also included an additional riparian classification section to account for invasive species abundance. GPS data points were recorded for all sampling sites, along with photographs of each site, to provide visual documentation of each site.

Analytical methods

Raw water quality data, with triplicate replication per site, was averaged for each test. These averages were then multiplied by a Q (quality) value to get a score out of 100, which roughly determines the health of the site for that specific test (Hippensteel 2004). All eight water quality tests were given weighting factors, which were multiplied by the score for each test, respectively. These weighted scores were then summed to obtain a final Water Quality Index (WQI) rating out of 100. The WQI, habitat scores and macroinvertebrate taxa scores, based on richness and tolerance, were aggregated to produce a single score of ecological integrity for each site. These provide a means of comparing each site with each other. From these scores regression analyses were run on the WQI scores compared to distance from the headwaters (Fig. 2) and on the habitat versus macroinvertebrate scores (Fig. 5). Additionally, statistical t-tests were performed to compare different types of sites based on the aggregate ecological integrity scores.

ArcGIS was used to create maps of the study area using GPS coordinates for the sites and National Land Cover Data 2001 (USGS Seamless 2001) for the land use layer. Catchments, or subwatersheds, were delineated for each site using the ArcHydro extension. Geostatistical interpolations of the data were performed using the Inverse Distance Weighted (IDW) method.

Results and Discussion

Longitudinal loading patterns

The sampling process was planned in a manner to obtain continuous longitudinally and temporally sequential data. This method intended to provide a more comprehensive picture of water quality by not decoupling the chronological time of testing from the longitudinal location. A negative correlation was found between water quality (WQI) and kilometer distance from the headwaters (Fig. 2). The regression for sampling period one had a slope of -0.224 (r^2=0.471) and for period two the slope was -0.536 (r^2=.502). For both sampling periods water quality fluctuated from site to site, but there was an overall declining trend in the WQI of sites (Fig. 2). If water quality degrades as it moves downstream, then human and ecological communities downstream are at a disadvantage compared to those upstream. Because site habitat quality did not exhibit a similar negative trend, the water quality decline can be attributed to accumulation of nutrients and pollutants.

One important nutrient that was tested for and detected is phosphorus. By mapping the averaged total phosphate (PO_4) for both periods, it showed visually that larger amounts of phosphorus were entering the stream from tributaries of agricultural catchments (Fig. 3), creating hot spots of high phosphorus. For this map, any area of the stream in yellow or red represents higher levels of total phosphate, associated with poor water quality (Fig. 3). This influx of nutrients from tributaries indicates that the addition of water from other streams adds to nutrient loading downstream of the headwaters. It also illustrates that not all land-uses contribute equally to certain aspects of water quality. Managing for inputs of phosphorus then means that efforts should focus on agriculturally intense areas rather than other land-uses.

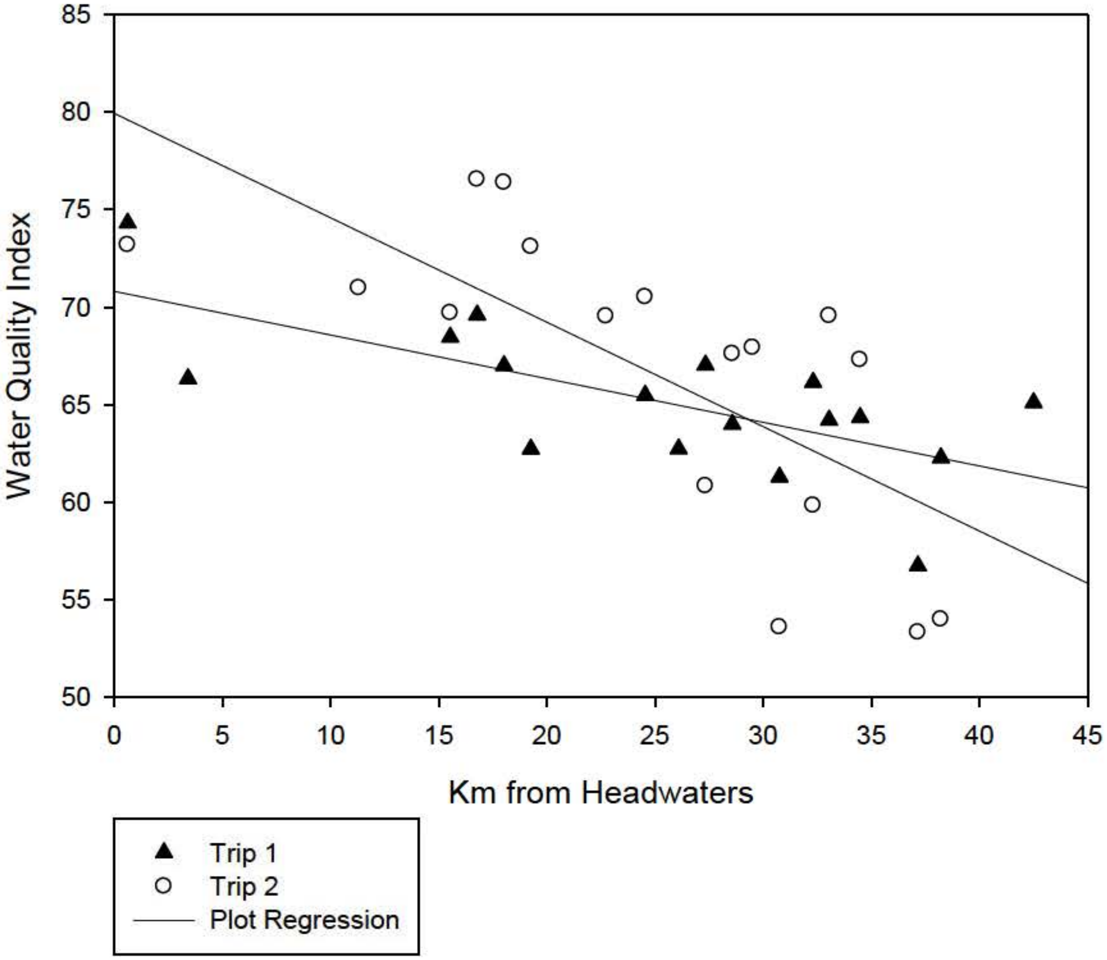

Fig. 2. The water quality scores for each site are shown for both sampling trips. The x-axis represents each site's distance from the headwaters. The linear regression shows that as the km from the headwaters increase along the x-axis, the WQI decreases.

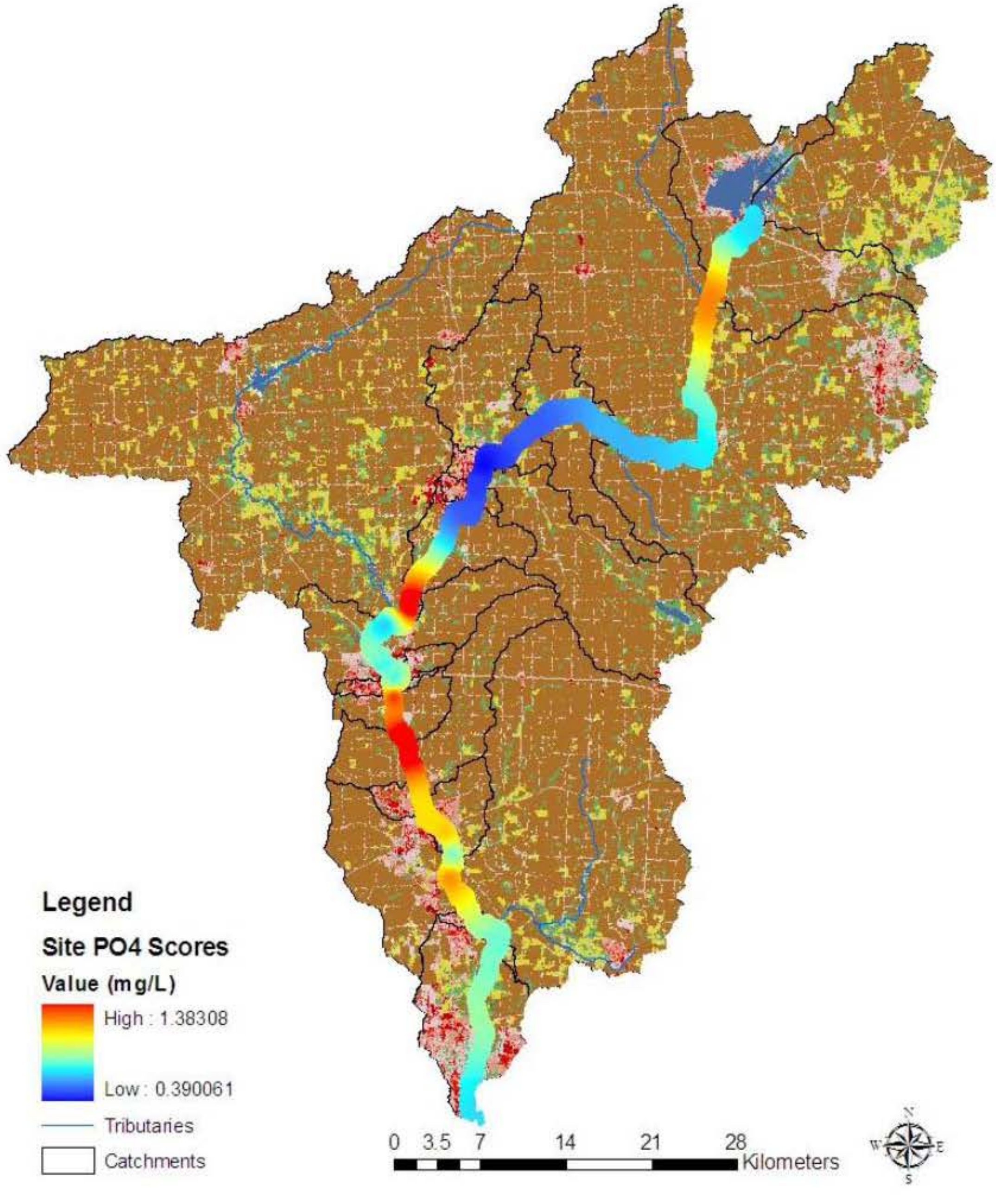

Fig. 3. This map of the study area shows the land-use as a background, with brown representing agriculture, green representing forested areas and red/pink representing developed land. The GMR is shown as color gradient that represents the changes in measured phosphorus levels. Red areas are hotspots of high level of phosphorus.

River continuum gradient patterns

Overall site ecological integrity was lower in urban (urban and suburban) sites than in non-urban (agriculture and confluence) sites (Fig. 4). This was true for both sampling trips (Fig. 4). Urban sites were often channelized (Piqua and Troy) and had lower habitat and macroinvertebrate taxa scores, but non-urban sites also varied with land use and riparian width. Statistical t-test confirmed that channelized urban sites (existence of a levee) had significantly lower integrity scores than urban sites without a levee (P=0.003). It is important to recognize that urban stretches of river differ from non-urban ones in a negative way because the amount of land developed for urban and suburban areas is increasing, partially due to urban sprawl and more impervious surfaces.

As would be expected, a positive correlation between site habitat and macroinvertebrates was found (Fig. 5). When habitat quality increased so did the macroinvertebrate score representing both richness and pollution intolerance. However, because the habitat score assessed overall site quality, not specifically macroinvertebrate habitat quality, some of the highest habitat scoring sites did not have the highest macroinvertebrate scores (Fig. 5). But, if habitat quality is associated with impacts from land use, and macroinvertebrates are indicators of biological stream health and water quality, then the presence of macroinvertebrates can serve as a sign of non-insidious land-use.

The upper Great Miami River truly represents a river continuum comprised of a fluctuating gradient of land-use. While the majority of land-use in the watershed is agriculture (Miami Conservancy District 2002), the river flows through or near three small municipalities (Fig. 6). This land-use dynamic creates a variation of inputs to the stream system and such a vacillation should be reflected in the overall habitat, biota and water quality scores for each. Such complex inputs can lead to covariance among natural and anthropogenic factors, making it difficult to separate influences (Allan 2004). However, ecological site integrity variation can be seen in the map of Fig 6, especially the ‘hotspots’ of poor site quality. Comparing before, in and after each urban area, the combined integrity scores of before and after urban areas were significantly higher than those within a municipality (P=0.046), creating a land-use gradient surrounding the urban areas, from agriculture to suburban to urban and back again.

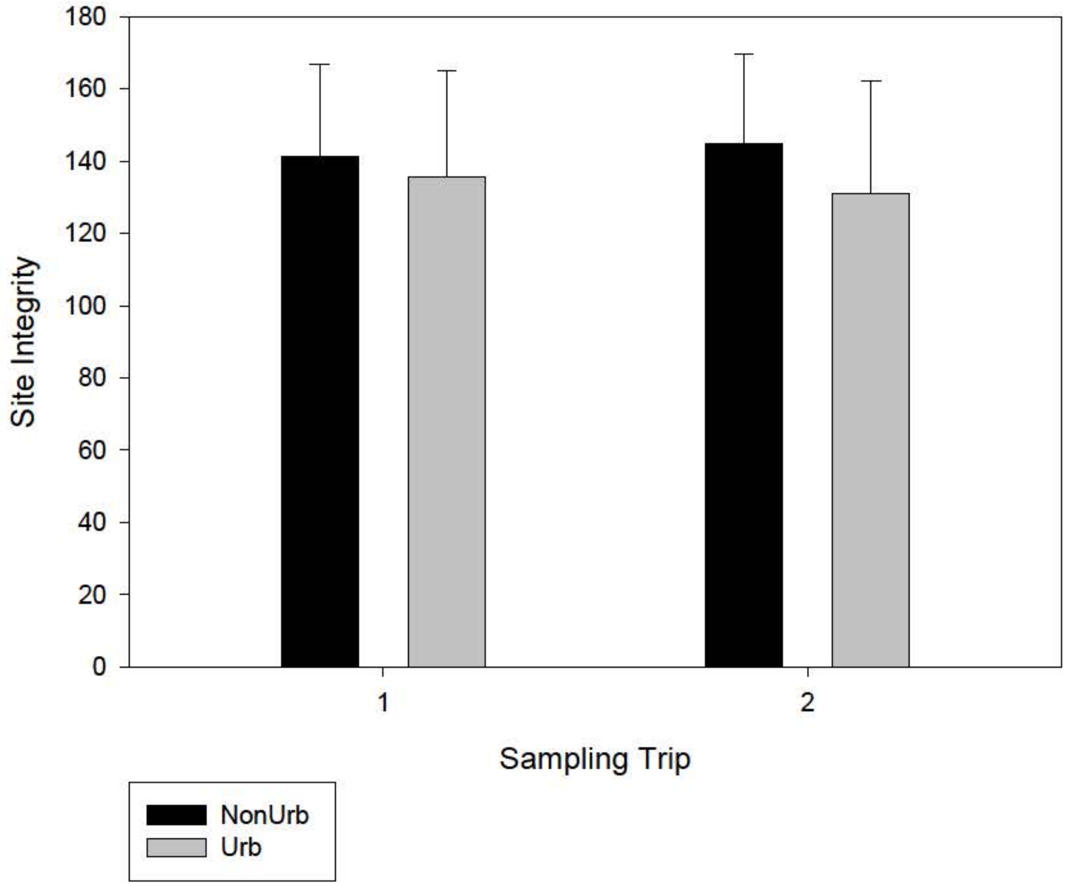

Fig. 4. Comparison of non-urban and urban site integrity for each sampling trip. The grey bars, representing urban sites, are lower than the black non-urban bars, indicating that on average the urban sites had poorer ecological integrity.

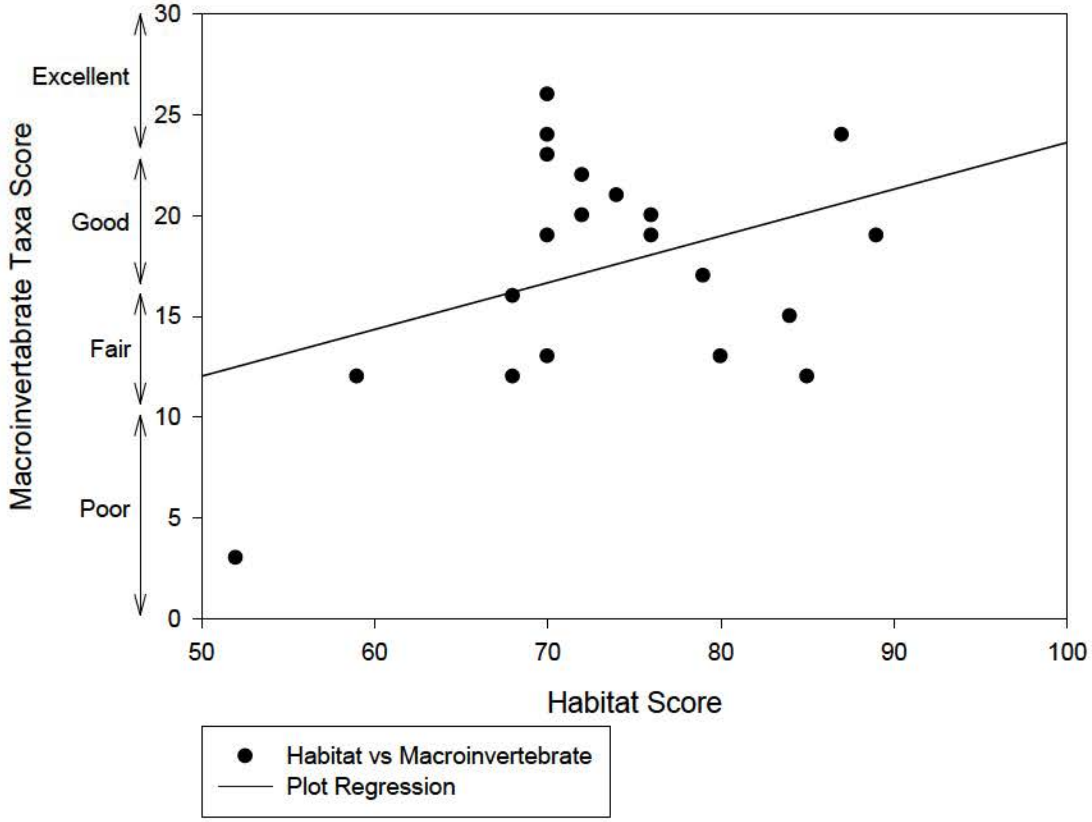

Fig. 5. Macroinvertebrate sampling was performed at all suitable sites. This graph plots the macroinvertebrate taxa scores with the habitat scores of each site. The regression line shows the overall positive trend between the two variables. A higher habitat score then increases the chances of having a better macroinvertebrate score.

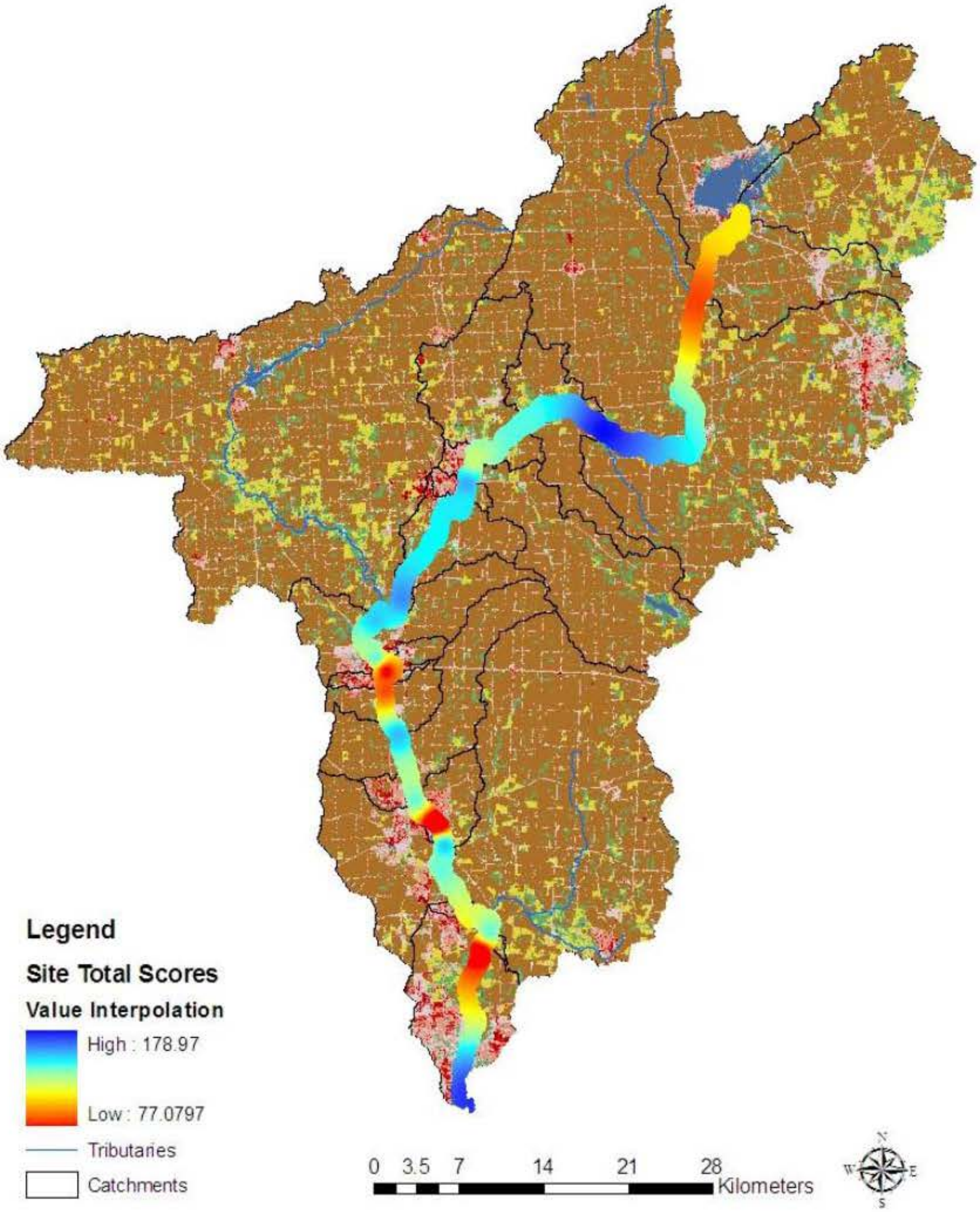

Fig. 6. This map shows land-use, with brown representing agriculture, green representing forested areas and red/pink representing developed land. The GMR is shown as color gradient that represents the changes in ecological integrity of the test sites. Red areas are places with lower site integrity, while blue areas have the best site integrity.

Conclusion

Implications for Management

(1) Upstream land-uses influence downstream water quality through nutrient loading, but the degree of influence depends directly on the type of land-use. Therefore, best management practices (BMP) and rehabilitation projects must focus on more than just one downstream section of the larger watershed, especially if excess nutrients from runoff contributing to Gulf hypoxia are to be reduced.

(2) A diverse landscape mosaic of land-use creates an ecological gradient which generates competing influences, including those of urban and agricultural lands. As the amount of urban land increases though, its negative influence will grow and must be addressed if more river habitat is to be maintained.

(3) Because of these accumulation and continuum dynamics, the GMR watershed requires annual testing to build a regional dataset that can accurately inform management and river repair.

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