DO LOCAL ENVIRONMENTAL POLICIES, LAND USE PLANNING, AND FRAGMENTATION WITHIN LAKE CATCHMENTS AFFECT LAKE WATER CLARITY?

By

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ABSTRACT

DO LOCAL ENVIRONMENTAL POLICIES, LAND USE PLANNING, AND FRAGMENTATION WITHIN LAKE CATCHMENTS AFFECT LAKE WATER CLARITY?

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Michigan has 11,037 inland lakes, 3,288 miles of Great Lakes shoreline, and 36,000 miles of streams. These freshwater resources require diligent management to preserve and protect their quality. Federal, state and local governments share responsibility for setting policy and implementing management. Land use planning decisions are primarily made through local government. My research aimed to understand how local (government) environmental regulations affect inland lake water quality, as measured by water clarity. My questions were: 1) is water clarity negatively impacted by fragmentation (i.e. multiple jurisdictions within one lake catchment)?, and 2) does local land use and environmental policy have a positive effect on inland lake water clarity? I expected lake water clarity to be better in unfragmented catchments with stronger environmental policies. I answered these questions by examining 420 lakes and their corresponding local regulations in southwest Michigan. I gathered local policy information using a survey and used GIS to combine land use/cover and landscape characteristics with policy data. I used ANOVA and multiple regressions and found that water clarity was negatively affected by fragmentation. Once local policy was included in the regression, fragmentation was no longer significant. Some specific policies were found to have a positive effect on water clarity. The complex and dynamic interactions between land use and water quality make it difficult to evaluate the sole effects of policy on water quality, which could be a reason why little scholarly research has been completed on the direct policy to water quality links.

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INTRODUCTION

Approximately 99% of the Earth's water exists in the form of salt water, groundwater, or ice (Dodds 2002), making it virtually inaccessible and/or expensive to use. The remaining 1% is freshwater, which includes streams, rivers, wetlands, marshes, and lakes. The Great Lakes are the largest surface freshwater system on Earth and hold approximately 84% of North America's surface freshwater. Michigan has nearly 36,000 miles of streams and over 11,000 inland lakes that ultimately end up in the Great Lakes system (MDEQ 2009). Throughout the state, water quality of these lakes is ecologically, recreationally, and economically important.

Water clarity is a widely accepted coarse method of measuring water quality. Nutrient loading (i.e. an increase in phosphorus and nitrogen inputs to a lake) generally decreases water clarity due to increased algal blooms (Carpenter et al. 1998, Wetzel 1999). These algal blooms can cause many problems within lakes, from decreased dissolved oxygen to the algal blooms themselves being toxic, both of which negatively affect species diversity and overall ecosystem health.

Federal, state, and local regulations are designed to protect these freshwater bodies from various sources of pollution (i.e. excess nutrients from urban sprawl and agriculture runoff), but they vary in scope, degree of enforcement, and effectiveness. While Federal and state regulations apply equally throughout the state, local regulations can be stronger than those of the national or state government. However, these local regulations are highly variable across the state and their effects on inland lake water quality have not been thoroughly studied.

Federal and state (Michigan) environmental regulations related to water quality

The Federal and state governments overlap in their jurisdiction of regulating point source pollution. Since the 1970s, many laws and acts have regulated point source pollution without addressing nonpoint source pollution, now a primary concern of water quality impairment (MDEQ2009, EPA 2010). The leading causes of land use-related nonpoint source pollution are the transfer of sediment and nutrients to aquatic resources, mainly through urban and agricultural runoff (EPA 2008). Agricultural erosion contributes to an increase in phosphorus loading to aquatic resources from heavily fertilized croplands (Carpenter et al. 1998). Some dominant nonpoint sources include stormwater, agricultural runoff, and construction impacts (Korfmacher 1998).

Although land use is a main driver of nonpoint sources affecting watershed ecosystem health (Langpap et al. 2008, Doppelt et al.1993, Korfmacher 1998, EPA 2010), the Federal and state government cannot mandate laws pertaining to land use planning and zoning in Michigan because it is a home-rule state. Home-rule means that local jurisdictions have authority to provide land use planning and zoning for their respective jurisdictions. Federal and state regulations pertaining to aquatic resources are presented in Appendix A.

In July 2008, a nonpoint source pollution program (NPS program) was created by the Michigan Department of Environmental Quality (MDEQ) to address nonpoint source pollution through state-wide monitoring (local, volunteer and state) and enforcement programs (MDEQ 2009). The program mission states that because the local government is in charge of land use planning, the state is working with local governments to provide information on efficient land use planning combined with economic and business needs (MDEQ 2009). The NPS program is focused on taking a watershed-based approach for addressing land use issues, which in turn addresses water quality issues. The NPS program is evaluated every four years to determine feasible approaches and create more long-term and short-term goals for land use planning. These adaptive management evaluations provide the program with built in assessments of whether intended goals and criteria are being met.

The NPS program works closely with the agriculture industry because it is the second largest industry in Michigan, consisting of 29% of the land in the state (USDA 2002), mainly in southern Michigan. This program works in partnership with many agricultural groups in order to create voluntary or incentive-based programs to promote good water quality within the farming community. Through a combination of state and Federal funding, programs such as the Michigan Agriculture Environmental Assessment Program and Generally Accepted Agricultural Management Practices (GAAMPs) are encouraged for farms, and there are state incentives for farms to implement Best Management Practices to ensure better water quality (www.maeap.org). However, local governments cannot mandate laws for agriculture that conflict with the Right to Farm Act. They focus on land use planning and have the authority to implement other environmental policies such as riparian buffers and nutrient bans when trying to protect Michigan's water bodies.

Local governmental organization in Michigan as related to land use planning and environmental policies

Local governments are required to meet Federal and state environmental regulations (described above); however, the potential to go above and beyond the minimum state standards to create more protective ordinances is an option for local governments. The state has overarching environmental policies, such as agricultural land use laws and water quality testing for public health and safety that affect counties, townships, cities and villages equally. In

Michigan, there are approximately 1,700 local jurisdictions that include 83 counties, 1,241 townships, 273 cities, and 261 villages, all of which have the authority to develop or influence local planning for their specific jurisdiction as required by the Michigan Planning Enabling Act (MPEA), Public Act 33 of 2008 (MCL 125.3801 *et seq.*). Townships, cities, and villages (referred to as municipalities), are all located within a county, but are separate jurisdictional entities. Cities and villages are also located within a township, but have separate jurisdictional responsibilities if they choose to take them on (Table 1).

Table 1. Organization of local jurisdictions and their responsibilities related to planning and environmental policies related to water resources (X represents responsibility for their respective jurisdiction). A MS4 is a conveyance system that is owned by a state, city, town, village, or other public entity that discharges to waters of the U.S.; designed or used to collect or convey stormwater (including storm drains, pipes, ditches, etc.); not a combined sewer; and not part of a Publicly Owned Treatment Works (sewage treatment plant).

Responsibilities per jurisdiction	County	Township, city, village
Enacting and enforcing local ordinances	--	X
Implementing a land use plan	Only if township rejects responsibility	X
Managing parks	--	X
Managing recreational facilities	X	X
Management of septic systems	X	--
Management of sewers	X	--
Managing stormwater	X	X (if a MS4 is present)
Implementing a zoning ordinance	Only if township rejects responsibility	X

Local governments (county, township, city, village) possess great influence in determining the quality of Michigan's waters through their impact on land use planning and zoning. Counties have planning and zoning jurisdiction only if a township decides not to delegate their authority to the county or if there is an intergovernmental contract in place (Wyckoff 2008). According to the MPEA planning guidance (2008), county planning has the potential to provide a larger cohesive strategy between municipal planning and zoning that should be integrated with transportation, sewer and water, and air and water quality strategies. Even though municipal planning is inherently important, and legally, municipalities have the right and authority to plan within their jurisdictional boundaries, the cumulative impact of local planning, by the sheer number of jurisdictions, has the potential to cause negative impacts to the ecological health of the state (Ardizone and Wyckoff 2003). This means that policies may be competing or opposite in adjacent areas, thereby nullifying any potential benefit the policies may have on an individual level. This negative impact may be related to a lack of knowledge of how land use affects water quality, institutional agendas failing to promote growth management techniques, or an absence of intended goals of the land use plans and zoning ordinances (Carter et al. 2005). Therefore, it is important that we quantify the effects of local policies on lake water quality.

Prior to 2008, local governments had the option to implement a master plan for its jurisdiction (Institute for Public Policy and Social Research (IPPSR) 2004). “A master plan is a land use and infrastructure plan that sets forth local goals, objectives and policies for community growth and/or redevelopment over the next 20-30 years” (Wyckoff 2008). The MPEA provides a combination of previous plans into one overarching simplified plan for all local governments to follow. In 2004, the IPPSR surveyed all of Michigan local governments to determine which had master plans. At that time, only 67% of townships had an adopted master plan (IPPSR, 2004). Olson (2008) also conducted a survey throughout Michigan regarding the types of natural resource information local governments are using and the challenges and needs of local jurisdictions to incorporate natural resources information into a planning document. She found that many local governments did not know where to find natural resource information, and that if they did have the information, they did not know what to do with it (Olson 2008). Local jurisdictions are now required to have a land use plan and zoning ordinance developed by April 2011 that has to be updated every five years, as well as an elected planning commission by July 2011, allowing them time to develop plans if they did not already have one in place (Wyckoff 2008 and MTA 2009). Thus, land use planning and zoning responsibilities are now required of local governments in Michigan.

A master plan is essential for establishing guidelines to satisfy public safety, health, and general welfare, in addition to the promotion of or adequate provisions for the use of resources (Wyckoff 2008). It also serves as the basis for the zoning ordinance, which can be included within the master plan or in a separate document. The purpose of the zoning ordinance is, among many other concerns related to human health and safety, including the environment, to "promote the public health, safety, and general welfare, to encourage the use of lands in accordance with their character and adaptability, to limit the improper use of land, to conserve natural resources and energy, to meet the needs of the state's residents for food, fiber, and other natural resources" (Wyckoff 2008). A zoning ordinance, rather than a master plan, is designed to address natural resource management through determination and implementation of local environmental policies. The use of zoning as a protection strategy for water quality is the "second generation" of US regulations (Russel 2004) since nonpoint source pollution in now the primary focus of regulatory action.

Counties, along with regional planning associations, do not often have planning authority within the jurisdiction. However, they may create plans based on a more holistic or watershed-based approach. Many times the townships within these counties or regional planning association do not adopt management plans that were created by counties, despite the fact that the work is already done. This situation may be because policy and land use controls are more controversial and difficult to predict than technological requirements of other facets of water quality (i.e. industry or wastewater rather than biological or chemical). Therefore, many different factors need to be carefully considered and incorporated into watershed models for land use policy (Korfmacher 1998). However, little is known empirically about the effects of local policy on water quality.

There are many ways for local governments to strengthen natural resource protection within their jurisdiction (Erickson 1995 and Waldner 2009). This strengthened protection could be implemented through a zoning ordinance or a master plan that includes open space requirements, greater flood plain restrictions, or low impact development options (see Table 2 for additional strategies). However, having a master plan that is friendly to water quality does not ensure real, in-the-lake changes. Erickson (1995) analyzed master plans and zoning ordinances in ten townships within the River Raisin watershed in southeast Michigan, to determine land use and land cover (land use/cover) change over time and the policies related to those changes. Through interviews and policy reviews, she looked for guiding changes to protect forest areas, such as open space regulations. She found that many times, goals of the master plan did not correspond to any land use planning restrictions or implementation of ordinances (Erickson 1995). Therefore, jurisdictions need to state the goals of the master plan, and then enact, implement and enforce relevant policies to meet those goals.

Table 2. Local opportunities for increased environmental protection adopted through the master plan or zoning ordinance (Ardizone and Wyckoff 2003). Note that this is not an exhaustive list, but demonstrates some opportunities to increase environmental protection at the local level, mostly related to nonpoint source pollution.

Options for increased protection from local jurisdictions
Land use surrounding inland lakes and streams • Riparian buffers • Setbacks around development from lakes and streams • Phosphorus bans on lawn fertilizer surrounding lakes
Isolated wetlands or wetlands less than 5 acres • Buffer strips around wetlands in the zoning ordinance • Preservation of isolated or less than 5 acres
Floodplains • Less than 100-year • Require a site plan review for environmentally sensitive areas • Greater building code restrictions within floodplain areas
High Risk Erosion Areas (HREA) • Greater setbacks from HREA (must be approved by the MDEQ)
Environmentally friendly development options • Low impact development • Cluster development • Transfer of development rights • Minimized set-backs • Open space requirements
General increased environmental options • Riparian buffers • Limits on fertilizer • Woodland regulations • Shoreline regulation • Soil erosion and sedimentation regulations

Other entities exist within governmental jurisdictions that focus on improving or preserving natural resources and water quality. For example, within the River Raisin basin, a non-governmental network exists that provides environmental education to promote the basin's health. This network has had some success in educating the community, but did not have the funding to become a viable planning agency within the region (Erickson 1995). Other watershed groups and regional authorities, when given the power, have successfully coordinated land use issues (Erickson 1995). If guidance and tools were provided to local governments on how to protect Michigan's natural resources, human health and environmental benefits could occur (Ardizone and Wyckoff 2003, Olson 2008). Therefore, it is necessary to educate local governments on the effects of land use planning on water quality, especially using a catchment (watershed) or river basin perspective.

Watershed planning and management has become increasingly popular when addressing water quality issues (Naiman 1992, Erickson 1995, Allan et al. 1997, Wang 2002, Ardizone and Wyckoff 2003). This type of management allows a focus on the balance between ecological, economic, and social values while providing a framework for sustainability coupled with human use (Naiman 1992). Water travelling throughout the watershed/lake catchment (downhill) and across jurisdictional boundaries gathers pollutants and sediment along the way, and depending on the type of land use, will determine how clean the water is when it enters a river, stream, or lake. Wetlands and riparian areas are known to filter nutrients and toxins, which in turn provide cleaner water (Wetzel 2001). Therefore, local governments could better manage urban runoff to aquatic resources through its increased protection of riparian areas, limits on impervious surfaces within a jurisdiction and encouragement of low impact development (Osborne and Kovacic 1993). Because development continues to expand, implementation of these types of ordinances could promote better water quality through decreased impervious surfaces and increased wetland and riparian filtering of nutrients.

The next sections introduce how fragmentation (the number of jurisdictions within a watershed/catchment), modeling and evaluation of policies have been previously addressed within a local or regional setting to address water quality concerns.

Fragmentation in relation to water quality

Nonpoint source pollution may be best addressed through a regional approach rather than addressing each jurisdiction individually (Wyckoff 2008). Fragmentation of policy is a result of using political boundaries rather than ecological boundaries to establish environmental resource policies. For example, multiple jurisdictions governing one lake catchment can lead to inefficient natural resource management because of the many differing and potentially conflicting policy approaches to aquatic resources (Erickson 1995, Allan et al. 1997). The idea that fragmentation may negatively impact water quality has been widely noted (Wyckoff 2008, Olson 2008, Ardizone and Wyckoff 2003); however, few have explored the underlying mechanisms that make fragmentation problematic or quantified how fragmentation actually affects water resources. My research attempts to fill this knowledge gap by quantifying the effects of differing local policies on water quality for individual lake catchments.

Because of the vast number of political jurisdictions within the state, fragmentation is not only present, but difficult to avoid without collaboration. Therefore, collaboration is important for maintaining good water quality. Calls for greater collaboration between jurisdictions, the public, and relevant stakeholders are common in conjunction with water quality management (Erickson 1995, Wang 2001, EPA 2008, Carter 2005, Gerber et al. 2005). However, there have been few empirical studies on how collaboration affects aquatic resources. It may be difficult for jurisdictions to work together given limitations on time, money, and the legal authority (Gerber et al. 2005). On the other hand, in addition to better water quality, intergovernmental cooperation could lead to an increase in economic development, provide cohesive and comprehensive planning across borders, and meld common goals and interests into one greater plan (Wyckoff 2008).

Modeling to assess land use effects on natural resources and water quality

Many modeling approaches have been used that incorporate policy assessment to predict the effects of specific environmental or land use policies on natural resources. For example, simulation modeling has been used to predict the outcomes of differing policies on natural resources. One study incorporated various land use decisions into their simulation model to determine how effective their model would be at evaluating the effects of land use on pollutants entering the Great Barrier Reef, Australia (Smaigl et al. 2009). The model included implications of different policy options by integrating all stakeholders (i.e. economic-driven, environmental-driven) rather than only modeling based on economic outputs to address the ongoing issue of declining water quality (Smaigl et al. 2009). Simulation of land use options was a composite of market and nonmarket based systems that take spatial dynamics into account. Results of this study concluded that policy implications can be incorporated into models to predict water quality. This study allows policymakers to see that models might predict outcomes pertaining to water quality based on the policy to be implemented (Smaigl et al. 2009).

In addition to simulation modeling, empirical models have been used to assess the effects of land use (and therefore the policies supporting land use) on water quality and aquatic species. For example, empirical models of conventional ambient water quality measures (nutrients, dissolved oxygen, and pH) and the toxic ambient water quality measure (copper, nickel, zinc, and chromium) in response to changing land use have been used (Hasic and Wu 2006). Their results demonstrated that with increased impervious surfaces (i.e. resulting from different land use types), the amount of nutrients entering a waterbody was increased. Many studies have shown that greener land use (to protect resources) positively affect water quality (Smaigl et al. 2009, Hasic and Wu 2006, Wolf et al. 2004). Support for research connecting local land use policy to water quality is essential since land use is governed by local jurisdictions that have the overall regulatory authority (Wheater and Evans 2009).

Evaluation of policies is an important aspect to actual implementation of ordinances within a planning document. A few studies have attempted to incorporate land use policy and management into an evaluation of water resources (Beven et al. 2008, Wheather and Evans 2009). Both studies analyzed historical data sets to assess whether impacts of land use and management affected flood generation in Europe. Rainfall data was assessed over several decades and used Dynamic Harmonic Based Regression (DHR) methods to identify whether there was change in rainfall and flow data on a catchment-scale basis. Their model results did not reveal a significant impact of land use change on increased flood runoff (Beven et al. 2008). However, they felt some variables were being overshadowed by the effects of climate, and call for more research in this area to produce better predictive models to improve land management (Beven et al. 2008). Their results begin to demonstrate the difficulty in assessing land use management techniques and evaluating their success at improving water resources, however, they also show the importance of further research to incorporate evaluation of policies to improve water quality.

Geographic Information Systems (GIS) has been used as a tool for data analysis, problem identification or policy formation at all spatial scales, and it allows for many factors such as land use, demographics, and landscape characteristics to be used within a single framework for forming policy. Many studies show the importance of GIS as a framework for crafting environmental policy, evaluating landscape, land use and nutrient inputs (Fassio et al. 2005, Lant et al. 2005, Walsh et al. 2003). Unlike these past studies that used GIS as a tool to predict water quality by simulating land use changes, I used GIS as a tool to evaluate the effects of on-the-ground policies on lake water clarity.

Evaluation of land use planning at the local level

Because it is known that land use affects water quality and that local governments, through planning and zoning efforts have the power to affect land use, it follows that there is a need to study the effects of local policies on water quality. Many Michigan-based studies have noted that when evaluating watershed health, you must take into account a complex web of overlapping political jurisdictions that oversee land management such as land use planning and zoning (Erickson 1995, Allan et al. 1997). However, many jurisdictions lack knowledge about natural resource information, as well as the authority to influence surrounding jurisdictions (Allan et al. 2003, Olson 2008). The following studies express the importance and need for evaluative processes to be implemented within jurisdictions to protect and improve water quality.

The River Raisin basin in southeast Michigan has had many research projects conducted within it because of its poor water quality. One of the many studies used a simulation model to predict the effects of different land uses on the health of the River Raisin including soil erosion, nutrients, habitat quality, and biological integrity (Allan et al. 1997). They concluded that agriculture was the single best predictor of stream conditions, causing streams to have poor water quality. Once they knew the type of land use that affected stream quality, they then wanted to know if master plans and zoning ordinances within the basin reflected the findings of their study, such as added protection features within the basin to help improve water quality. They found that many different land use plans and zoning ordinances existed for one particular catchment, without specific attention to lake water quality, and that coordination was lacking between land use decision makers (Allan et al. 1997).

The River Raisin studies (Allan et al. 1997, Erickson 1995) and others (i.e., Roth et al. 1996) suggest that the management of local and regional scale land cover is important for maintaining and improving the habitat integrity and habitat index for stream quality. Some studies suggest that open space and riparian areas could also provide benefits to stream quality (Doppelt et al. 1993, Allan et al. 1997), meaning that local policy could potentially affect water quality. Allan et al. (1997) looked at local planning and evaluated master plans and zoning ordinances based on their content. They concluded that within the River Raisin basin, master plans and zoning ordinances were out of date and that protection of open space and riparian areas were lacking, even though that was a written goal in the many of the plans (Allan et al. 1997).

Effectiveness of policies is extremely important to assess to know whether the policies are reaching their intended goals (Allan et al. 1997). Norton (2008) evaluated master plans according to their stated goals using content analysis in Genesee County, Michigan. Content analysis refers to analyzing the plans based on factors that influence the plan itself, such as the focus of development management and landscape goals, and the means in which to communicate these goals and policies (Norton 2008). Many master plans are commonly evaluated to assess "growth management", which includes different types of development within a community (Norton 2008). He argues that in order for a plan to be evaluated, clear intended functions of the plan need to be stated and understood (Norton 2008). To clarify, although it is known that land use affects water quality, the goal of a master plan may not be to explicitly improve or protect water bodies. Therefore, it is of utmost importance to be intentional when creating master plans and corresponding goals when it comes to effecting water quality.

Evaluation of policies with intentional purposes has been attempted in the past. Land use change was evaluated based on conversion of agriculture and forested areas to urban areas in a study completed by York and Munroe (2010). They used counties to assess the regrowth of forests on private lands, since there has been a decrease in forested lands within southern Indiana. They concluded that zoning might protect agriculture land, however, rent, land characteristics and population were major predictors of the ratio of agriculture to urban lands (York and Munroe 2010). Another study investigating the integration of land use policy with local planning used an empirical model to evaluate land use planning effects on water supply and quality in Canada (Carter et al. 2005). The model was developed using key principles of integrated and sustainable management to characterize activities that could serve as a benchmark to provide baseline criteria with which to evaluate local land use policies (Carter et al. 2005). Results suggest that definitive questions and criteria within a plan are essential for evaluating success towards measurable targets (Carter et al. 2005). While these studies assessed the plans themselves, which is an integral part in policy evaluation, it is also important to quantify how the policies within master plans affect lake water quality within a jurisdiction's corresponding catchment. Most previous studies that attempted to link policy with water quality outcomes were simulations that evaluated policies prior to implementation.

Evaluation is an important step in policymaking that is essential to provide justification of an implemented policy. Some policies do not make it past the books, but if evaluation is planned for, the policies have a better chance of being implemented and enforced. Waldner (2009) surveyed counties in Atlanta, Georgia and found that comprehensive plans created by counties were not necessarily implemented. So, before evaluation can occur, clear policy goals or targets need to be established, and then the plans need to be implemented (Nelson and Moore

1998). Many respondents of Waldner's (2009) survey stated that the plans or ordinances were implemented when there was political support, but were otherwise not followed through.

Once laws are in place and established, many techniques could be applied to evaluate the master plans. One way for townships to evaluate laws based on land use would be to count the number of trees on an urban parcel before and after the policy was implemented (Landry et al. 2010). Once a protection policy is mandated, the result could be positive, such as greater tree cover (Landry et al. 2010). Landry et al.'s study is a good example of policies being implemented, evaluated, and successful within the community. The goal of the policy was clearly stated, a solution in place (tree protection) and executed.

A more technical approach to evaluating local policy could be the use of predictive models. Langpap et al. (2008) used an econometric model based on land use choice with three watershed health indicators. They used parcel-level data collected via a survey of Oregon, California, Washington and Idaho. The watershed health indicators included conventional water pollution, toxic water pollution, and the number of aquatic species at risk of extinction over an eight year period (Langpap et al. 2008). The results suggest that watersheds with a higher proportion of agriculture and urban land relative to forest have more water quality degradation (Langpap et al. 2008). They also found that preferential property taxation and purchase of development rights have the most positive impact on water quality and species at risk. By linking better watershed health to local land use policies, this study precedes my research where I assess the effects of local environmental policies on inland lake water quality.

My research aimed to understand the importance of local governments' environmental regulations on inland lake water quality. I used regression models to understand these effects while accounting for landscape characteristics that are also known to affect lake water clarity. I also examined the effect of fragmentation on water quality. I hypothesized that 1) inland lake water clarity would be positively affected by water quality friendly local land use and environmental policy, and 2) fragmentation (i.e. multiple jurisdictions within one lake catchment) would negatively affect water clarity. These hypotheses were addressed using 420 lakes in southwest Michigan to model the effects of different land use and environmental policies on water clarity.

METHODS

Study Area

My study area included 21 counties in southwest Michigan (Figure 1), which is an area that is dominated by agriculture and urban land use. This area was chosen in part due to the availability of previously-delineated lake catchments with quantified landscape characteristics.

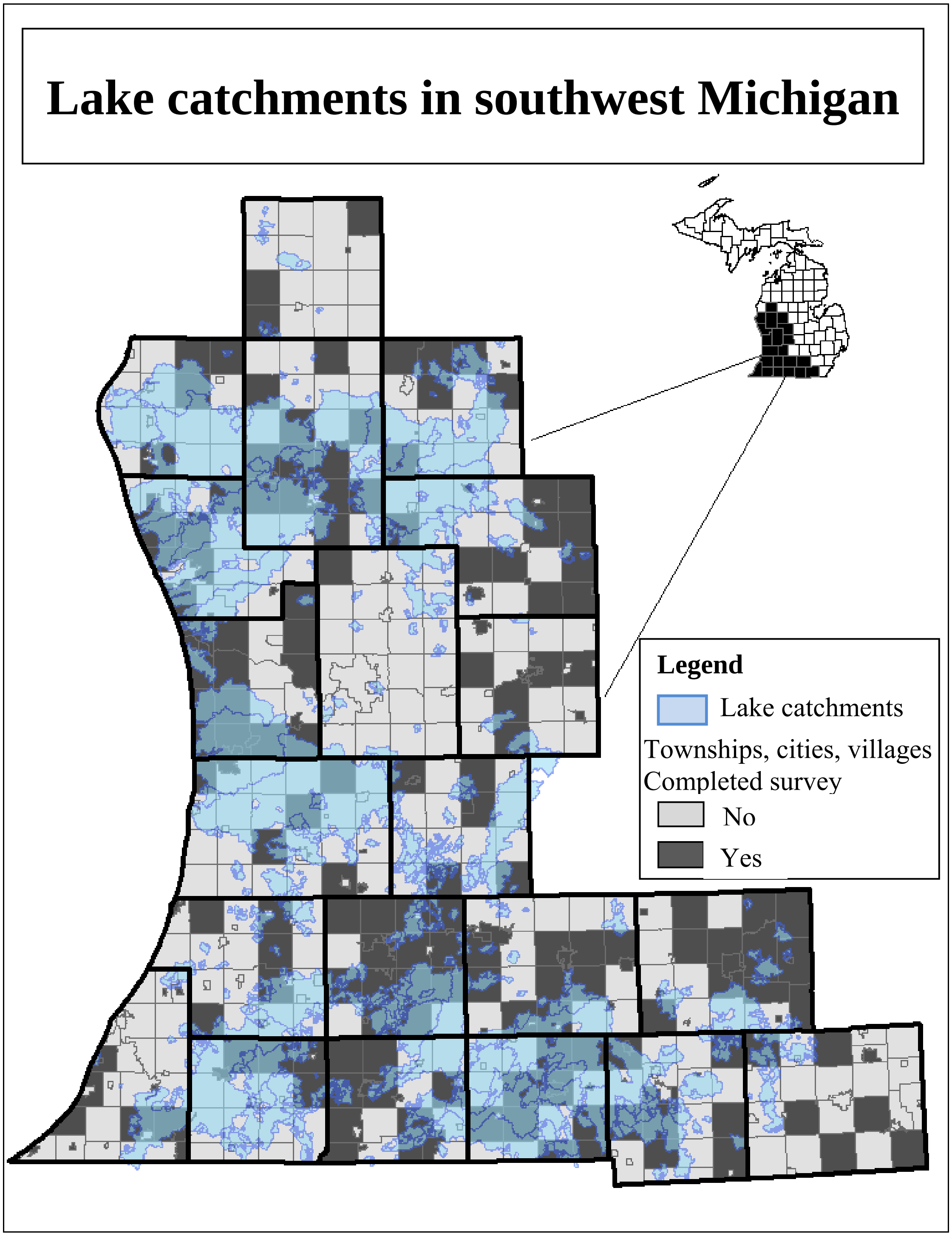

Figure 1. Study area of 21 counties in southwest Michigan; Allegan, Barry, Berrien, Branch, Calhoun, Cass, Hillsdale, Ionia, Jackson, Kalamazoo, Kent, Lake, Lenawee, Mecosta, Montcalm, Muskegon, Newago, Oceana, Ottawa, St. Joseph, and Van Buren.

Water clarity, land use/cover, and local policy data collection

Lake water clarity data collection

I used lake water clarity as the dependent variable in all of the regression models. Water clarity is commonly measured using a Secchi disk, which entails a person lowering a black and white disk over the shady side of a boat until it is no longer visible at the surface. This depth is called the Secchi depth transparency (SDT) and is a commonly used coarse measure of lake transparency that is used as an indicator of water quality or lake health.

For areas with thousands of lakes, such as southwest Michigan, there are many lakes that are not sampled. Therefore, recent efforts have been made to detect water transparency remotely in unsampled lakes. A recent study by the United States Geologic Survey (USGS), in cooperation with the MDEQ, investigated the use of satellite imagery for the prediction of water clarity (USGS 2007). They built a statistical model of the Trophic State Index (TSI) for lakes greater than 25 acres from predicted SDT or Chlorophyll *a* (algal biomass; Chl-*a*) using Landsat satellite imagery. The imagery was taken during the productive summer months that produce the best predictive models using water clarity (USGS 2007). USGS-predicted SDT values were ground-truthed with physical SDT measurements from at least 20 points within the deepest part of inland lakes and within 7 days before or after the satellite acquisition date for calibration of the model (USGS 2007). The model was recalibrated every year to extrapolate the data to unsampled lakes throughout the state. I used these remotely sensed estimates of SDT as my measure of lake water clarity.

Lake catchments and land use/cover data collection

I used a subset of the MSU's Michigan Freshwater Landscape database (Soranno and Cheruvelil unpublished) for my lake and landscape data. I used the Coastal Change Analysis Program (C-CAP; http://www.csc.noaa.gov/digitalcoast/data/ccapregional/) coverage to quantify land use/cover proportions within lake catchments. Agriculture was reclassified as either row crops or pastureland. I also included measures of landscape characteristics including baseflow, road length, runoff, precipitation and catchment area for each lake (Table 3 and 4).

Table 3. Descriptive statistics for water clarity (dependent variable), land use/cover and landscape characteristic predictor variables within lake catchments (n=420).

Variable	Max	Min	Mean	Median	Standard Deviation
Water clarity	5.6	1.2	3.062	3.2	0.8
Lake catchment area (ha)	88700.6	21.2	2660.4	526.8	9140.1
% water	15.9	0.1	1.9	1.3	1.7
% urban	67.2	0	6.3	3.8	7.6
% developed	45.5	0	2.4	0.5	4.5
% grass	19.0	0	2.0	0.9	2.8
% agriculture pasture	67.3	0	11.9	10.6	9.7
% agriculture row crop	87.7	0	29.6	28.6	18.4
% wetlands	47.3	0.8	13.6	12.2	8.0
Road length (m)	149037.8	123.1	50961.5	11994.3	168043.9
Mean runoff (cm/yr) [a]	15.0	8.0	12.2	11.9	1.5
Mean baseflow index [b]	82.0	49.9	71.8	72.6	6.4
Mean precipitation (cm) [c]	37.5	1.4	27.9	32.5	8.2

[a] *Average Annual Runoff in the U.S., 1951-1980* database (http://water.usgs.gov/GIS/metadata/usgswrd/XML/runoff.xml#stdorder)

[b] Baseflow index is the estimated percent of stream flow within the catchment calculated from the *Base-flow Index Grid for the conterminous U.S.* database (http://water.usgs.gov/GIS/metadata/usgswrd/XML/bfi48grd.xml)

[c] *US Average Annual Precipitation from 1971-2000* database (http://www.prism.oregonstate.edu/docs/meta/ppt_30s_meta.htm)

Table 4. Data sources, years, and sample sizes for the 21-county study area

Data type	Data acquisition and year	Number of available data in my study area
Water clarity	USGS 2005 USGS 2007	469 lakes 420 lakes
Policy	Survey responses from jurisdictions, 2009/2010	273 responses
Land use/cover	CCAP 2000	520 lake catchments
Landscape characteristics		
Mean runoff (cm/yr) [a]	USGS 1951-1980	520 lake catchments
Mean baseflow index [b]	USGS 2003	
Mean precipitation (cm) [c]	The Spatial Climate Analysis Service at Oregon State University, 1971-2000	

[a] *Average Annual Runoff in the U.S., 1951-1980* database (http://water.usgs.gov/GIS/metadata/usgswrd/XML/runoff.xml#stdorder)

[b] Baseflow index is the estimated percent of stream flow within the catchment calculated from the *Base-flow Index Grid for the conterminous U.S.* database (http://water.usgs.gov/GIS/metadata/usgswrd/XML/bfi48grd.xml)

[c] *US Average Annual Precipitation from 1971-2000* database (http://www.prism.oregonstate.edu/docs/meta/ppt_30s_meta.htm)

Policy data collection

I collected local policy information by sending surveys to a total of 566 local jurisdictions (townships, cities and villages) in the study area (Figure 1). I obtained email addresses for the planning commissioners, township supervisors, and/or zoning administrators by calling local government offices, and then sent invitations to complete electronic surveys via Survey Monkey. Not all jurisdictions had internet access or email. Therefore, I also mailed postcards with a link to the online survey and mailed a paper copy. I then followed up with a phone call. I began the survey process with a much longer survey (81 questions, see Appendix B), but took the most answered questions from the first mailing and sent the shorter survey to increase my response rate (20 questions, Appendix B). Out of the 566 jurisdictions, 262 responded resulting in a 46% response rate (Table 5). Of the 256 respondents, I used 161 responses for the statistical analysis that were all from townships. Cities and villages were excluded from my analysis due to the small amount of land mass that they actually encompass (only six percent of the landmass throughout the whole state; Olson 2008).

Table 5. Number of jurisdictions that completed an online, paper, or phone survey.

Municipality	Number of surveys sent	Number of completed surveys	Response rate %
Townships	350	161	46
Cities	150	60	40
Villages	66	41	62

My survey questions were informed by two previous surveys that were conducted in Michigan: the Institute for Public Policy and Social Research from 1997 and 2004 (IPPSR 2004) and the Olsen survey from 2008 (Olson 2008). My survey inquired about master plans, zoning, and local environmental policies related to water quality, including those related to land use, aquatic buffers, and nutrient regulations (Table 6; see Appendix B for the complete survey). I subsequently refer to the collection of these regulations as “water policy”. My survey also included questions about enforcement, collaboration, and budgeting issues within the communities, although these were only included in the longer survey (Appendix C for all survey responses). For the statistical analysis in this paper, I focused on a set of 12 questions that were most often answered and not highly correlated with one another (Table 6).

Table 6. Survey questions used in statistical analyses (see Appendix B for entire survey and shortened survey).

Question #	Survey Question
1	Does your community have a comprehensive land use plan?
4	Does your community have a watershed management plan?
5	Are your aquatic resource management regulations based on model ordinances of a local watershed council (i.e. model ordinances)?
6	Are you collaborating with any neighboring jurisdictions on water issues?
9	Does your community have a stream buffer ordinance?
10	Does your community have a riparian buffer ordinance?
11	Does your community have a wetland buffer ordinance?
12	Are wetlands less than 5 acres protected in your community?
13	Are streams and rivers protected (more stringent than the state) in your community?
14	Are inland lakes protected (more stringent than the state) in your community?
15	Does your community have a nutrient lawn care ordinance for Phosphorus?
16	Does your community have a nutrient lawn care ordinance for Nitrogen?
17	Do you regulate residential water use for lawn watering?

Survey responses about policies were used as covariates in multiple regressions to understand how policies may cumulatively affect lake water quality. I did this in two ways: for individual survey questions and for all survey questions combined. I first looked at the aggregate effect of policies of multiple townships within one lake catchment (multiple jurisdiction catchment). I calculated a policy strength (aggregate) variable that was weighted by summing the percent of land mass of a jurisdiction with the catchment multiplied by their policy (number of yes responses)[∑ (land mass*policy)/# questions], resulting in a “policy strength variable”. I then considered the effect of policies for the case of catchments that are completely within one township (single jurisdiction catchments), thereby isolating the effect of one township’s policies. Responses to questions regarding specific policies for townships within one catchment were aggregated into a separate overall policy strength variable (# of yes responses/total questions).

Individual policy questions were also analyzed with both multiple and single jurisdiction catchments.

Statistical analysis

All statistics were run using SAS statistical software, version 9.2 (SAS Institute Inc., Cary, NC, USA). All variables were tested for normality and transformed when necessary; the lake catchment area was log transformed, while all other variables remained untransformed.

My analysis proceeded in two stages in accordance with my research questions of whether fragmentation and local policy affects inland lake water clarity (described below). To begin my policy analysis, I examined the effects of fragmentation (number of townships per catchment), land use/cover, and landscape characteristics within a catchment on water clarity. I then wanted to understand the effects of one township's policies within a lake catchment.

Does fragmentation affect water quality?

The relationship between fragmentation and water clarity was analyzed using ANOVA and multiple regressions. To be sure that results found were appropriately attributed to differences in policies and their fragmentation, I controlled for the other features of the landscape that are known to drive lake water quality in the models. These features included baseflow, size of catchment, and runoff. Correlations between water clarity, catchment area, land use/cover, landscape characteristics, and the number of townships per catchment were checked and correlated variables were eliminated as necessary (Table 2 in Appendix D - Statistics). Question 2 and forest land cover were not included in models due to high correlations with other variables ($r > 0.8$). However, question 2 was left in the table and the descriptive statistics to illustrate that many jurisdictions also had zoning ordinances. Multiple regression analysis was used to isolate the effect of fragmentation on water clarity by controlling for these other factors. Finally, a best model selection was used with individual policy questions to predict water clarity. The model selected was based upon the highest AIC value.

Does local policy affect water quality?

A similar approach to above was used to determine the effects of just one township's policies on water clarity, however, I included only single jurisdiction catchments (approximately 87 townships). Next, all policy questions were run in a multiple regression without land use/cover and landscape characteristics to determine whether policies on their own affected water clarity. All policy questions, plus land use/cover and landscape characteristics were then used in a best model selection multiple regression to determine if a smaller set of policy and landscape variables would better predict water clarity. The model was selected based upon the highest AIC value. The best model selection had a lower sample size (n=61) than the other analyses within one township because it did not include non-responses in the model, therefore reducing the sample size substantially.

RESULTS

In this section, I will first introduce the overall survey results, then present the results from my regressions and ANOVAs used to answer my questions, which are: 1) is water clarity negatively impacted by fragmentation (i.e. multiple jurisdictions within one lake catchment)?, and 2) does local land use and environmental policy have a positive effect on inland lake water clarity? First, the descriptive statistics are presented to show the number of yes responses to each policy question. Next, I analyzed just policy questions with water clarity to determine if policy itself had a relationship to water clarity. Then, I looked at the effects of fragmentation within a catchment. Policy was introduced into the fragmentation analysis and finally, the effects of individual townships' policies on water clarity within one catchment will be presented.

Of the 350 surveys sent out for township response, 161 (46%) responded by returning the mailed survey, completing the online survey, or answering the questions over the phone (see Figure 1 for areas completed). Responses of "yes" to the survey questions indicated greater efforts to protect water quality in this study. The position respondents held within their jurisdiction varied by municipality: 13% clerks, 53% supervisors, and 33% individuals who were part of the planning commission or the zoning/building boards.

One survey question that was not statistically analyzed because of extremely low response rates was related to who would be in charge of ordinance enforcement within the jurisdiction. Responses indicated that a variety of entities would be responsible depending on the jurisdiction, ranging from the township supervisor or zoning administrator to the police. When asked when enforcement took place in the community, the main answer was when someone reported wrong-doing (80%). When asked if the enforcement agent received natural resource education about the ordinances, 79% said no. Enforcement and public education of ordinances was also lacking in jurisdictions, with a majority of communities (92%) having less than 5 hours per week dedicated to enforcement of noncompliance issues. Without a large sample size, it is difficult to draw conclusions from these responses; however, they indicate that there is likely room for improvement related to how enforcement occurs.

Over 80% of the townships reported that master plans were in use, leaving nearly 20% without a master land use plan or zoning ordinance, which is currently required by law (Table 7).

Table 7. Results of IPPSR, Olson and Environmental Policy Surveys. The number and percent of respondents having a land use plan and zoning ordinance.

Survey collectors	Township Responses (total townships survey was sent to)	Percent of townships responding "YES"
IPPSR (2004)		
Yes – master plan	756 (1124)	67
Yes – zoning ordinance	809 (1138)	71
Olson (2008)		
Yes - master plan	607 (845)	72
Yes – zoning ordinance	649 (857)	76
Auvenshine (2009)		
Yes – master plan	132 (163)	81
Yes – zoning ordinance	137 (163)	84

Although nearly 80% of jurisdictions had a land use plan and zoning ordinance, 70% of single jurisdiction catchments and 80% of multiple jurisdiction catchments did not have environmental policies that protect water quality within those plans (Table 8). The yes responses to questions were very low, with 37% being the highest percentage of yes responses to 'Does your community have a watershed management plan' (aside from the master plan and zoning ordinance questions) (Table 8).

Table 8. Descriptive statistics of all survey questions of single jurisdiction catchments and multiple jurisdiction catchments.

		Townships not sharing a catchment (n=47)		Townships sharing a catchment (n=87)	
Question #	**Survey Question**	**Proportion answered yes**	**Standard deviation**	**Proportion answered yes**	**Standard deviation**
1	Does your community have a comprehensive land use plan?	0.90	0.30	0.86	0.30
2	Does your community have a zoning ordinance?	0.90	0.30	0.85	0.31
4	Does your community have a watershed management plan?	0.32	0.47	0.37	0.39
5	Are your aquatic resource management regulations based on model ordinances of a local watershed council?	0.28	0.45	0.29	0.38
6	Are you collaborating with any neighboring jurisdictions on water issues?	0.32	0.47	0.15	0.31
9	Does your community have a stream buffer ordinance?	0.02	0.13	0.18	0.12
10	Does your community have a riparian buffer ordinance?	0.18	0.39	0.17	0.32
11	Does your community have a wetland buffer ordinance?	0.29	0.46	0.18	0.34
12	Are wetlands less than 5 acres protected in your community?	0.18	0.39	0.18	0.34
13	Are streams and rivers protected (more stringent than the state) in your community?	0.07	0.26	0.07	0.22
14	Are inland lakes protected (more stringent than the state) in your community?	0.18	0.38	0.07	0.22
15	Does your community have a nutrient lawn care ordinance for phosphorus?	0.21	0.41	0.16	0.34

Primary analysis of the survey findings resulted in some differences between single and multiple jurisdiction catchments. The most prominent difference was that 17% more single jurisdictions collaborate with their neighboring communities than multiple jurisdiction catchments. Single jurisdictions also had more strict inland lakes protection (14% more) and wetland buffers (11% more) than multiple jurisdiction catchments. On the other hand, 16% of multiple jurisdiction catchments protect streams more stringently than single jurisdictions. These are not large differences, but needed exploration to determine potential reasons for the differences between single and multiple jurisdiction catchment regulations considering the extremely low yes response rate.

Next, I investigated whether the question responses affected water clarity using a multiple regression model with only policy variables as independent predictors. Questions 10, 11, 12 and 14 were significant ($p<0.10$) in the regression of single jurisdiction catchments, and the overall model was also significant ($p<0.05$), with 50% of the variability in water clarity explained by the policy questions (Single Township, Table 9). For multiple jurisdiction catchments, policy questions also produced a significant model ($p<0.05$), which explains approximately 58% of the variability within water clarity (Multiple Townships, Table 9).

Table 9. Results of multiple regressions with individual policy question responses as predictors.

	Single Township (n=42, Model R^2=0.50,Model p<0.05)			***Multiple Townships (n=38, Model R^2 =0.58, Model p<0.02)***		
Variables	**Coefficient**	**Standard Error**	**P**	**Coefficient**	**Standard Error**	**P**
Q1	-0.61	1.08	0.58	-0.24	0.49	0.63
Q4	0.05	0.38	0.91	0.07	0.35	0.85
Q5	0.36	0.35	0.31	-1.32	0.41	**0.004**
Q6	0.19	0.35	0.58	0.47	0.47	0.33
Q9	-0.12	0.92	0.90	0.38	2.00	0.85
Q10	-1.56	0.82	**0.07**	1.08	0.84	0.21
Q11	-1.53	0.76	**0.06**	0.37	0.45	0.42
Q12	2.55	0.92	**0.01**	0.50	0.68	0.47
Q13	1.30	1.22	0.30	-0.88	2.01	0.66
Q14	1.63	0.94	**0.09**	0.80	1.05	0.46
Q15	0.81	0.57	0.17	-0.03	0.65	0.97
Q16	-0.53	0.88	0.55	0.17	2.34	0.94

Does fragmentation affect water clarity?

Before policy variables were introduced into multiple regressions, I examined the individual effects of fragmentation (multiple townships within one catchment) on water clarity. I found a significant decrease in water clarity with an increase in the number of townships per lake catchment ($p < 0.001$) (Figure 2). However, there were large ranges in catchment area. One to four townships per catchment only varied in acreage by about 3,700, however, more than five township catchments' area increased by 55,000 acres (Figure 2). When I compared catchment area to the water clarity graph, the water clarity in catchments with five or more townships is the worst. The water clarity of one and two township catchments is above three meters, while three and four townships result in water clarity between two and a half and three meters, and lastly, five or more townships per catchment typically have water clarity below two and a half meters (Figure 2).

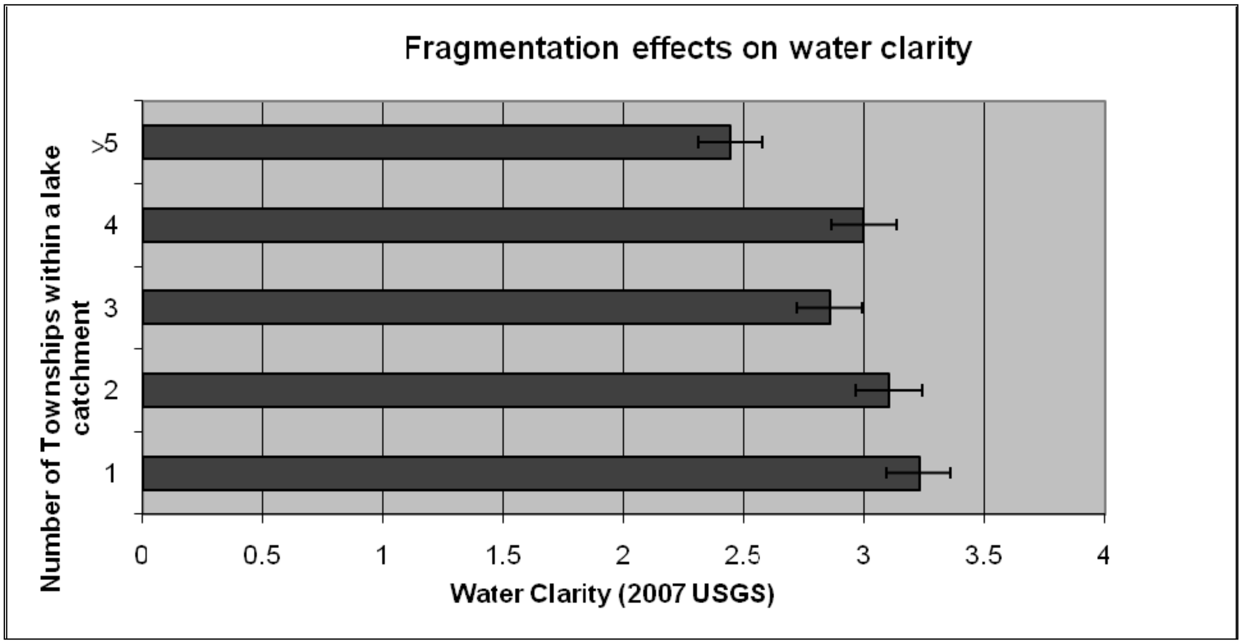

Figure 2. The number of townships in relation to the average water clarity (2007) within lake catchments that are within multiple townships (n=470, error bars are the standard error, $p<0.001$, df = 4).

Although striking, other factors in addition to fragmentation, such as catchment area and land use/cover may be underlying reasons for this pattern between fragmentation and water clarity. For example, between one and four townships, the lake catchment size only varies about 3,700 acres (1,500 hectares) (Figure 3), but between four and five or more townships, the size varies by 55,550 acres (22,500 hectares). Using a regression model, lake catchment area was a significant factor in predicting water clarity ($p < 0.05$, overall model $p < 0.001$). A model containing land use/cover, landscape characteristics, and number of townships explain approximately 22% of the variability of water clarity (Table 10). Although included in the regression, the number of townships was not significant.

Table 10. Results of fragmentation multiple regressions demonstrating the effects of fragmentation on lake water clarity, policy independent (n = 216, R^2 = 0.22, p< 0.001).

Variable	Coefficient	Standard error	p
Agriculture row crop*	-0.010	0.004	**0.017**
Agriculture pastureland*	-0.002	0.007	0.775
Urban*	-0.020	0.014	0.137
Developed open space*	0.003	0.026	0.919
Grassland*	-0.032	0.024	0.182
Wetlands*	-0.001	0.007	0.852
Lake catchment area	-0.434	0.149	**0.004**
Water	0.016	0.045	0.725
Road length (m)	6.44E-8	3.31E-7	0.846
Mean base flow	0.035	0.010	**0.0004**
Mean runoff (cm/yr)	-0.084	0.069	0.228
Mean precipitation (cm)	-0.001	0.009	0.931
Fragmentation (number of townships)	0.053	0.061	0.386

*The land use/cover variables were used as a percent of land use within a lake catchment

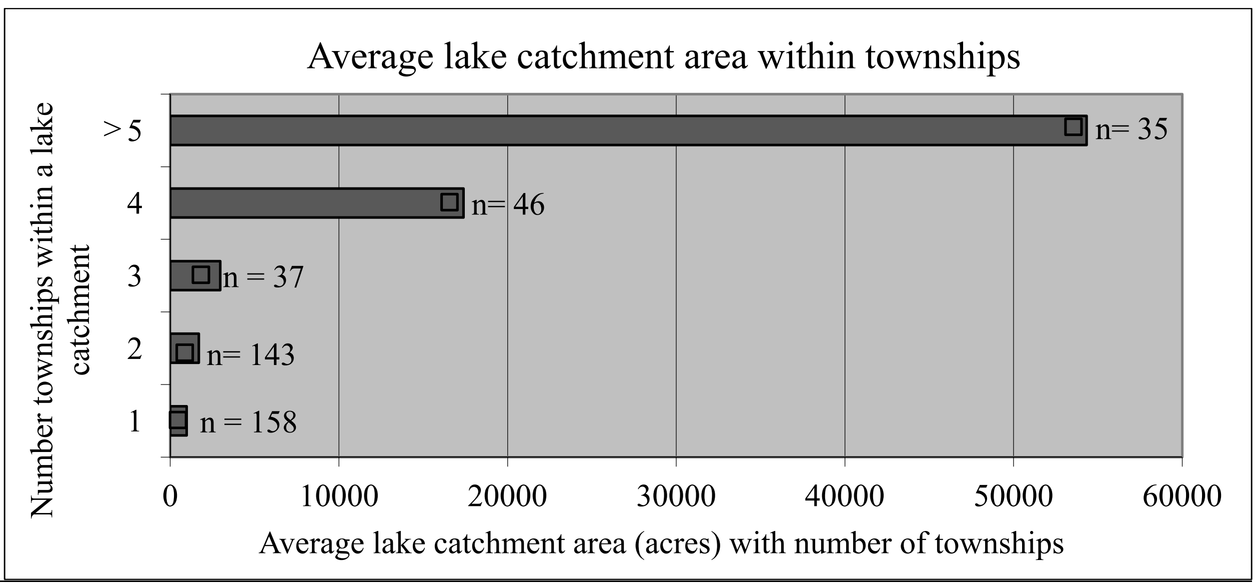

Figure 3. Average lake catchment area for townships. Catchment area increases dramatically when there are more than 5 townships (p=0.6952, F=0.15, R^2=0.004).

Much of the land use in southwest Michigan is designated and used as agriculture, which is a confounding variable of the lake catchment area. The percentage of agriculture row crops was significant in the fragmentation regression (p<0.05), which could be driving the relationship between water clarity and fragmentation (Table 10). Individual analysis on land use variables indicated that pastureland and row crop agriculture dominated the lake catchments by 40 to 50% in all categories of townships (1, 2, 3, 4, and greater than 5) (Figure 4).

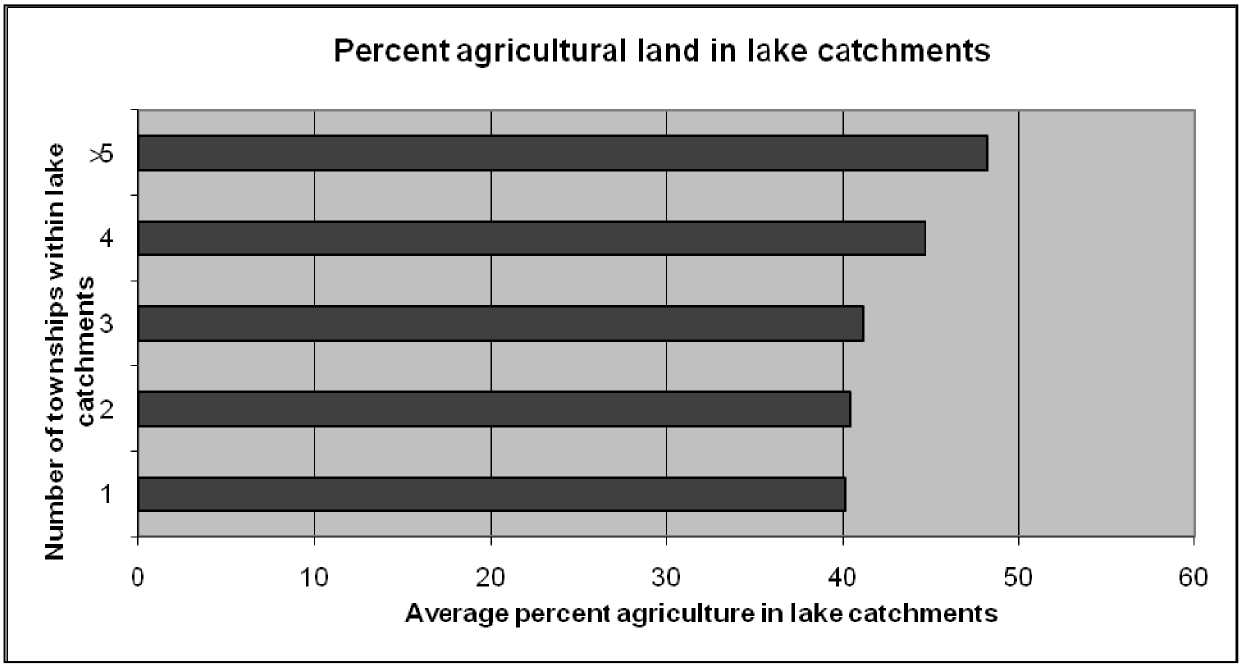

Figure 4. The average percentage of all agriculture in lake catchments that are within 1, 2, 3, 4, and greater than 5 townships (n = 429, R^2 = 0.0532, p<0.001).

As the average percent of row crops increased, the number of townships within a lake catchment also increased. Within larger lake catchment areas were more townships and a high percentage of agriculture, which were probably the driving factors in lower water clarity within these catchments. Policy was the next variable to add into regressions to determine whether it had an effect on water clarity.

Does local policy affect water clarity?

Next, I added an aggregate policy variable [∑ (land mass*policy)] to the 'Multiple regression to determine effects of policy on water clarity' model (Table 11, Multiple Townships). The policy variable did not significantly impact water clarity. The model was not significant and resulted in a low R^2 value, indicating that the model explains little (only 16%) of the variability in water clarity. Therefore, an aggregate policy variable did not produce a significant effect on water clarity as analyzed using a multiple regression with more than two townships within one lake catchment.

To isolate the effect of one township's policies on water clarity, I examined catchments comprised of only one township and did not include fragmentation. First, I used policy strength as a combination of all policy questions within one township as the policy predictor variable. This policy strength was calculated using the sum of yes responses across the jurisdiction; it was not weighted by land mass because the catchment was completely within one township. The regression model was not significant and policy strength was also not significant within the model ($p<0.10$) (Table 11, Single Township).

Table 11. Multiple regressions to determine effects of aggregate policy on water clarity. The land use/cover variables were used as a percent of land use within a lake catchment.

	Single Township (n=90, R^2= 0.1796, p = 0.2439)			***Multiple Townships (n= 46, R^2= 0.4074, p = 0.1608)***		
Variables	**Coefficient**	**Standard Error**	**p**	**Coefficient**	**Standard Error**	**p**
Agriculture row crop	-0.003	0.006	0.591	0.019**	0.008	**0.031**
Agriculture pastureland	0.018	0.013	0.175	-0.005	0.020	0.824
Urban	-0.018	0.026	0.483	0.043	0.058	0.458
Developed open space	0.048*	0.028	**0.086**	-0.109	0.11	0.339
Grassland	0.034	0.031	0.290	-0.048	0.067	0.480
Wetlands	0.002	0.012	0.860	-0.007	0.019	0.740
Lake catchment area	0.264	0.531	0.620	-0.503	0.487	0.309
Water	0.082	0.068	0.238	0.211	0.130	0.114
Road length (m)	-0.000	0.000	0.742	0	0	0.607
Mean base flow	0.050**	0.019	**0.012**	0.043*	0.023	**0.074**
Mean runoff (cm/yr)	-0.172	0.129	0.185	-0.170	0.163	0.306
Mean precipitation (cm)	-.0032*	0.017	**0.062**	0.025	0.028	0.363
Fragmentation (number of townships)	---	---	---	0.045	0.229	0.849
Policy	0.060	0.058	0.307	0.075	0.084	0.380

(*p<0.10, **p<0.05, *** p<0.001)

Following the policy strength regression analysis, I used a best model selection to investigate which variables would produce a significant model to predict water clarity when individual policy questions were used, rather than an aggregate policy strength (Table 12). I used responses from all 12 policy questions (Table 8), land use/cover, and landscape characteristics in a best model selection based on AIC values. The final model was significant for multiple jurisdiction catchments (p<0.001) and explained 60% of the variability in water clarity, with similar predictor variables as presented earlier in the fragmentation regression, including baseflow and row crops, developed open space, mean runoff, mean precipitation, and responses to questions 5 (Are your aquatic resource management regulations based on model ordinances of a local watershed council?), 6 (Are you collaborating with neighboring jurisdictions?), 10 (Does your community have a riparian buffer?), and 11 (Does you community have a wetland buffer ordinance?) (Multiple Townships, Table 12). Question 5 was negatively related to water clarity, therefore producing poor water clarity when jurisdictions had regulations based on a local watershed council. Developed open space and mean runoff were also negatively related to water clarity.

Using the same best model selection described above, questions 11 (Does you community have a wetland buffer ordinance?), 12 (Are wetlands less than 5 acres protected in your community?), 13 (Are streams and river protected (more stringent than the state) in your community?), and 14 (Are inland lakes protected (more stringent than the state) in your community?) were included in the best model for single jurisdiction catchments. Question 11 was negatively related to water clarity, meaning that if a community had a wetland buffer ordinance, their water clarity was worse. The negative relationships was opposite of what was expected. The model explained 45% of the variability in water clarity (Table 12, Single Township) and also included similar significant policy questions as well as land use/cover and landscape characteristic variables as the previous models (Tables 9 and 11, Single Township). Due to the significance of the final best model selection (Table 12), policies similar to those in questions 11, 12, 13, and 14 may be important to consider when creating and implementing land use planning documents.

Table 12. Best model selection using land use/cover, landscape characteristics, and individual policy questions, model ranked based on the highest AIC value.

	Single Township (n = 61, R^2 = 0.45, p<0.0001)			*Multiple Townships (n = 38, R^2 = 0.60, p<0.0001)*		
Variables	**Coefficient**	**Standard Error**	**P**	**Coefficient**	**Standard Error**	**P**
Q5	---	---	---	-1.23	0.29	0.0001
Q6	---	---	---	0.63	0.32	0.06
Q10	---	---	---	1.94	0.40	<.0001
Q11	-1.12	0.31	0.00	0.52	0.27	0.06
Q12	0.87	0.32	0.01	---	---	---
Q13	2.02	0.60	0.002	---	---	---
Q14	0.48	0.31	0.13	---	---	---
Developed open space	0.05	0.02	0.017	-0.04	0.04	0.30
Mean baseflow	0.04	0.01	0.002	0.027	0.02	0.08
Mean precipitation	0.02	0.01	0.12	---	---	---
Mean runoff	---	---	---	-0.20	0.08	0.02

DISCUSSION

Research Question 1: Does fragmentation affect water clarity?

My results suggest that fragmentation (i.e., more townships per catchment) resulted in a decrease in water clarity (Figure 2; $p<0.001$). Several reasons may explain this pattern. For example, catchments with greater area might have poor water clarity, especially if these catchments have large amounts of agricultural land use, which could be driving this relationship. Upon further exploration of land use/cover within the catchments, I discovered that agriculture encompasses over 40% of each catchment within my study area (Figure 4). The percentage of agriculture throughout the catchment area could be another reason that the number of townships within a lake catchment affected water clarity. In fact, the percent of row crops increased as more townships were in a catchment, which could be due to large agricultural operations across expansive land, thereby crossing jurisdictional boundaries. Agricultural lands may also explain the decrease in water clarity since agricultural runoff is a main driver of impaired water quality (Langpap et al. 2008, Doppelt et al. 1993, Karfmacher 1998, EPA 2010). Since there is more surface area for water to drain into a lake, and water flowing over the land picks up nutrients and then deposits them into waterbodies, we would expect fragmented catchments with high amounts of agriculture to have low water clarity.

When land use/cover and landscape characteristics were added to a regression with fragmentation, the overall model was significant ($p<0.001$), but only explained about 22% of the variability of water clarity. Within the model, the lake catchment area, agriculture row crops, and mean base flow were significant (Table 10). This model had the largest sample size in this study ($n=216$) because policy was not included in the model, meaning there was not a factor restricting the size. The ANOVA and regression results match in significant variables affecting water clarity, with the exception of fragmentation, which was not significant within the regression model. This could be explained by the confounding factors described above of agriculture and catchment area. In conclusion, there is little evidence supporting the idea that fragmentation alone is negatively affecting water clarity, but that fragmentation is a contributing factor to poor water clarity.

Research Question 2: Does local policy affect water clarity?

Local environmental policy was examined in two different ways to explore the question of local policy affecting water clarity: 1) an aggregate policy strength was calculated using a weighted sum of all the responses within one catchment, and 2) individual policy questions were included in analysis. Both of these approaches were used for analyses of multiple jurisdiction catchments and single jurisdiction catchments.

The aggregate local policy variable did not significantly affect water clarity of either catchment type (Table 11, Single or Multiple Township). In the regression, land use/cover and landscape characteristics were used to control for factors known to affect water clarity. Developed open space, mean base flow, and mean precipitation were significant within the model (n=90) for single jurisdiction catchments and agriculture row crop and mean base flow were significant for multiple jurisdiction catchments (n=46). Interestingly, different land use/cover and landscape characteristics were included for each regression, however, mean base flow was a common predictor across regressions.

From a policy standpoint, local governments cannot provide more stringent regulations than the state, or that conflict with the Right to Farm Act, for agriculture practices within their planning or zoning authority. This could explain why the aggregate policy strength variable did not tend to affect water clarity in my analysis, especially since many catchments were large and did not contain more stringent local land use planning agricultural regulations. Although agriculture is a necessary industry, typical farms produce much phosphorus and nitrogen, which then enters a water source, negatively effecting water quality. Thus, local governments are more likely to positively influence water quality by focusing on non-agricultural policies that can be defined within their master plans and zoning ordinances.

When land use/cover and landscape characteristics were not controlled for in a regression, models that included individual policy question responses of single and multiple jurisdiction catchments were significant in predicting water clarity ($p<0.05$). The sample size of single (n=47) and multiple jurisdiction catchments (n=38) independent policy question regressions was very low due to a lack of answers to the questions (Table 9). For single jurisdiction catchments, 50% of the variability in water clarity was explained by this model, and for multiple townships, 58% of the variability in predicting water clarity was explained by policy. For the single township catchment models (Table 9), question 10 (Does your community have a riparian buffer ordinance), 11 (Does your community have a wetland buffer ordinance, 12 (Are wetlands less than 5 acres protected in your community), and 14 (Are inland lakes protected (more stringent than the state) in your community) were all significant ($p<0.10$). However, question 10 and 11 were negatively related to water clarity, meaning that when jurisdictions had these policies, water clarity was low (poor). The negative relationship of riparian and wetland buffers could be due to retrospective policies taking place when there was already a problem, meaning the lake could have already had poor water quality and to treat this, riparian and/or wetland buffers were implemented to try to improve the water quality.

In the multiple jurisdiction catchment regression with individual policy questions (Table 9), the only individually significant variable within the model was question 5 (Are your aquatic resource management regulations based on model ordinances of a local watershed council) ($p<0.001$). This question was also negatively related to water clarity. Again, the same retrospective reasoning could be applied to explain the negative relationship of a response that would seemingly improve or produce good water clarity.

Some townships implemented riparian and wetland buffers around lakes and streams to help filter nutrients out of the water before it enters the lake or stream and improve water quality. Others provided guidance for open space requirements to help decrease impervious surfaces and help retain some natural areas. However, just because guidance is provided within a master plan or zoning ordinance does not mean that the policy has been implemented or enforced on the ground. It is clear through previous research that local officials need and want to be trained in natural resource management (Olson 2008) in order to best run their jurisdiction with guidance on what and how to implement natural resource planning.

When land use/cover and landscape characteristics were controlled for in a regression that also included all policy questions, the significant models included four policy questions for single jurisdiction catchments (questions 11, 12, 13, and 14) and four questions for multiple jurisdiction catchments (questions 5, 6, 10, and 11; Table 12). Developed open space and mean runoff were negatively related to good water clarity, which could be explained because runoff typically contains many nutrients and developed open space are typically areas such as golf courses, which also tend to use many nutrients. Question 11 (wetland buffer ordinance) was the only question that overlapped in significance between the two models. However, it was negatively related to water clarity in single jurisdiction catchments, and positive with multiple jurisdiction catchments. The wetland buffer ordinance could have been put in place due to already poor water quality in single jurisdiction catchments, and perhaps within multiple jurisdiction catchments, the buffer was put into place to prevent nutrients from entering waterbodies.

In single jurisdiction catchments, having wetlands greater than five acres, streams and rivers, and inland lakes protected more stringently than the state was positively related to water clarity. This result is intuitive considering that these ordinances are used to improve water clarity. Still, only 18% of jurisdictions answered yes to the wetland and inland lakes ordinance and only 7% protected streams and rivers more stringently than the state. For multiple jurisdiction catchments, collaborating with neighbors, riparian buffer and wetland buffer were all positively related to water clarity. These questions were also only answered as yes 15% (single township) to 18% (multiple township) of the time. These percentages are very low, and it is surprising that such a low percentage would capture this positive effect on water clarity. The collaboration result is particularly intriguing because in previous studies and surveys, many jurisdictions do not like to collaborate and/or relinquish any type of power they have over their jurisdiction (Gerber et al. 2005 and Olsen 2008). In conclusion, certain policies do show a trend in good or poor water clarity, providing a starting point for policymakers or future research to continue.

Implications of Survey Responses: Fragmentation and policy effects on water quality

Although some questions in my survey were not statistically analyzed, mainly because very few jurisdictions answered these questions, they are still important aspects to creating good policy, but resulted in sample sizes that were too small for inclusion in the regressions. For example, along with planning, enforcement is a major responsibility and an important aspect of successful laws. Most jurisdictions reported that enforcement was only used if someone reported wrong-doing and that very few hours, if any, were dedicated to enforcement or ordinances. In addition, public education involving the ordinances was lacking. These two aspects of implementing water protection are important steps to achieving successful results. It is imperative to the natural resources and water quality in Michigan that staff responsible for land use planning and zoning, along with the public, be educated in natural resource management and that enforcement of policies is dedicated to the budget.

The presence of multiple jurisdictions within a lake catchment may result in conflicting and therefore ineffective policies. When asked if jurisdictions collaborated with neighbors, 84% of jurisdictions that share lake catchments responded no, while 70% of single jurisdiction catchments responded no. This difference in response could indicate a type of free riding mentality; if one jurisdiction knows there is already more stringent policy within their combined catchment, they may not want to implement costly and aggressive policies too. Many government agencies lack funding to create, implement or enforce ordinances, therefore, if one knows the neighboring jurisdiction has more stringent laws than the state, they may think that is enough to improve the water quality. On the other hand, this thinking opens a potential avenue where collaboration would be beneficial. Many jurisdictions may not know who shares a catchment with them, let alone the catchments surrounding them. If jurisdictions worked together on similar issues, they would not have to reinvent the wheel to create policies or solutions that have previously been implemented by others.

Many previous studies have evaluated land use policy and their potential effect on water health. However, evaluation needs to be completed once policies are implemented and years after to assess whether their intended goal is being met. Because master plans will now have required review after five years, evaluation of effects on natural resources and water quality could be built into this requirement and assessed at this time. The evaluation data could be uploaded to an online database (assuming all jurisdictions gained internet access), and managed by the state. Once the evaluation was complete, results could be conveyed to local jurisdictions, including summaries on which policies were effective in meeting goals, and which were not.

By comparing the results of my survey to past surveys, I was able to document general improvements in the planning sector over a seven year period for townships that completed my survey (2010). I documented an increase in master plans and zoning ordinances compared to Olson (2008) and IPPSR (2004). In the IPPSR (2004) survey, 67% of jurisdictions had master plans, then four years later for Olson's survey 72% of townships had master plans, while one year later 80% of townships responded to having a master plan implemented for their jurisdiction (Table 7). This 13% increase in jurisdictions now having master plans could be due to the legal requirement of having master plans. According to the results presented here, despite the rise in master plans and zoning ordinances, very few townships have innovative water quality policies or an awareness of the linkages between land use planning and water quality.

When I compared the proportion of jurisdictions answering "yes" to questions, I found that not much difference occurred between how single jurisdictions versus multiple jurisdictions answered the questions. Only a few questions stood out as having a 10% or greater difference between types of catchments (Table 8). For example, more townships that share a catchment had stream buffer ordinances than did single jurisdiction catchments. This could be due to more streams being present in larger catchments that have multiple townships, leading to a higher likelihood of implementing an ordinance. Still, only 18% of multiple jurisdictional catchments answered yes to this question. On the other hand, single jurisdiction catchments answered yes to question 11 (29%; Does your community have a wetland buffer ordinance), question 13 (7%; Are inland lakes protected (more stringent than the state)), and question 6 (32%; Are you collaborating with any neighboring jurisdictions on water issues). It was surprising that single jurisdictions answered yes to collaborating with neighboring jurisdictions more than multiple townships. As previously mentioned, one reason for this result could be that aggressive policies are more costly to implement, monitor, and enforce; therefore, townships may avoid more stringent policies particularly when a neighboring township already has more aggressive policies. However, it has also been noted that many jurisdictions may not know who shares a catchment with them, let alone what policies they may have.

Olson's survey results (2008) indicated that surface water, groundwater, and land use/cover were "very important" to townships in terms of having information on these subjects in order to make land use decisions. Results of my study showed that many jurisdictions did not have increased environmental ordinances in their respective master plans. The lack of environmental ordinances could indicate that local jurisdictions do not know that they have the authority to increase levels of protection, they may not know how to do so, or they may not have the appropriations to do so. In Olson's survey, many townships stated that in regards to natural resources information, they did not know how to interpret it, incorporate it into land use planning, or what to do with it once they obtained the information. One person from my environmental policy survey said, "(unnamed township) does not do planning and zoning. I would like to know what, if anything, we should do in regards to water quality and what tools are available". This comment expresses an interest in obtaining and using information, but a lack of knowledge of where to find it.

Some jurisdictions were happy to receive my survey because they did not realize they were able to implement more stringent regulations. One person said: "Please send results, I have been an advocate of these ideas for over 30 years. Governmental units do not address these issues unless it is mandated. Very seldom does government do something because it is the right thing to do." This could be why every question had an overall low yes response (less than 37%). When funding is not available, it could be difficult for people to find information about how to manage natural resources. A few respondents commented that they have no money allocated to implement more stringent regulations even if they wanted to. When asked who should be in charge of protecting water quality and implementing programs for their jurisdictions, an overwhelming majority (95%) stated that local governments should be (Appendix C for all survey results). One participant mirrored this point by saying: "Our largest problem in this agricultural district is massive state and Federal interference..." Another person stated that it would be helpful if state or Federal government could help implement and/or fund programs. One potential way to alleviate the financial stress surrounding the creation and implementation of new regulations could be collaboration between jurisdictions.

Along with increasing collaboration among jurisdictions, communication between local jurisdictions and the science community needs to be increased. The inherent link between land use and water quality was not recognized by many township officials when the survey began, but because this study reached out to local officials, hopefully they now have the understanding that land policy can affect water quality. The results of my study indicated a missing link between land use affecting water quality, which strengthens the call for education on natural resources management to local jurisdictions (Olsen 2008). Other responses to initial inquiry divulged that some jurisdictions were not up to date with technology (e.g., did not have access to the internet and requested a hard copy of the survey). Local jurisdictions need to know that land use does affect lakes, and that the plans and ordinances of their jurisdiction will directly and indirectly affect lake water quality. Multiple jurisdiction catchments tend to have lower water clarity, which means that these jurisdictions need to collaborate at least within their catchments. Not only natural resource management information needs to be disseminated to local jurisdictions, but information about catchments and the surrounding area affecting the lakes within multiple jurisdictions. For such dissemination to occur, all township offices should have appropriate technology.

Assumptions, limitations, and future directions

One major challenge in developing my study was locating email addresses and phone numbers for planning and zoning officials. I had hoped that my survey would be received by a planning or zoning official since they are the main creators of master plans and zoning ordinances. However, due to the lack of easy access to contact information, some respondents were clerks, supervisors, and a small array of others within a township. One clerk was reluctant to give me contact information for the planning commissioner because he was a very busy, full time farmer; she also said the area had no zoning and thought that he would just direct us to the waste water treatment plant, demonstrating a lack of understanding surrounding the potential effects of policies on natural resources and who should be responsible for such policies. The lack of clear points of contact within a jurisdiction could also prove difficult when jurisdictions are trying to collaborate. To overcome this challenge in my study, I used a mailing list and the post office instead of email, and broadened the recipient of my survey to township supervisors and others who had the knowledge to answer the questions for their jurisdiction. A centralized database for updated township contact information would be a benefit not only to researchers, but to township officials for sharing information.

Some assumptions incurred within my research were about what survey responses meant that may have influenced my results. For example, what is the meaning of questions that were left blank? Did the jurisdiction not know the answer to the question? Did they not want to answer the question because of the implications of answering no? Did they get tired of taking the survey and decide not to answer some questions? When I used a predictor variable of question completed yes, no, or blank in a regression, there was a positive relationship between water clarity and the blanks. However, I left the non-responses out of the rest of my analyses because I did not have enough information to interpret their meaning. Because a relationship exists between non-response and water clarity, further research such as follow-up interviews with survey respondents is needed to ascertain the meaning of the non responses.

The time difference between the collected policy information (2010/11) and the water quality information that was available (2007) also may have had an effect on my results. Although many policies have been in place since 2007 or before, some could have been fairly recent and their effects would not be reflected in the water clarity dataset yet. In the models, the assumption was that if a jurisdiction had a policy, their water quality would be affected, regardless of when those policies were enacted. Ultimately, the effect of new policies would not be captured by water clarity data that was collected prior to the implementation of regulations (Hasic and Wu 2006). However, the policy data used in this study was collected after the water clarity data, which increases the likelihood of detecting effects.

Water clarity could be impacted by many other factors not involved in this study, including invasive species, weather, the amount of pesticides used in agriculture and on individual lawns, or pollution from boaters. Further study that includes such factors as well as socio-economics, demographics, population density and tax base could improve the accuracy in predicting water clarity by helping to explain some additional variation.

CONCLUSIONS

A positive relationship between policy and good water quality was expected, especially within unfragmented catchments. I did find some individual policy questions were significantly related to good water clarity and that fragmentation within a lake catchment may contribute to decreased water clarity. However, when fragmentation and policies were included in models together, the effects of fragmentation were insignificant. These results demonstrate the need for studying the effects of inter-jurisdictional collaboration of water policy and land use planning on water clarity to further increase the protection of natural features.

Water quality is an important asset in Michigan, for recreation, tourism, and as a source of drinking water. Land use affects water quality, specifically water clarity. Because master plans and zoning ordinances guide land use planning, they indirectly affect water clarity. It is important for local policymakers to understand that the ordinances they do or do not enact, implement, and enforce have the potential to affect the water clarity within their jurisdictions as well as neighboring jurisdictions. Questions that were significant in my models are likely good places for policymakers to start in order to protect water quality. For example, enacting laws within the master plan or zoning ordinance such as wetland buffers, and stringent wetland, stream, and inland lake protection could be a successful way to begin protecting the waters of single jurisdiction catchments, while multijurisdictional collaboration and riparian buffers may be successful in multiple jurisdiction catchments.

Many factors are involved in policy formation, implementation and enforcement. Policies that are written in the master plan and zoning ordinance are a good starting point for a municipality and its resources, however, these policies need to be communicated to the public and to the elected officials in order to have a positive impact on natural resources. Because land use/cover influences water clarity and these policies are addressing issues mostly involving surface water runoff (nonpoint sources), policy needs to be implemented for more than a short amount of time to see their true effects.

APPENDICES

Appendix A: Federal and State Regulations Pertaining to Water Quality

Table 13. Federal and state regulations pertaining to water quality.

Regulatory Agency	Responsibilities	Missions	Regulatory Authority
US Army Corps of Engineers	Navigable waters Coastal waters Wetlands Flood protection	Through its Civil Works program the Corps carries out a wide array of projects that provide coastal protection, flood protection, hydropower, navigable waters and ports, recreational opportunities and water supply.	Yes
EPA	Clean Water Act Safe Drinking Water Act National Environmental Policy Act Resource Conservation and Recovery Act	To protect human health and the environment	Yes
US Fish and Wildlife Service	Preserve and restore aquatic habitat Fish and wildlife conservation and restoration	The Region is Committed to Expanded partnerships offering innovative opportunities to enhance the Region Healthy fish and wildlife trust species populations and habitats to support them Providing the public with quality hunting, fishing, wildlife watching, and other wildlife-dependent recreational opportunities on Service lands National: The mission of the U.S. Fish and Wildlife Service is working with others to conserve, protect, and enhance fish, wildlife, plants, and their habitats for the continuing benefit of the American people.	Yes
Natural Resources	Water quality and quantity studies related	Provide leadership in a partnership effort to help	Yes

Table 13. Federal and state regulations pertaining to water quality.

Regulatory Agency	Responsibilities	Missions	Regulatory Authority
Conservation Service	to agriculture Conduct soil surveys Work with farmers to develop conservation plans	America's private land owners and managers conserve their soil, water, and other natural resources.	
Michigan Department of Environmental Quality (Department of Natural Resources and Environment)	NPDES permit	Regulates point source pollution through permitting and enforcement -wastewater treatment facilities - industry	Yes
Michigan Department of Environmental Quality Water Resources Division	http://www.michigan.gov/deq/0,1607,7-135-3306_28610---,00.html Most things water, but not drinking water	Clean and safe water	Yes
County Health Department	Septage permits	Liscencing and handling of domestic septage	Yes
County Drain Commission	Stormwater infrastructure	Implements stormwater management based on each county jurisdiction	Yes
Local Government (township, village, city)	Land use planning and zoning	Master plans for their respective jurisdiction	Yes
Michigan Association of Regions (MAR)	Regional Land Use Planning	Provides assistance to local governments -lead and/or participate in watershed management groups -involved in coastal zone management	No
Board of Water and Light	Produces residential and Industrial energy	Provides water for residential use	Yes
Watershed			No

Table 13. Federal and state regulations pertaining to water quality.

Regulatory Agency	Responsibilities	Missions	Regulatory Authority
councils			
MAEAP	Provides guidelines for sustainable farming operations	Provides incentives to farmers to implement BMPs to reduce water pollution	No
Great Lakes Fisheries Council (GLFC)	The commission coordinates fisheries research, controls the invasive sea lamprey, and facilitates cooperative fishery management among the state, provincial, tribal, and federal management agencies.	-To develop coordinated programs of research on the Great Lakes, and, on the basis of the findings, to recommend measures which will permit the maximum sustained productivity of stocks of fish of common concern; and -To formulate and implement a program to eradicate or minimize sea lamprey populations in the Great Lakes	Yes
Michigan Lake and Stream Association	Nonprofit, statewide organization to protect and preserve inland lakes and streams	Preservation and protection of Michigan's inland lakes and streams	No

Appendix B: Complete Shortened Environmental Policy Survey and Long Environmental Policy Survey

Michigan State University
Local Environmental Policy Survey (Shortened)

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1. **Please write the jurisdiction you are in, starting with county and then either township, city or village:**
    a. County: ____
    b. Township: ____
    c. City: ____
    d. Village: ____
2. **Who is most in charge of land use planning in your jurisdiction (circle those that apply):**
    a. County
    b. Consultant
    c. Part-time staff
    d. Full time staff
    e. Nobody
    f. Other (please specify) _____________________________________
3. **Would you please provide your email address:** ______________________
4. **What is your title in the jurisdiction (i.e.: township supervisor, clerk, etc):**

    ____
5. **Does your community have a comprehensive land use plan? If yes, when was it last updated?**
    a. Yes – updated in _____________________________________
    b. No
6. **Does your community have a zoning ordinance? If yes, when was it last updated?**
    a. Yes – updated in _____________________________________
    b. No
7. **Do you have GIS data of your land use Plan?**
    a. Yes
    b. No

8. Would you be willing to share your GIS files? If yes, whom should I contact to get these?

a. Yes
b. No
c. Name and email or address of person to provide these:

____

9. What percentage of your jurisdiction is zoned for the following housing densities (please write in the percentage next to each of the following).

a. % high density single-family residential: _________________
b. % high density multi-family residential: _________________
c. % medium density single-family residential: ______________
d. % medium density multi-family residential: ______________
e. % low density single-family residential: _________________
f. % low density multi-family residential: __________________
g. % planned unit development: _________________________
h. % rural: ____
i. % agriculture ______________________________________
j. % commercial _____________________________________
k. % other (please specify) _____________________________

10. Does your community have a watershed management plan?

a. Yes, DEQ approved plan
b. Yes, other plan (please specify) ________________________
c. No

11. Are your aquatic resource management regulations based on model ordinances of a local watershed council (i.e. Model ordinances). If yes, which council:

a. Yes ____
b. No

12. Are you collaborating with any neighboring jurisdictions on water issues, if yes whom?

a. Yes ____
b. No

13. Do you have a growth management ordinance? Please circle all that apply:

a. Green belt
b. Urban growth boundary
c. Agriculture and forest protection district
d. Conservation subdivision
e. Purchase of Development Rights
f. Transfer of Development Rights
g. Orderly annexation agreement
h. General subdivision standards

14. Does your community have a stormwater ordinance?

a. Yes
b. No, the county regulates stormwater
c. No, county or township does not regulate stormwater

15. Do you use a Low Impact Development manual to guide development options? If yes, which guide?

a. Yes ____
b. No

16. Indicate whether you have the following natural features ordinances (circle all that apply):

a. Stream buffer
b. Riparian buffer
c. Wetland buffer

17. Are the following natural features protected in your community (i.e. more stringent than the state level)?

a. Wetlands (less than 5 acres)
   i. Yes
   ii. No
b. Streams/rivers (not including ditches, culverts and drains)
   i. Yes
   ii. No
c. Lakes (inland lakes)

i. Yes

ii. No

18. Does your community have a lawn care ordinance for the following nutrients? Please provide the distance if you circle answer ii.

a. Phosphorus

i. Yes, restricted use

ii. Yes, restricted within a certain distance to a waterbody ___________

iii. No

b. Nitrogen

i. Yes, restricted use

ii. Yes, restricted within a certain distance to a waterbody __________

iii. No

19. Do you regulate residential water use for lawn watering?

a. Yes

b. Yes, but only in drought years

c. No

20. Approximately how many hours per week are dedicated to environmental inspection/enforcement in your jurisdiction?

21. In your opinion who should be most responsible for protecting water quality and implementing programs in your community? (circle all that apply.)

a. Federal government

b. State government

c. Local government (county, city, township, village)

d. Individual citizens

e. Don't know

22. Do you believe your local environmental regulations are more stringent than the state level? If yes, how so?

23. Any other comments you have on water management/land use planning within your jurisdiction?

Table 14. Long Local Environmental Policy Survey Questions. Full pdf version of questions with answer options is available (in an electronic version) upon request.

Question #	Question
1	Please indicate which jurisdiction/community you represent by selecting the county followed by one of the following:
2	Who is most in charge of land use planning in your jurisdiction?
3	Would you please provide your email address?
4	Does your community have a comprehensive land use/master plan?
5	Does your community have a zoning ordinance?
6	Indicate if your community has the following documents, and if so, when the documents were last updated:
7	Do you have GIS data for your land use plan?
8	Would you be willing to share the GIS files with us?
9	Does your community have an open space ordinance?
10	Does your zoning ordinance permit cluster development?
11	If your community has cluster development, what percent is required to be open space?
12	What percentage of your jurisdiction is zoned for the following housing densities?
13	What percentage of land must be impervious surface (what is the maximum allowed area to be non-pervious) for each of the following? (please specify what “other” stands for.)
14	What is the set-back for each housing density? (please specify what “other” stands for.)
15	What is the maximum lot size for each housing density?
16	What is the minimum lot size for each housing density?
17	Is there an invasive species action plan in your community?
18	Does you community have bait use or release guidelines stricter than the state?
19	Are boat rental facilities mandated to use a boat wash down (power sprayers and/or chemicals) between boat rentals?
20	Does your community have any boat washing stations?
21	Are there any segments of river or stream in your community that interferes with one or more aquatic species passage or migration (e.g. raised culverts, roads, dams, ditches, channelization)?
22	Check the box if you plan includes these provisions for each density of housing: - Sidewalks required to be sloped to drain to the front yard rather than street - Part of forest of specimen tree stands in residential development sites

Table 14. Long Local Environmental Policy Survey Questions. Full pdf version of questions with answer options is available (in an electronic version) upon request.

Question #	Question
	have to be preserved
23	Does your community have a watershed management plan?
24	Are your aquatic resource management regulations based on model ordinances of a local watershed council (i.e. model ordinances)?
25	Are you collaborating with any neighboring jurisdictions on water issues?
26	Do you have a growth management ordinance?
27	How long is your permitting process for development from the time a permit application is submitted until a decision is made?
28	Are curbs and gutters required for public residential streets?
29	Are curbs and gutters required for private roads?
30	Do you have road salt restrictions?
31	Are there incentives for developers to provide parking within garages rather than surface parking lots?
32	Is a minimum percentage of parking lot required to be landscaped?
33	Does your community have a stormwater ordinance?
34	Check the box if you offer incentives for the following (rain barrels, green roofs, green building, infiltration of stormwater, other)
35	Can stormwater be directly discharged into a jurisdictional wetland without pretreatment?
36	Check all established design criteria for best management practices that can provide stormwater quality treatment within your community (bioswales, grass swales, rain gardens, bioretention island, biofilters, dry swales)
37	Do you use a Low Impact Development manual to guide development options?
38	What are your performance standards for post-construction runoff control for new development and redevelopment?
39	Does your community provide incentives for farms that enroll in Michigan Agricultural Environmental Assurance Program (MAEAP) verification?
40	Do you require a soil test before the application of fertilizer in regards to agricultural practices?
41	Does your community require restrictions on the following agricultural practices (manure. Fertilizer, or herbicidal application quantities, timing of fertilizer/herbicide)?
42	Indicate whether you have the following natural features ordinances (stream buffer, riparian buffer, wetland buffer)?
43	What is the width of each buffer?
44	Are the following natural features protected in your community (i.e. more stringent than state level) (wetlands less than 5 acres, streams/rivers, lakes)
45	Do you have a floodplain management ordinance that restricts or prohibits development within the 100 year floodplain?
46	Does your community have a nutrient/lawn care ordinance for the following (phosphorus, nitrogen)?

Table 14. Long Local Environmental Policy Survey Questions. Full pdf version of questions with answer options is available (in an electronic version) upon request.

Question #	Question
47	If you answered yes to the previous question, how is this lawn care ordinance communicated to the public (flyers, radio, tv commercials, website, public meetings, none)
48	Are residents required to have their septic systems inspected or maintained?
49	Do you regulate residential water use for lawn watering?
50	Do you have any of the following in your jurisdiction? Please state how many of each in the comment section (lake associations, lake boards, none)
51	Do you have an ordinance regulating water softeners?
52	Is one staff member solely responsible for enforcement of your community's ordinances?
53	How many hours per week are dedicated to environmental inspection/enforcement in your jurisdiction?
54	How many part time and/or full time employees do you have dedicated to environmental planning and zoning?
55	Is specific training regarding the ordinances in your jurisdictions required for the enforcement agent?
56	When is enforcement of your communities ordinances implemented?
57	Approximately what percentage of your community's budget is allocated to enforcement of environmental ordinances?
58	How many citations were given in your community during 2008?
59	Do you believe your community effectively enforces aquatic resources ordinances on a scale of 1 to 5 (1, yes very effective, 5, no not at all effective)? Please add comments if you would like to explain further.
60	Please check the ways members of the general public or stakeholders are involved in the decision making process regarding aquatic issues in your jurisdiction (initially identifying problem areas, identifying methods to mitigate negative impacts to aquatic resources, continually involved and working together with local government groups in collecting samples and monitoring, voter approved fees, general public not involved, stakeholders not involved, no local involvement, other)
61	Do you have part of the budget set aside for public relations, outreach and/or education of aquatic issues or policy change?
62	Please identify the following actions taken by your community to increase public education/awareness of aquatic issues (e.g. water quality, habitat degradation).
63	How important to your jurisdiction are the following aquatic issues that are currently being faced throughout Michigan (1, really important, 5, not important at all, or N/A, not applicable). (mining practices, military bases, industrial discharges, dams, channelization of spawning routes, wild animal contamination of water, forestry practices, agricultural practices, municipal wastewater discharges, septic systems, adequate amount of water, water quality, groundwater protection, stormwater management, expanding

Table 14. Long Local Environmental Policy Survey Questions. Full pdf version of questions with answer options is available (in an electronic version) upon request.

Question #	Question
	residential and commercial development, urban runoff, road construction, bank or dune erosion, rangeland management, aquatic plant management, recreational user conflicts, other)
64	Have you had any interaction/collaborated with any of the following stakeholders regarding aquatic issues (e.g. water quality, habitat degradation)? (general citizens, native American groups, minority groups, private landowners, environmental groups, watershed groups, recreational groups, universities/colleges, K-12 education, local businesses, developers, professional consultants, agricultural groups, local industry, forestry groups, civic groups, surrounding local government, state government, Federal government, other)
65	In your opinion, who should be most responsible for protecting water quality and implementing programs in your community? (Federal, state, local government, individual citizens, don't know)
66	What are some freshwater protection issues you feel are NOT being addressed with current policies?
67	Does your community monitor water quality (not including state monitored waterbodies) of the following waterbodies? Check all that apply (if none, skip to page 16). (streams/rivers, lakes/ponds, wetlands, beaches, none)
68	How often are STREAMS/RIVERS in your community monitored (i.e. if they are monitored only during the swim season, how many times during the swim season, and if it's year round how many times per year or month?
69	Check all ways in which water quality is currently being monitored in STREAMS/RIVERS. (visual, biological, chemical/toxicological, physical/habitat)
70	Check all ways in which habitat quality is being monitored and if there is any restoration efforts for the following in STREAMS/RIVERS. (waterfowl, fishes, amphibians, mollusks, macroinvertebrates)
71	How often are LAKES/PONDS in your community monitored (i.e. if they are monitored only during the swim season, how many times during the swim season, and if it's year round how many times per year or month?
72	Check all ways in which water quality is currently being monitored in LAKES/PONDS. (visual, biological, chemical/toxicological, physical/habitat).
73	Check all ways in which water quality is currently being monitored in BEACHES. (visual, biological, chemical/toxicological, physical/habitat)
74	Check all ways in which habitat quality is being monitored and if there is any restoration efforts for the following in BEACHES. (waterfowl, fishes, amphibians, mollusks, macroinvertebrates)
75	Check all ways in which water quality is currently being monitored in WETLANDS. (visual, biological, chemical/toxicological, physical/habitat).
76	Check all ways in which habitat quality is being monitored and if there is any restoration efforts for the following in WETLANDS. (waterfowl, fishes,

Table 14. Long Local Environmental Policy Survey Questions. Full pdf version of questions with answer options is available (in an electronic version) upon request.

Question #	Question
	amphibians, mollusks, macroinvertebrates)
77	Check all of the following aquatic remediation/restoration projects currently being implemented within your jurisdiction (restoring native species, managing invasive or exotic species, acid mine drainage remediation, septic system fixes, dam removal/remediation, combined sewer overflow, sanitary system overflow, wetland restoration, stream restoration, other)
78	How many people were needed to fill out this survey?
79	What is the position of the person who filled out most of this survey (e.g. township supervisor, chair of planning commission, etc.). There can be more than one title if multiple people filled it out.
80	Are there any policies or ordinances that we have left out of this survey that your community has pertaining to aquatic resources? Pleas list if there are.
81	Additional comments.

Appendix C: Survey responses to Shortened Local Environmental Policy Survey

Table 15. Survey Responses to questions that had yes or no responses – number of people who answered yes, no or no response (Non).

Question	Yes	No	Non
Is one staff member solely responsible for enforcement of your community's ordinances?	59	26	85
Do you have GIS data of your Land Use Plan?	54	71	126
Does your community have an open space ordinance?	55	23	78
Does your zoning ordinance permit cluster development?	55	20	75
Is there an invasive species action plan in your community?	4	77	81
Are your aquatic resource management regulations based on model ordinances of a local watershed council (i.e. model ordinances)?	19	80	99
Are curbs and gutters required for public residential streets?	10	74	84
Are there incentives for developers to provide parking within garages rather than surface parking lots?	2	82	84
Do you have a floodplain management ordinance that restricts or prohibits development within the 100 year floodplain?	32	44	72
Do you have any of the following in your jurisdiction? Please state how many of each in the comment section. Lake association or lake board	Lake association = 36 Lake board = 9	46	91
Is one staff member solely responsible for enforcement of your community's ordinances?	59	26	85
Is specific training regarding the ordinances in your jurisdictions required for the enforcement agent?	16	62	78
Do you have part of the budget set aside for public relations, outreach and/or education of aquatic issues or policy change?	5	69	74

Appendix D: Additional Statistics

Table 16. Individual policy question analysis (of yes/no questions) of a lake catchment completely within one township with lake water clarity to determine whether any of the policy questions were impacting water clarity.

Ttest on each question with corresponding SDT	P value
Question 1	0.5351
Question 2	0.5351
Question 3	0.3789
Question 4	0.8342
Question 5	0.8328
Question 6	0.1578
Question 7	0.0885
Question 8	0.6170
Question 9	0.3197
Question 10	0.0118
Question 11	0.0820
Question 12	0.2518
Question 13	0.4322
Question 14	0.0556
Question 15	0.8181
Question 16	All no’s

Table 17. Correlation matrix of all variables.

	Variable	0	1	2	3	4	5	6	7	8	9	10
0	**Number of townships**											
1	**Q1**	-0.04 0.63										
2	**Q2**	-0.01 0.94	0.96 <.0001									
3	**Q4**	-0.03 0.73	0.07 0.47	0.10 0.28								
4	**Q5**	-0.04 0.65	0.26 0.01	0.27 0.00	0.20 0.04							
5	**Q6**	-0.14 0.16	0.25 0.01	0.25 0.01	-0.22 0.04	0.11 0.26						
6	**Q7**	-0.17 0.08	0.33 0.00	0.34 0.00	0.03 0.76	0.23 0.02	-0.05 0.60					
7	**Q9**	-0.01 0.94	0.04 0.71	0.04 0.70	0.21 0.04	0.04 0.69	0.15 0.16	0.19 0.06				
8	**Q10**	-0.02 0.82	0.19 0.05	0.20 0.05	-0.14 0.18	0.47 <.0001	0.23 0.03	0.08 0.43	0.13 0.18			
9	**Q11**	-0.03 0.73	0.21 0.03	0.22 0.03	-0.23 0.03	-0.16 0.11	-0.09 0.39	0.05 0.63	-0.09 0.39	0.14 0.15		
10	**Q12**	-0.03 0.76	0.18 0.06	0.19 0.05	-0.23 0.03	0.18 0.06	-0.03 0.75	-0.02 0.87	0.13 0.18	0.54 <.0001	0.38 <.0001	

Table 17. Correlation matrix of all variables.

	Variable	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
11	**Q13**	-0.02	0.11	0.11	0.15	0.02	-0.02	0.30	0.30	0.16	0.14	0.22
		0.84	0.27	0.26	0.13	0.86	0.88	0.00	0.00	0.10	0.15	0.03
12	**Q14**	-0.10	0.15	0.15	0.05	0.11	0.18	0.12	0.17	0.50	0.18	-0.07
		0.32	0.12	0.11	0.62	0.26	0.08	0.24	0.08	<.0001	0.06	0.50
13	**Q15**	-0.07	0.09	0.10	-0.01	-0.16	-0.11	0.27	0.11	0.14	0.35	-0.17
		0.48	0.36	0.32	0.92	0.12	0.31	0.01	0.28	0.15	0.00	0.08
14	**Q16**	0.03	0.09	0.09	0.19	0.12	-0.09	0.19	-0.04	0.06	-0.09	0.14
		0.73	0.36	0.35	0.06	0.24	0.40	0.05	0.72	0.53	0.34	0.17
15	**Q17**	0.05	0.05	0.05	-0.07	0.12	-0.05	0.08	-0.02	0.24	-0.06	0.23
		0.64	0.64	0.64	0.49	0.23	0.64	0.42	0.86	0.02	0.57	0.02
16	**Q18**	-0.05	0.06	0.06	0.26	0.16	.	0.11	-0.03	-0.09	-0.09	-0.08
		0.60	0.56	0.55	0.01	0.11	.	0.28	0.76	0.39	0.35	0.39
17	**SDT**	-0.01	-0.01	0.00	-0.08	-0.08	-0.04	0.16	0.09	0.09	0.14	0.16
		0.95	0.95	0.99	0.40	0.43	0.71	0.10	0.37	0.39	0.16	0.10
18	**catchment area**	0.45	-0.02	-0.02	0.00	-0.05	0.04	0.04	0.04	-0.15	-0.09	-0.17
		<.0001	0.77	0.81	0.98	0.58	0.67	0.64	0.67	0.13	0.37	0.09
19	**% water**	-0.21	0.01	0.00	-0.05	-0.03	-0.11	-0.07	0.05	0.00	0.05	0.14
		0.01	0.93	0.96	0.62	0.73	0.29	0.46	0.62	0.97	0.62	0.14
20	**% urban**	-0.06	0.16	0.16	0.30	0.31	-0.01	0.22	0.22	0.34	-0.05	0.33
		0.49	0.07	0.07	0.00	0.00	0.91	0.02	0.03	0.00	0.63	0.00

Table 17. Correlation matrix of all variables.

	Variable	0	1	2	3	4	5	6	7	8	9	10
21	% forest	0.06	0.07	0.04	-0.16	0.08	0.00	-0.10	0.13	0.40	0.28	0.29
		0.48	0.39	0.60	0.09	0.39	0.97	0.28	0.20	<.0001	0.00	0.00
22	% developed open space	-0.07	0.16	0.17	0.29	0.27	0.00	0.20	0.25	0.11	-0.01	0.13
		0.39	0.06	0.05	0.00	0.00	0.98	0.04	0.01	0.28	0.89	0.17
23	% grassland	-0.07	0.08	0.05	0.15	0.19	-0.01	-0.02	0.01	0.14	0.00	0.16
		0.42	0.38	0.53	0.11	0.04	0.88	0.80	0.95	0.16	0.97	0.09
24	% ag pastureland	-0.08	-0.23	-0.22	-0.03	-0.29	-0.21	0.03	-0.12	-0.35	-0.13	-0.22
		0.37	0.01	0.01	0.79	0.00	0.03	0.76	0.22	0.00	0.17	0.02
25	% ag row crop	0.07	-0.02	0.02	-0.01	-0.15	0.10	0.02	-0.19	-0.31	-0.13	-0.27
		0.43	0.83	0.81	0.91	0.13	0.32	0.80	0.06	0.00	0.18	0.01
26	% wetlands	-0.04	-0.13	-0.14	0.00	-0.03	0.01	-0.04	-0.05	-0.26	-0.21	-0.30
		0.67	0.14	0.11	1.00	0.77	0.90	0.70	0.60	0.01	0.03	0.00
27	road length	0.58	-0.04	0.01	0.06	-0.04	-0.09	0.01	0.03	-0.04	-0.10	-0.02
		<.0001	0.65	0.90	0.51	0.71	0.37	0.95	0.77	0.65	0.30	0.82
28	avg Runoff	-0.03	0.10	0.10	0.10	0.09	0.15	0.01	0.10	0.35	0.17	0.33
		0.71	0.23	0.24	0.28	0.33	0.13	0.90	0.33	0.00	0.08	0.00
29	avg baseflow	-0.01	0.18	0.19	0.03	-0.15	0.13	0.10	0.16	-0.01	0.34	0.24
		0.88	0.03	0.03	0.74	0.12	0.19	0.31	0.10	0.94	0.00	0.01
30	avg precipitation	0.11	0.00	-0.01	-0.30	-0.36	0.03	-0.06	0.09	-0.37	0.22	-0.19
		0.19	0.99	0.95	0.00	0.00	0.80	0.55	0.37	0.00	0.03	0.05
31	policy	-0.01	0.61	0.62	0.15	0.51	0.21	0.55	0.29	0.57	0.36	0.36
		0.95	<.0001	<.0001	0.11	<.0001	0.03	<.0001	0.00	<.0001	0.00	0.00

Table 17. Correlation matrix of all variables.

	Variable	11	12	13	14	15	16	17	18	19	20
11	Q13										
12	Q14	0.53 <.0001									
13	Q15	0.37 <.0001	0.59 <.0001								
14	Q16	0.25 0.01	-0.08 0.42	-0.09 0.35							
15	Q17	0.30 0.00	-0.04 0.70	-0.06 0.58	0.52 <.0001						
16	Q18	-0.05 0.62	-0.07 0.49	-0.09 0.35	-0.02 0.87	-0.02 0.86					
17	SDT	0.30 0.00	0.26 0.01	0.21 0.03	-0.09 0.33	-0.02 0.88	-0.12 0.20				
18	catchment area	-0.01 0.89	-0.07 0.45	-0.09 0.38	0.16 0.09	0.20 0.04	0.09 0.33	-0.12 0.16			
19	% water	0.09 0.35	0.00 0.98	0.16 0.09	-0.09 0.35	-0.09 0.38	-0.12 0.20	0.05 0.55	-0.60 <.0001		
20	% urban	0.36 0.00	0.15 0.13	0.06 0.52	0.21 0.03	-0.01 0.91	0.24 0.01	0.03 0.72	-0.18 0.03	0.22 0.01	

Table 17. Correlation matrix of all variables.

	Variable	11	12	13	14	15	16	17	18	19	20
21	% forest	0.29	0.03	0.13	-0.02	-0.01	0.13	0.15	0.04	-0.22	0.09
		0.00	0.78	0.19	0.81	0.93	0.20	0.11	0.68	0.01	0.28
22	% developed open space	0.13	0.44	0.18	0.10	0.12	0.01	0.28	0.14	-0.02	-0.02
		0.17	<.0001	0.06	0.31	0.21	0.95	0.00	0.09	0.82	0.80
23	% grassland	0.16	0.26	0.13	-0.03	0.12	0.35	0.00	-0.05	-0.08	0.12
		0.09	0.01	0.17	0.80	0.20	0.00	0.98	0.54	0.36	0.17
24	% ag pastureland	-0.22	-0.09	-0.11	-0.05	-0.12	-0.12	-0.21	0.02	0.15	-0.23
		0.02	0.34	0.27	0.62	0.20	0.23	0.03	0.86	0.09	0.01
25	% ag row crop	-0.27	-0.19	-0.14	-0.01	0.03	-0.13	-0.21	-0.06	0.25	-0.23
		0.01	0.05	0.15	0.92	0.76	0.19	0.03	0.48	0.00	0.01
26	% wetlands	-0.30	-0.13	-0.13	0.05	-0.17	-0.04	0.01	-0.02	0.12	0.10
		0.00	0.19	0.18	0.60	0.08	0.69	0.89	0.85	0.18	0.27
27	road length	-0.02	0.07	-0.11	-0.10	0.18	0.33	0.19	-0.12	0.69	-0.26
		0.82	0.45	0.27	0.31	0.06	0.00	0.05	0.16	<.0001	0.00
28	avg Runoff	0.33	0.00	-0.01	-0.06	0.22	0.17	0.22	0.00	-0.12	0.06
		0.00	0.99	0.94	0.55	0.02	0.08	0.02	0.98	0.15	0.48
29	avg baseflow	0.24	-0.02	-0.08	0.14	-0.05	0.00	-0.01	0.22	-0.04	0.03
		0.01	0.85	0.41	0.16	0.62	0.99	0.93	0.01	0.65	0.72
30	avg precipitation	-0.19	-0.07	0.01	0.24	-0.21	-0.34	-0.34	0.02	0.12	-0.09
		0.05	0.50	0.94	0.01	0.03	0.00	0.00	0.81	0.15	0.30
31	policy	0.36	0.48	0.54	0.39	0.22	0.20	0.11	0.07	-0.03	-0.03
		0.00	<.0001	<.0001	<.0001	0.02	0.05	0.25	0.41	0.75	0.71

Table 17. Correlation matrix of all variables.

	Variable	21	22	23	24	25	26	27	28	29	30	31
21	% forest											
22	% developed open space	-0.05 0.55										
23	% grassland	0.34 <.0001	-0.05 0.59									
24	% ag pastureland	-0.55 <.0001	-0.16 0.06	-0.34 <.0001								
25	% ag row crop	-0.77 <.0001	-0.24 0.01	-0.37 <.0001	0.29 0.00							
26	% wetlands	-0.30 0.00	-0.13 0.12	-0.17 0.05	0.10 0.24	-0.08 0.36						
27	road length	-0.10 0.24	0.08 0.34	0.05 0.56	-0.04 0.63	0.08 0.36	0.05 0.60					
28	avg runoff	0.45 <.0001	-0.07 0.40	0.35 <.0001	-0.51 <.0001	-0.20 0.02	-0.33 0.00	-0.01 0.89				
29	avg baseflow	0.06 0.46	-0.07 0.41	0.01 0.95	-0.24 0.00	0.15 0.08	-0.10 0.26	-0.06 0.46	0.53 <.0001			
30	avg precipitation	-0.17 0.05	-0.18 0.03	-0.24 0.00	0.29 0.00	0.21 0.01	0.10 0.24	-0.09 0.32	-0.55 <.0001	0.02 0.86		
31	policy	0.19 0.03	0.30 0.00	0.22 0.01	-0.33 <.0001	-0.16 0.06	-0.24 0.00	0.02 0.84	0.23 0.01	0.10 0.23	-0.14 0.09	

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