GEOGRAPHIC INFORMATION SYSTEMS-BASED ANALYSIS OF AQUACULTURE VENTURES IN WISCONSIN

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ABSTRACT

In the last several decades, longevity of aquaculture businesses has been sporadic throughout Wisconsin. Part of the problem centers on the inability to target ideal farm locations as well as ascertaining all the key factors in operating a profitable fish farm. An issue with the expansion of the aquaculture industry is the difficulty to conduct the needed analyses of the industry's potential. The purpose of this study was to examine and evaluate areas around current fish farms in the state in an attempt at determining if certain characteristics of the landscape have an effect on the longevity of the fish farm operation. I evaluated a total of 314 fish farms along with 253 watersheds which contained fish farms. The landscape and site indicators evaluated included: slope, water quality (pH, alkalinity, hardness, and temperature), soil quality (pH and Ksat), land cover/use, production system used, and species of fish raised at the farm. The fish farms and watersheds were evaluated by creating a GIS model in ArcMap which used the aforementioned indicators to access their suitability. The water quality indicators of alkalinity and hardness were found to likely have the most influence on the overall longevity of fish farm operations within Wisconsin. The land cover/use indicators also were found to be influential to fish farm success, while soil indicators were found to have little influence on the success of a fish farm staying in operation. Predictive models were created by Koeller et al. (*in progress*) which sought to determine suitable locations for aquaculture operations in Wisconsin for either raceway or pond production systems. A summary review of the predictive model work by Koeller et al. (*in progress*) can be found in Appendix D. These models looked at several different water quality criteria (alkalinity, hardness, pH, iron, manganese, and chloride), soil characteristics (clay content, pH, organic matter, and permeability), and land cover/use. The model criteria were weighted based on their potential influence to the longevity of fish farms. The suitability locations for water quality, soil and land use characteristics were combined to show the areas within the state which were suitable for fish farm operations utilizing either raceway or pond production systems. The raceway site suitability model had 73.8% of the state found in unsuitable locations while the pond site suitability was unsuitable for 58.7% of the state. The suitability for raceway systems was highly affected by the water quality with 55.4% of the state being unsuitable while soil and land use were 39.5% unsuitable. Pond systems had 41.4% unsuitable location for water quality and 33% unsuitable land based on soil and land use.

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CHAPTER ONE: LITERATURE REVIEW

AQUACULTURE INDUSTRY

Aquaculture is defined as the controlled rearing of aquatic animals and plants for food or natural resource enhancement (Swann 1992 and WAA 2009). Since the mid-1980’s the capture of fish and seafood from wild fisheries has met or exceeded the “maximum sustainable yield” of worldwide fisheries – estimated to be about 185 million metric tons per year (FAO 2012). Consequently, the supply of seafood products from the wild is limited and all additional increases in supply will have to be met through aquaculture.

Aquaculture is the fastest growing food production system globally, with an increase in production of animal crops of about 9% per year since 1985 (Diana 2009). In the United States alone, the projected per-person increase in seafood consumption beginning in the early 2000s should lead to a total increase of 1.5 million to 2 million metric tons by 2020 (Diana 2009). Due to the expanding U.S. population and increasing awareness of the health benefits of seafood in our diets, the demand for seafood products in this country is steadily growing. An increasing amount of seafood is being imported into the U.S., and in 2015 the U.S. trade deficit in seafood, both wild caught and aquaculture products, was over $13.0 billion. Fish and shellfish contribute the most, of any agriculture product, to the U.S. trade deficit. During the last 20 years the commercial culture of food fish in the U.S. has increased at an annual rate of greater than 15%, making it the fastest growing sector of food production in the country. The U.S. aquaculture industry is currently valued at over $1 billion (Lowther and Liddel 2016).

GEOGRAPHIC INFORMATION SYSTEMS & AQUACULTURE

An underlying issue with expansion of the aquaculture industry is that it has been difficult to conduct the necessary analyses to find optimal sites for domestic aquaculture. Aquaculture development potential can be assessed synoptically using a geographic or spatial information system (Kapetsky et al. 1990). GIS, remote sensing, and mapping have been used extensively worldwide to manage and identify the development of marine aquaculture (Kapetsky and Aguilar-Manjarrez 2007). GIS has been used in aquaculture studies for at least 15 years to evaluate the suitability of coastal areas for fish farming activities (Simms 2002). Aquaculture management issues such as the multiple uses of estuarine waters, the impact of water quality on shellfish leases, aquaculture and habitat availability and conflict issues between aquaculture operations and marine waterfowl habitats have been addressed using GIS (Simms 2002).

Recent reports suggest that GIS can be further deployed in a number of ways that would be beneficial to the sustainability of aquaculture (Nath et al. 2000, McLeod et al. 2002, McIntosh et al. 2003, Kapetsky and Aguilar-Manjarrez 2007). Rajitha et al. (2007) applied satellite remote sensing technology and GIS to investigate the sustainable management of shrimp culture in India through the analysis of various datasets depicting the criteria of sustainability. Using GIS, intertidal areas (mudflats) were evaluated for the development of brackish water aquaculture (shrimp farming) and the data on 37 parameters under six major categories namely, engineering parameters, water quality parameters, soil quality parameters, infrastructure facility, meteorological parameters, and social restriction were used for analysis of site selection in India (Karthik et al. 2005).

Furthermore, GIS can be used for site suitability and location of potential new aquaculture facilities. In the U.S., the most notable uses of GIS to assess sites using marine environments have been the Site Suitability Modeling Process (SSMP) developed by the NOAA National Marine Aquaculture Initiative, the Marine Policy Center of the Woods Hole Oceanographic Institution where they compared alternative locations for aquaculture in terms of economic and environmental parameters for marine aquaculture (Kapetsky and Aguilar-Manjarrez 2007). Also, a comprehensive GIS analyses of Louisiana for crawfish (*Procambarus clarkia*) and channel catfish (*Ictalurus punctatus*) culture industries showed that GIS can provide estimates of the surface area and locations available for different kinds of aquaculture development and clarify development alternatives and feasibilities before investments are made in unsuitable areas (Kapetsky et al. 1990).

The Danish Ministry of Food, Agriculture & Fisheries examined the placement of mariculture using GIS to allocate different weights to technical requirements for the production of fish in the marine environment (bathymetry, salinity & temperature) along with competing interests (animal production areas, areas for raw material extraction, & areas for shipping; Geitner 2002). A comparison using GIS of Kolleru Lake, India's largest freshwater body, showed from 1967 to 2004 aquaculture development represented a 55.3% change in total area developed (99.74 km^2 change between 1967 and 2004; Jayanthi et al. 2006). GIS processing of clam net coverage information combined with existing shore substrate data and new littoral bathymetry data for Baynes Sound, Vancouver, Canada resulted in an accurate enumeration of clam net coverage for each of Baynes Sound's major substrate types and for the farmed clam species' optimum habitat. The results showed shellfish tenures occupied 20.3% and clam netting 2.9% of the intertidal area of Baynes

Sound. These techniques offered a cost-effective method of assessing inter-tidal resource utilization, provided a basis for time-series evaluation, and were a useful tool for adaptive resource management (Carswell et al. 2006).

Nevertheless, there has been a paucity of GIS applications in U.S. aquaculture overall, and GIS has been unevenly deployed in relation to target species, culture systems, environments, and in terms of states that are important for aquaculture production. The continued role of GIS application in aquaculture development is the demand for better predictions of the sustainability of aquaculture (Kapetsky 2002).

Planning activities to promote and monitor the growth of aquaculture inherently have a spatial component because of the differences among biophysical and socio-economic characteristics across locations. Biophysical characteristics may include criteria pertinent to water quality (i.e. temperature, dissolved oxygen, alkalinity, turbidity, and pollutant concentrations), water quantity (i.e. volume and seasonal profiles of availability), and soil type (i.e. slope, structural suitability, water retention capacity, and chemical nature). Pemsl et al. (2007) suggested the integration of socio-economic variables in GIS models, by applying methodology comprising of four stages: 1) identification of key factors for successful adoption of target technologies on the micro-level, 2) development of indicators on the meso-level, 3) generation of geo-referenced meso-level indicator data sets for the target area, and 4) assignment of rankings/weights to the indicators. Socio-economic characteristics that may be considered in aquaculture development include administrative regulations, competing resource uses, market conditions (i.e. demand for products and accessibility to markets), infrastructure support, and availability of technical expertise. The spatial information needs for decision-makers who evaluate such biophysical and socio-economic characteristics as part of aquaculture development efforts can be well served by GIS (Nath et al. 2000).

GIS based decision support models can facilitate the prioritizing of state research, development, and extension strategies and targeting of development assistance for aquaculture because they can provide information to stakeholders as to where and under what conditions certain aquaculture technologies would be feasible. Factors that determine the adoption of aquaculture technologies by farmers include agro-ecological (rainfall, temperature, soil type, and slope), socio-economic (land, labor, capital, and infrastructure), and institutional characteristics (extension services, applied research, and producer's organizations; Pemsl et al. 2007). Simms (2002) listed the advantages of using a GIS as part of the decision-making process as: 1) GIS provide the capability to integrate, scale, organize and manipulate spatial data from many different sources, 2) data can be maintained, updated, extracted and mapped efficiently, and 3) GIS permit quick and repeated testing of models which could be used to aid the decision-making process.

In aquaculture, the use of GIS for project management and as a tool for decision-making can allow for more effective and proactive development. The strong dependence on the natural environment for success lends importance to using GIS as a management tool. First, a wealth of GIS layers are available from government agencies, conservation groups, and universities that provide base maps with accurate water resources, current aquaculture facility locations, environmental data, land use data, zoning, and growth management areas, to name a few. The benefit in implementing a GIS application for the Wisconsin aquaculture industry is to integrate the use of GIS with project management and decision-making. Understanding why production levels are attained in aquaculture can be more clearly understood if production at a site is analyzed using spatial relationships. Predictive models can be developed to determine the allocation of resources, such as staff and equipment, the spatial and temporal analysis of production data, or site specific environmental conditions to ensure regulatory compliance. Aquaculture is a water resource-based industry that could benefit from a well-designed GIS (Cooper & Moore 1999). GIS models can be used by extension personnel, fish farmers, land-use managers and others who may be familiar with the specific requirements of aquaculture to evaluate potential sites for aquaculture development and expansion.

THESIS OBJECTIVES:

Research Question Defined

In the field of aquaculture, there is a research void in the determination of the most significant geographic characteristics that determine the longevity of an aquaculture operation; with longevity serving as a proxy for success. The research question was: what locational factors are statistically significant for determining if commercialized fish farms will succeed or fail? In order to ascertain the validity of this question, this study sought to determine if landscape and site characteristics around current and past fish farms are correlated to the longevity of the continuous operation of fish farms in Wisconsin. The overall objective was to determine what (if any) landscape or site characteristics affect the longevity of fish farm operations. A GIS evaluative model was created to examine the potential indicators to determine their connections with fish farm longevity. The results of the evaluative model were compared across various longevity years for fish farms in Wisconsin.

To accomplish this overall objective the following three questions were examined:

1. What are the geographic (locational) factors that influence the longevity of a commercial fish farm in Wisconsin?
2. Do particular geographic (locational) factors make a statistically significant difference in the longevity of a commercial fish farm?
3. Does extending the geographic extent of a fish farm location to its associated watershed change the effect of locational?

These questions were developed from the premise that particular landscape factors have a significant effect on the longevity of fish farm operations and that particular factors can enhance fish farm success. The inclusive null hypothesis for this study being that: (H_o: Landscape (locational) factors have no effect on the longevity of fish farms in Wisconsin).

LITERATURE CITED

Carswell, B., S. Cheesman and J. Anderson. 2006. The Use of Spatial Analysis for Environmental Assessment of Shellfish Aquaculture in Baynes Sound, Vancouver Island, British Columbia, Canada. Aquaculture 253: 408-414.

Cooper, K. and P. Moore. 1999. The Application of GIS to Commercial Aquaculture. Fishery/Aquatic Research Group, Conference Abstract.

Diana, J.S. 2009. Aquaculture Production and Biodiversity Conservation. Bioscience 59:27-38.

Food and Agriculture Organization of the United Nations (FAO). 2012 The State of World Fisheries and Aquaculture. Rome.

Geitner, K. 2002. Use of GIS for Placement of Mariculture. Second International Symposium on GIS/Spatial Analyses in Fishery & Aquatic Sciences. Conference Abstract.

Jayanthi, M, P.N. Rekha, N. Kavitha and P. Ravichandran. 2006. Assessment of Impact of Aquaculture on Kolleru Lake [India] Using Remote Sensing and Geographical Information System. Aquaculture Research 37: 1617-1626.

Kapetsky, J., J. Hill, L. Worthy, and D. Evans. 1990. Assessing Potential for Aquaculture Development with a Geographical Information System. Journal of the World Aquaculture Society 21:241-249.

Kapetsky, J.M. 2002. Aquaculture Sustainability and GIS. Second International Symposium on GIS/Spatial Analyses in Fishery and Aquatic Sciences. Conference Abstract.

Kapetsky, J. and J. Aguilar-Manjarrez. 2007. Geographic Information Systems, Remote Sensing and Mapping for the Development and Management of Marine Aquaculture. FAO Fisheries Technical paper 458: 1-115.

Karthik, M., J. Suri, N. Saharan and R.S. Biradar. 2005. Brackish Water Aquaculture Site Selection in Palghar Taluk, Thane District of Maharashtra, India Using the Techniques of Remote Sensing and Geographical Information System. Aquacultural Engineering 32: 285-302.

Lowther, A. and M. Liddel. 2016. Fisheries of the United States 2015. Current Fishery Statistics No. 2015. National Marine Fisheries Service.

McIntosh, D., T.K. Baldwin, and K. Fitzsimmons. 2003. Aquaculture Development Potential in Arizona: A GIS-based approach. World Aquaculture Magazine 34:32-35.

McLeod, I., F. Pantus and N. Preston. 2002. The Use of Geographical Information System for Land-Based Aquaculture Planning. Aquaculture Research 33: 241-250.

Nath, S.S., J.P. Bolte, L.G. Ross, and J. Aguilar-Manjarrez. 2000. Application of Geographical Information Systems for Spatial Decision Support in Aquaculture. Aquacultural Engineering 23:233-278.

Pemsl, D.E., M.M. Dey, F.J. Paraguas and M.L. Bose. 2007. Determining High Potential Aquaculture Production Areas. oneFish Newsletter, May.

Rajitha, K., C.K. Mukherjee and R.V. Chandran. 2007. Applications of Remote Sensing and GIS for Sustainable Management of Shrimp Culture in India. Aquacultural Engineering 36:1-17.

Simms, A. 2002. GIS and Aquaculture: Assessment of Soft-Shell Clam Sites. Journal of Coastal Conservation 8:35-47.

Swann, L. 1992. A Basic Overview of Aquaculture. Illinois-Indiana Sea Grant. Technical Bulletin #102.

Wisconsin Aquaculture Industry: Value and Economic Impact. University of Wisconsin-Extension and University of Wisconsin-Stevens Point Northern Aquaculture Demonstration Facility (WAA). 2009. www.wisconsinaquaculture.com/Docs/2009_WI_Aqua_Industry_brochure_2.pdf.

CHAPTER TWO: EVALUATIVE MODEL

ABSTRACT

In the last several decades, longevity of aquaculture businesses has been sporadic throughout Wisconsin. Part of the problem centers on the inability to target ideal farm locations as well as ascertaining factors that result in the operation of a profitable fish farm. An issue with the expansion of the aquaculture industry is the difficulty to ascertain the key factors that promote successful fish farms. This study examined and evaluated areas around current fish farms in the state in an attempt at determining if certain characteristics of the landscape have an effect on the longevity of the fish farm operation. I evaluated a total of 314 fish farms and 253 geographic associated watersheds. The landscape indicators evaluated included: slope, water quality (pH, alkalinity, hardness, and temperature), soil quality (pH and Ksat), and land cover/use. The site indicators evaluated were production system used and species of fish raised at the farm. The fish farms and watersheds were evaluated by creating a GIS model in ArcMap which examined all the different indicators around the fish farms. The water quality indicators of alkalinity and hardness were found to likely have the most influence on the overall longevity of fish farm operations within Wisconsin. Land cover/use also were found to have an effect on the longevity of operations. Conversely the soil indicators did not have a significant influence on the success of a fish farm staying in operation.

INTRODUCTION

Aquaculture has been an industry in Wisconsin since 1856 (WAA 2009). The industry in the state raises a wide variety of fish species from minnows for bait, walleye and yellow perch for stocking, and trout for food (WAA 2009). This industry produces fish grown in ponds, flow through, and recirculating aquaculture systems. In 2009, it was estimated that Wisconsin Aquaculture contributed over $21 million to the state's economy and provided over 400 jobs in the state (WAA 2009). In 2005, Wisconsin was ranked the 20th in state aquaculture production (USDA 2006). In the same year, Wisconsin was ranked ninth in trout production and second in baitfish production (USDA 2006). This contribution to the Wisconsin rankings comes from over 2,700 registered fish farms producing over 30 different fish species.

An issue with the expansion of the aquaculture industry is the difficulty to conduct the needed analyses of the industry's potential. Using modern technology like Geographic Information Systems (GIS), these ideal locations and factors can be more easily identified and tested (Kapetsky et al. 1990). A GIS can be defined as an "integrated assembly of computer hardware, software, geographic data and personnel designed to efficiently acquire, retrieve, analyze, display, and report all forms of geographically referenced information geared towards a particular set of purposes" (Nath et al. 2000). A GIS is able to look at multiple aspects of the landscape to locate areas with high suitability for future aquaculture ventures (Meaden and Aguilar-Manajarrez 2013). It is the utility of this tool in conjunction with an integrated geospatial database of fish farms that could provide potential Wisconsin fish farmers answers to what factors are most important to the longevity of a fish farm.

Fish farms in Wisconsin are classified into three different registration farm types (DATCP 2011). Type 1 fish farms are able to have angling, collect eggs from its own brood stock, obtain live fish and eggs from other sources, sell or distribute live fish and eggs for food processing, retail stores, and restaurants, raising bait for personal use at the farm, and moving live fish between Type 1 farms operated by the same owner (DATCP 2011). A high percentage of these farms are considered 'hobby farms' and generally do not sell fish but are registered to have fish stocked in a private pond.

Type 2 allows for all of the Type 1 operations but also allows for raising bait for sale, raising, buying, trading, or importing fish/eggs for resale, stocking, processing, or exchange, and distributing fish and eggs from inside to outside the state (DATCP 2011).

Type 3 (started in 2009) includes all the operations of Types 1 and 2 and allows for obtaining live fish and eggs from a wild source (DATCP 2011). This type of fish farm is mainly used by Wisconsin Department of Natural Resources hatcheries.

Of those 2,700 fish farms registered with the Wisconsin Department of Agriculture, Trade, and Consumer Protection roughly 330 are considered commercial and are producing the fish for food, stocking, and bait. These 330 fish farms are classified as Type 2 and 3.

Past studies have potentially identified general influencing factors on the longevity of fish farm operations (Hossain et al. 2007; Kapetsky et al. 1988; Kapetsky et al. 1990; McIntosh et al. 2003; Salam et al. 2005). These factors could have both positive and negative influences on the farm's longevity. These may include indicators of the landscape, farm site, production systems, water source, and markets. Landscape indicators consist of land cover, slope, and soil quality. Site indicators were made up of water quality components such as alkalinity, pH, and dissolved oxygen. Infrastructure indicators were the production system, water source, and fish species raised.

Landscape Indicators

The indicator of land cover examines land use is around the fish farm location. This indicator was used because the surrounding land use can have substantial negative or positive effects on the aquaculture site. It is possible that the land cover categories that may have an influence on fish farms are agricultural crops, forests, developed land, pasture land, open water, wetlands, and grasslands. For example, nearby agriculture fields may have higher instances of nutrient run-off into the water supply and thus could create unsuitable water quality conditions that negatively affect the fish (Salam et al. 2005; Tong and Chen 2002). Different land cover types can affect the permeability of water into the soil and groundwater. Forested land cover and wetlands slow the flow of water on the surface and are able to aid in the filtration of water going into the soil (Endreny 2002 and Lowrance et al. 1997). Impervious land covers, such as roads, do not slow the overland water flow and can increase the water temperature by creating a large surface area which the water must flow across. Thus, neighboring land cover may affect the water quality characteristics of an area. Several types of land cover are better suited for fish farms which are forests, grassland, and pasture land. These types allow the water to permeate slowly into the ground and rarely have fertilizer added for plant growth as the soil tends to contain adequate nutrients (Salam et al. 2005).

The slope indicator looked at the percent slope of the land that the fish farm is constructed on. The slope of the landscape can influence the movement of water. Slope also plays a role in the possible erosion of the soil (Hossain et al. 2007). This may be an important indicator because in most cases farms will not be found in areas with steep slopes (Kapetsky et al 1990). In a farm operation, utilizing a pond production system, it would not be beneficial to build a pond on a site with a steep slope; the reason for not building on a steep slope is that the pond water depths could vary greatly. The water depth to the bottom would be small at the higher portion of the pond located up the slope, while the lower portion of the pond on the down slope side would have a larger depth to bottom. With a pond constructed like this, the fish would likely all gather in the deeper end causing the density of fish, and its corresponding biological oxygen demand, to go up for that portion of the pond. There may be some cases where farms that are using raceway (flow-through) systems would rather build on a slope to reduce the amount of water being pumped to create a flow. In these locations, gravity aids in the water moving through the raceway. Hossain et al. (2009) determined that the most suitable slope on the landscape for carp farming in a pond production system was 0 to 2%. Moderately suitable slopes were 4 to 6% and 8 to 9% with all other slopes being unsuitable for carp ponds. Slope also influences the runoff and internal soil drainage of the land. Areas found in low elevations, compared to surrounding land, could be susceptible to flooding during times of heavy rainfall from runoff from the higher areas. The rain will run down the hill into the lower spot. The steeper the slope, the faster the rain will likely run downhill. Runoff dealing with slope also has a relationship with the indicator of land cover. If the production systems are located at the bottom of a hill, below an agriculture field or parking lot, there will be nutrients and chemicals that can enter the water that may harm the fish.

The indicator of soil type looked at physical aspects of soil and how it affects fish farm longevity. This indicator primarily deals with how quickly water infiltrates through the ground if the aquaculture system is using earthen substrate for their operations (Kapetsky et al. 1988; Kapetsky et al. 1990). McIntosh et al. (2003) found in Arizona the soil content was good if it contained <50% clay. The reason for this is that clay does not let water permeate through the substrate as quickly as other types of soil. This type of characteristic is crucial for farm ponds. Salam et al. (2005) states that soil for pond bottoms should be impervious to water, permit rapid mineralization of organic matter, absorb nutrients, and loosely bind and release the nutrients over time. Types of soils that contain these characteristics are loam, silty loam, clay loam, and sandy loam (Salam et al. 2005). Soil types that are not suitable for aquaculture are sand, peat, silty sand, silt, and clay. Sand allows the water to permeate rapidly (Nath et al. 2000; Salam et al. 2005). Peat contains a lot of organic matter that will increase the nitrogen and carbon dioxide in the water. Clay, although needed to some degree, at high levels does not allow any permeation of water into the ground. The soil indicator deals more with the engineering aspect of constructing an aquaculture system. The construction of an aquaculture system needs to take into consideration the ease in workability of the soil, does it shrink/swell when saturated or dry, is the soil able to hold the weight of the water without eroding away, and the permeability of the soil. This indicator also looks at the pH of the soil and how it could affect the water quality of the production systems. Fish need to have the water pH in a range of 6.5 to 9.0 to remain healthy (Wedemeyer 2001; Wurts and Durborow 1992).

Site Indicators

Water quality and its use during culture at the farm can have a direct impact on the biology of the fish (Hossain et al. 2009). The aspects of water quality that may be of importance are alkalinity, hardness, pH, dissolved oxygen (D.O.), carbon dioxide (CO_2), iron (Fe), and nitrogen (N). The interesting part about water quality is that each fish species can have a different level of tolerance for pH and other water quality elements (McIntosh et al. 2003). If the pH is unsuitable the fish may die or become sick. The pH range suitable for fish health is 6.5 to 9.0 (Wedemeyer 2001; Wurts and Durborow 1992). Any pH outside this range can lead to increased stress and possible mortality if not corrected (Wurts and Durborow 1992). Cold-water and cool-water species are more sensitive to high pH values than warm-water species. Low pH values can affect the reproduction ability in species (Wedemeyer 2001). Water quality levels with pH outside the tolerable range for fish would require the farm to increase production costs by having to adjust the pH so the fish do not die.

Alkalinity indicates the quantity of base (bicarbonates, carbonates, phosphates, etc.) present in water (Boyd 1979; Wurts 2002). These bases aid in the water's ability to resist large swings in the pH of the water (Boyd 1979; Boyd 1982; Wedemeyer 2001; Wurts 2002). Alkalinity levels for fish culture range from 75 to 400 mg/L $CaCO_3$ (Swann 1992; Wurts and Durborow 1992). When alkalinity is low (20 to 50 mg/L $CaCO_3$) there can be a large change in the pH of the water from 6 to over 10 due to plant photosynthesis and the release of carbonate (Wurts and Durborow 1992; Wurts 2002). With an alkalinity of 75 to 200 mg/L $CaCO_3$, the water pH does not experience such a large shift. This is assuming that there is also an adequate level of hardness in the water > 25 mg/L $CaCO_3$ (Wurts and Durborow 1992).

Hardness relates to the overall amount of divalent salts (Ca and Mg) in the water (Wedemeyer 2001; Wurts 2002). Salts (Ca and Mg) in the water are need by the fish for growth of bones and scales (Swann 1992; Wurts 2002; Wurts and Durborow 1992). A desired range for calcium hardness is 100 to 250 mg/L $CaCO_3$ but can be up to 400mg/L $CaCO_3$ (Swann 1992; Wurts and Durborow 1992).

Dissolved oxygen (DO) is needed for fish respiration. If the levels of DO get too low, the fish will struggle to breathe. This is a condition known as hypoxia and occurs when DO saturation is< 30% or 3 ppm (Mallaya 2007). With low DO, fish will become lethargic and not feed and sometimes the fish will swim to the surface where there is a better chance for oxygen uptake (Mallya 2007). A lack of oxygen will make the fish stressed and could lead to sickness and disease. Along with fish being harmed by lack of oxygen, having too much DO in the water can have negative effects on the fish (Mallya 2007). The condition when saturation of oxygen occurs is known as hyperoxia. This occurs when the oxygen saturation is > 100% (Mallya 2007). With excess oxygen in the water there can also be an excess amount of oxygen in the blood. This oxygen can form bubbles that can block capillaries for blood movement which can lead to death (Mallya 2007). The excess oxygen can even enter the gas bladder of the fish and cause problems with buoyancy (Mallya 2007). Dissolved oxygen for water should have a saturation of > 50% or > 4 ppm (Piper et al. 1986; Swann 1992; Wedemeyer 2001).

Nitrogen in the water takes on many different forms. The most toxic form of nitrogen in the water is unionized ammonia and this form comes from the excretion of metabolic waste by the fish (Hargreaves and Tucker 2004). The problem is keeping the level of unionized ammonia low enough so it is not harmful to the fish. Nitrite is another form of nitrogen that can be toxic to fish and must be monitored and controlled at low levels. Excessive nitrite can affect the blood's ability to transport oxygen (Malison and Hartleb 2005). Nitrate is the third most common form of nitrogen in the water and does not tend to be as harmful to fish at low levels. A safe level for unionized ammonia is < 0.02 ppm in the water (Swann 1992). Nitrite levels should also be < 0.60 ppm to avoid harm to the fish. Nitrate levels should remain < 3.00 ppm as any level higher can be toxic to fish.

Infrastructure Indicators

Type of production system used by each farm consists of three main categories in Wisconsin: pond, flow-through, and recirculating. Ponds are the most common type of aquaculture production system used in the U.S. and Wisconsin (Malison and Hartleb 2005; Stickney 2009; Swann 1992). This production system requires the lowest amount of human inputs to raise fish extensively. A large area of land is required to have multiple ponds for growing fish. Ponds tend to range in size from ¼ acre to >5 acres and often are 5 to 8 feet in depth depending on if they are going to be used year-round (Malison and Hartleb 2005). Fish must be raised at low densities to account for the amount of nutrients and DO in the water. The densities vary for each species of fish. Flow-through production systems, also called raceways, have continuously moving water. With the constant replacement of water, fish can be raised at high densities (Malison and Hartleb 2005; Wedemeyer 2001). The continuous flow of water aids in the addition of DO to the water and the removal of harmful nutrients. Raceways require more human interaction than ponds to maintain healthy growth of the fish. A recirculating aquaculture system (RAS) consists of many different tanks and pumps to move the water. Many RAS's are able to reuse 95 to 99% of the water in the system. The system consists of tanks for holding the fish for growth, along with filter tanks to remove solid waste, bio-filter tanks for removing harmful nutrients, gas exchanger tanks to remove CO_2, and pumps to maintain constant water flow (Wedemeyer 2001). Along with the filters to remove waste there are pumps needed to add oxygen to the system and the need to control temperature so heaters and chillers may be needed (Timmons and Ebeling 2007; Malison and Hartleb 2005). RAS's are usually the most intensive systems to operate. Also, they are often the most expensive to keep operational due to the need for electricity to run the essential pumps, heaters, and chillers in the system.

Water source refers to the supply water used to fill the production systems. Water source may be one of the biggest factors when choosing a location for aquaculture. The water source could be ground water, diverted stream, natural spring, artesian well, municipal city water, or surface run-off (Swann 1993). An aquaculture operation that is utilizing ground water by pumping it up from an underground well requires the farm to maintain a pump and have electricity or gas to power the pump. With a pond production system, a water pump will mainly be used to keep the water at the same level and may not need to be constantly on. With a flow-through system the pump will need to always be running to maintain the continuous water flow in the system. Thus, having a water pump for ground water will cost more for a flow-through system than with a pond system. There are also associated costs that needs to be considered such as having the well drilled and maintained. The use of city water requires paying for the water from the city and also the cost to remove the chlorine and fluoride that are added to the water by the city (Swann 1993). These added chemicals have harmful effects on the fish, and must be removed from the water before having fish added. Diverting a stream has a cost involved with getting the water into the system, and has a large cost before returning the water to the stream. The water entering the system will need to be treated and filtered to remove and pathogens, excessive nutrients and aquatic invertebrates (Swann 1993). This can be done by passing the water through a small filter for the invertebrates and then UV sterilization for the pathogens (Malison and Hartleb 2005). Just as the influent must be treated when coming from a stream, the effluent water from the aquaculture system must be treated so that pollutants are not returned to the waterway (Stewart et al. 2006 and Viadero Jr. et al. 2005). Three main pollutants from aquaculture operations are pathogenic bacteria or parasites, antibiotics, and food waste (Stewart et al. 2006).

Phosphorus discharge in the effluent is also regulated for aquaculture facilities to limit the phosphorus contributions from receiving waterways (True et al. 2004). Often the nitrogen, phosphorus, and other elements are sediment bound, thus removing the sediment is a way to treat the water before returning it to the stream (Stewart et al. 2006). The main way to remove the sediments is by the use of a settling basin (Stewart et al. 2006 and Viadero Jr. et al. 2005). Three main types are quiescent zones, off-line settling basins, and full-flow settling basins. Settling basins do not remove dissolved nutrients that are found in the water. Dissolve nutrients are able to be removed by the use of biological filtration (Stewart et al. 2006).

There are three classes of fish, based on optimal growth temperatures, which can be used as indicators. The first is cold-water fish which have an optimal growth temperature <15.5°C (Swann 1992). Cold-water fish species are found in the family Salmonidae such as brook trout (*Salvelinus fontinalis*), brown trout (*Salmo trutta*), rainbow trout (*Oncorhynchus mykiss*) and salmon (*Oncorhynchus sp.*). The second class is cool-water fish with an optimal growing temperature range of 15-24°C (Swann 1992). Cool-water species can include walleye (*Sander vitreus*), northern pike (*Esox lucius*), and yellow perch (*Perca flavescens*). The last class is warm-water fish with an optimal temperature >24°C (Swann 1992). Species in this temperature class include largemouth bass (*Micropterus salmoides*), bluegill (*Lepomis macrochirus*), tilapia (*Oreochromis sp.*), and a variety of baitfish. Each species temperature class can be grown in any of the 3 different production systems, but some fish grow better with a certain type of production system. Cold-water species tend to have higher production success in the raceways (Malison and Hartleb 2005). Cool-water fish can have high growth rates in ponds, raceways, and RAS systems. Warm-water fish are able to have good growth in ponds and RAS systems (Malison and Hartleb 2005). This indicator of fish species is used to determine if the longevity of a fish farm was affected by the species of fish raised. If a fish farm was not open many years could the species raised have been a factor in the closing of the farm? If a farm is raising fish that require warm water, but the farm's water source is from a spring and is cold water, it will be difficult to have optimal growth of the fish. In turn, it will take longer to grow to a marketable size and have a higher cost of production. The cost of production for raising fish includes the price to buy the eggs or fry, the cost of the food, cost of any medicine given to the fish, cost of operating the production system (pumps, lights, filters, etc.), and the cost of labor. If a fish takes longer to grow to a sellable size there will be increased food costs, operating costs, and labor costs.

METHODS AND MATERIALS

Study Area

The study area for this project was the entire state of Wisconsin that consists of 72 counties (Figure 2.1). Along with the counties, the study looked at 1,853 watersheds throughout the state (Figure 2.2). The watersheds were from the Hydrologic Unit Code (HUC) 12. This is the subwatershed and tends to cover an average area of 40 square miles. Type 2 and Type 3 fish farm locations were evaluated for the various landscape indicators as these are more commercial than Type 1 fish farms (Figure 2.3). Each farm location was evaluated based on the watershed it was located within and a 500-meter buffer around the farm. The buffer was needed because the fish farms were just points and the area surrounding these locations needed to be identified. The buffer enabled the landscape characteristics around the fish farm to be assessed and identified.

Data Acquisition

Geographic data were acquired from seventy-one of the seventy-two Wisconsin counties. Richland county data were not able to be acquired. A data request letter and email was sent to the county government offices. This letter was sent to the county administrator, county board chair, and the land information officer/ GIS coordinator for each county (Appendix A). Available data layers varied between the counties and are listed in Table 2.1. These data included information on the county parcels, land cover and use, hydrology, zoning, and orthophotography. Some counties had a large collection of GIS data available, while others had little available GIS layers (Table 2.1). For Instance,

Figure 2.1: Seventy-two counties in the state of Wisconsin that make up the study area of the project. GIS data were attained from all of the counties, except Richland. All but 6 counties contained a fish farm being evaluated in the study.

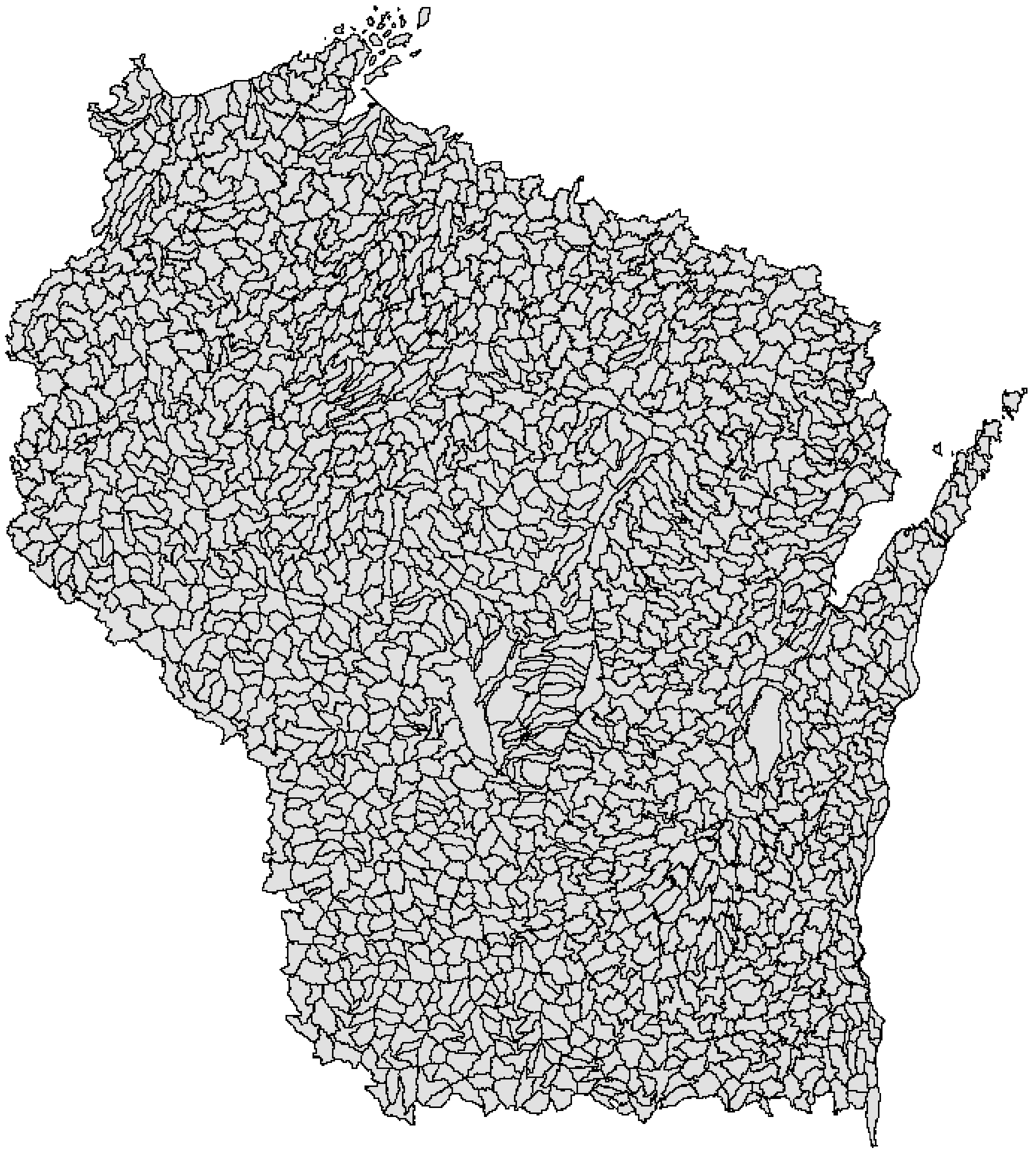

Figure 2.2: The 1,853 watersheds in the state of Wisconsin. The watersheds which contained fish farms were evaluated to determine important landscape characteristics that affect the longevity of the fish farms in the state.

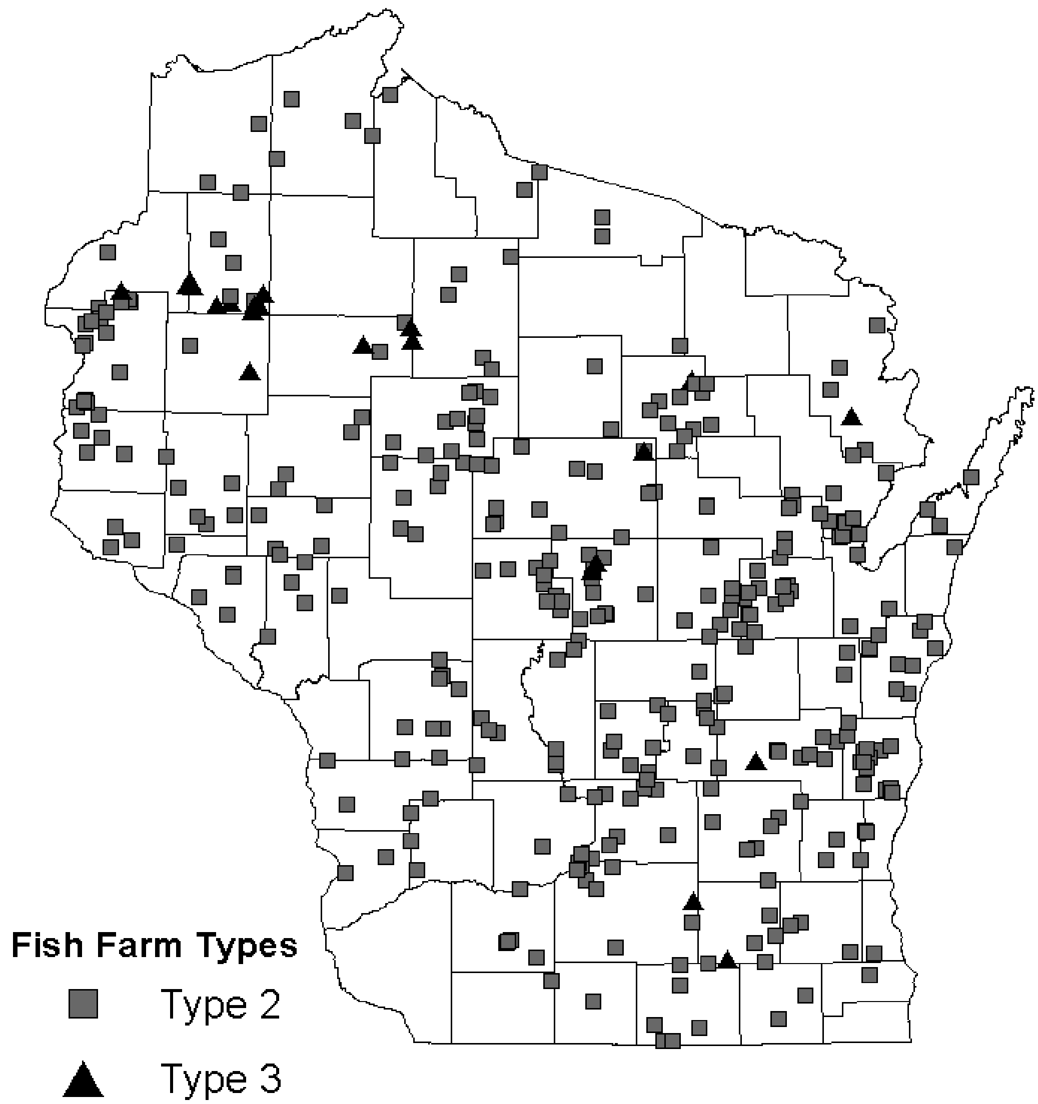

Figure 2.3: Type 2 and Type 3 fish farm locations in the state. These locations were evaluated to determine important landscape characteristics that affect the longevity of the fish farms. The fish farm locations were given a 500 meter buffer that was evaluated to ensure that the overall fish farm site was seen.

Table 2.1: Geographic data received from the 72 counties in Wisconsin. Some counties tended to have a multitude of data while others had a very limited amount. The data shown only includes the data that were utilized for the project**.**

County	Parcels	PLSS	Roads	Zoning	Hydro	LUC	Muni
Adams	x	x	x	x	x		x
Ashland	x	x	x		x		
Barron	x	x					x
Bayfield	x	x		x		x	
Brown	x	x	x	x	x	x	
Buffalo	x				x		
Burnett	x			x			
Calumet	x	x	x	x		x	x
Chippewa	x		x		x	x	x
Clark	x		x			x	x
Columbia	x	x	x	x	x	x	x
Crawford	x						
Dane	x	x	x	x	x	x	x
Dodge	x	x		x		x	
Door	x			x		x	
Douglas	x	x	x		x	x	x
Dunn	x	x					x
Eau Claire	x		x				x
Florence	x						
Fond du Lac		x	x	x		x	x
Forest	x	x	x	x	x	x	x
Grant	x	x	x	x	x		
Green	x	x	x		x		x
Green Lake	x		x				x
Iowa	x	x	x	x			

PLSS=Public Land Survey Systems
Hydro=Hydrology
LUC=Land Use and/or Land Cover
Muni=Municipalities

Table 2.1 continued: Geographic data received from the 72 counties in Wisconsin. Some counties tended to have a multitude of data while others had a very limited amount. The data shown only includes the data that were utilized for the project**.**

County	Parcels	PLSS	Roads	Zoning	Hydro	LUC	Muni
Iron	x	x					
Jackson	x	x	x	x	x	x	x
Jefferson	x	x		x		x	x
Kenosha	x	x		x	x		
Kewaunee	x	x	x		x		x
La Crosse	x	x	x	x	x		x
Lafayette	x		x	x	x		
Langlade	x	x	x	x	x		x
Lincoln	x			x	x	x	
Manitowoc	x	x	x	x	x	x	x
Marathon	x		x	x		x	x
Marinette	x			x			x
Marquette	x	x	x		x		x
Menominee	x	x		x		x	
Milwaukee	x	x					
Monroe	x	x	x	x	x		x
Oconto	x	x	x	x	x		
Oneida	x	x	x	x	x	x	x
Outagamie	x	x	x	x	x	x	x
Ozaukee	x		x		x	x	
Pepin	x						
Pierce	x	x		x	x		x
Polk	x		x			x	
Portage	x	x	x	x	x	x	x
Price	x	x	x	x	x		

Table 2.1 continued: Geographic data received from the 72 counties in Wisconsin. Some counties tended to have a multitude of data while others had a very limited amount. The data shown only includes the data that were utilized for the project**.**

County	Parcels	PLSS	Roads	Zoning	Hydro	LUC	Muni
Racine	x		x	x	x	x	
Rock	x	x		x	x	x	x
Rusk	x	x	x	x	x		
Sauk	x	x	x	x	x		x
Sawyer	x			x			
Shawano	x		x	x	x	x	x
Sheboygan	x			x	x	x	
St. Croix	x			x	x	x	x
Taylor	x	x	x		x	x	x
Trempealeau	x	x	x	x	x		
Vernon	x	x		x		x	x
Vilas	x	x	x	x	x	x	x
Walworth	x	x	x	x	x		
Washburn	x				x	x	
Washington	x	x	x		x		x
Waukesha	x	x	x		x		
Waupaca	x	x	x	x	x	x	x
Waushara	x	x	x	x	x	x	x
Winnebago	x	x	x	x	x	x	x
Wood	x	x	x		x	x	
Juneau	x			x		x	x
Richland							

the parcel data acquired from Juneau County were only from six townships that were surrounding the fish farm locations within the county, since these were the only areas in the county that included fish farms. Acquisition of the entire county was unnecessary for the project and the entire data set would have been too expensive. GIS data from Richland County was not obtained since the purchase price was cost prohibitive at $1,000 for the entire county.

The county data acquisition took close to a year for the county GIS data layers to be acquired as some counties required signed data sharing agreements to be completed. The counties that required a time and materials fee also took longer to process due to administrative oversight.

The fish farm location data were acquired from the Wisconsin Department of Agriculture, Trade and Consumer Protection (DATCP). The fish farm data contained 10 years of registration for farms starting in 2002 and ending in 2011. Wisconsin fish farms must register each year and include information about production systems and fish types along with the location of the farm. With 10 years of data, I was able to determine locations that once had farms but currently do not have commercial operations on site. The fish farm location points included information on the registration number, folder description, issue date, subcode, folder name, property house, property street, property city, property postal zip code, and the X, Y coordinates (the farm’s geographic location). Folder description included information on what type and size of production system, the water source, size of farm system, and the species of fish raised in the system. One problem encountered with the folder description was that after 2007, this data column was left blank for privacy reasons. Thus information about the system and species was unavailable for farms that opened after 2007. The folder name contained the name of the farm or owner. Subcode was related to the type of fish farm registration the farm had. Property house, street, city, postal zip code contained information as to the address of the fish farm location. Issues were found with these categories as some were the address of the owner's home and not the address of the actual fish farm location. The X, Y coordinates were the georeferenced locations in a defined geographic or projected coordinate system. A geographic coordinate system is defined by a datum, an angular unit of measure, and a prime meridian. A projected coordinate system consists of a linear unit of measure, a map projection, the specific parameters used by the map projections and a geographic coordinate system (ArcGIS). The X, Y coordinates in decimal degrees represented the location of the fish farm point as shown on a map. This is similar to how a Global Positioning System (GPS) unit shows the type of coordinates for the current location.

Data covering wetlands, watersheds, and hydrology were obtained from the Wisconsin Department of Natural Resources (WI DNR) data holdings. Hydrography included data on open water and river and streams. Watershed data contained the 1,853 HUC 12 watersheds found in Wisconsin (Figure 2.2).

Groundwater quality data acquired from the Center for Watershed Science and Education (CWSE) at the University of Wisconsin-Stevens Point (UWSP). These water quality data from UWSP contained over 70,000 different data points containing information from the potable private wells throughout the state. These data contained information on water pH, alkalinity, hardness, nitrate, chloride, calcium, copper iron, and lead. Water quality data were also retrieved from the United States Geological Survey

(USGS) National Water Information System from groundwater and surface water sources. The USGS water quality data contained information on dissolved oxygen, pH, temperature, hardness, alkalinity, CO_2, nitrite, nitrate, ammonia, iron, hydrogen sulfide, and depth to water. This water quality information set contained 1,917 different data points for the state.

Land cover data for Wisconsin were obtained from the National Land Cover Database (NLCD). This database was from 2006 and classified the land cover into 16 different classes. The different classes were determined using Landsat satellite imagery with 30-meter resolution. The classes were open water, ice/snow, developed open space, developed low intensity, developed medium intensity, developed high intensity, barren land, deciduous forest, evergreen forest, mixed forest, shrub/scrub, grassland/herbaceous, hay/pasture, cultivated crops, forested wetlands, and herbaceous wetlands.

Soil data were created by the Natural Resources Conservation Service (NRCS) of the U.S. Department of Agriculture. Soil attributes were derived from the State Soil Geographic (STATSGO) Data Base for the State of Wisconsin. These data were designed for used at a regional or state scale. There were also NRCS data tables that further explained in detailed information about the different areas of soil in the state. These tables included information about the soil type, soil permeability, and soil pH.

Slope of the land was able to be determined using a digital elevation model (DEM) at a three meter resolution. The slope was also a three meter scale. The DEM dataset used were created by the USGS. The USGS DEM data files were digital representations of elevation (topography) in a raster data form (Cote; GeoCommunity, 2001). Raster data were shown as a grid of equal sized three meter squares. The DEM contained an array of elevations for many ground positions at regularly spaced intervals. Each position represented a single data file that contained the information about that location's elevation. The DEM was used to develop slope maps for the study.

Data Preparation

The data received from the various sources were not in the same projected coordinate system. All data layers from each county were changed to the coordinate system NAD 1983 Wisconsin Transverse Mercator (WTM) to maintain the same spatial representation across the state of Wisconsin. Once the entire database was in the same geographic reference system, the data layers were able to be pieced together and the various layers overlaid. The changing of the coordinate system and projection allowed the data to be manipulated easier without projection error to attain the desired results.

The fish farm location dataset included all the registered fish farms from 2002 to 2011 throughout the state of Wisconsin. These data included the entire list of fish farms registered as Type 1, Type 2, and Type 3 and a data point for each year the farm was registered. Thus, a farm with ten years of operation had 10 points indicating the same location. This unaltered data contained 22,744 different fish farm points for the state. Preparation of this data layer included removing all the fish farm location points registered as a Type 1 fish farm since this type was non-commercial and not relevant to the study. This lowered the number of registered farm points to 3,571. Further preparation was done to remove the state run farms that included hatcheries and stocking ponds, along with schools and other non-commercial locations. After the non-commercial operations were removed, the farms locations were minimized to one data point, for each farm location; that included a start date and an end date and their fish farm registration number. There were several farm locations that had different registration numbers but had the same physical address or owners. There were also cases where a farm name changed causing the registration number to change but the farm location and farm description were the same. In these circumstances, several verification steps were utilized to confirm it was the same farm and to cross-check registration numbers. Once the farms locations data were reduced to one entry point per registration number, the point location was verified using orthophotography from the aerial photos of the counties. This task was important as the data points acquired from DATCP were geocoded to the address of the farm and were not always located over the actual farm production system. Some of the original farm point locations did not need to be moved, but there were several farm point locations that were not in the correct county where the farm was actually located. There were several farm address locations that were for the owner's home address in a city while the production system was miles away. Along with the use of the orthophotos to see the production systems, county parcels were used to verify the owner of the land that contained the production system. Once the site locations were verified and positioned over the production system, new higher accuracy X, Y coordinates were created.

The NLCD land cover data were acquired in a raster data format and were converted to a vector polygon format for easier compatibility with other data that were in vector format. This made it easier to evaluate the land cover types around the fish farm locations. The soil data were originally a vector polygon dataset that were accompanied by a series of attribute data tables. The data tables were joined to the polygon data to add more descriptive characters to the overall soil data. The water quality data were interpolated to a raster surface from the water quality points from CWSE and USGS using an inverse distance weighted (IDW) interpolation technique. This IDW raster was then converted to a vector polygon. The IDW assigned values for unknown points which were calculated using a weighted average of the values from the known points (Childs 2004; Li and Heap 2008). IDWs were created for each different aspect of water quality such as hardness and pH. Inverse distance weighted interpolation implemented the assumption that things closers to one another are more alike than those farther apart. In an IDW, a predicted value was determined by using the measured values surrounding the predicted location. The measured values which were the closest to the predicted locations have the most influences on the predicted value.

Model Setup

An evaluative model was created to look at the various landscape characteristics around the fish farm and the watersheds that contained fish farms. The fish farms were first classified into three longevity groups (Figure 2.4). The first class, short longevity, contained fish farms that were open 1 to 3 years. The second, medium longevity consists of farms with continuous operating years of 4 to 6 years. The last, high longevity is comprised of fish farms with annual operation of 7 or more years. To take into consideration some of the nuances with the fish farm data preparation, if a fish farm name and registration number changed but the exact physical location did not move it was considered to be continuously open (and essentially the same farm). For example, if a farm was the same name and number for 5 straight years, then the next year the name and

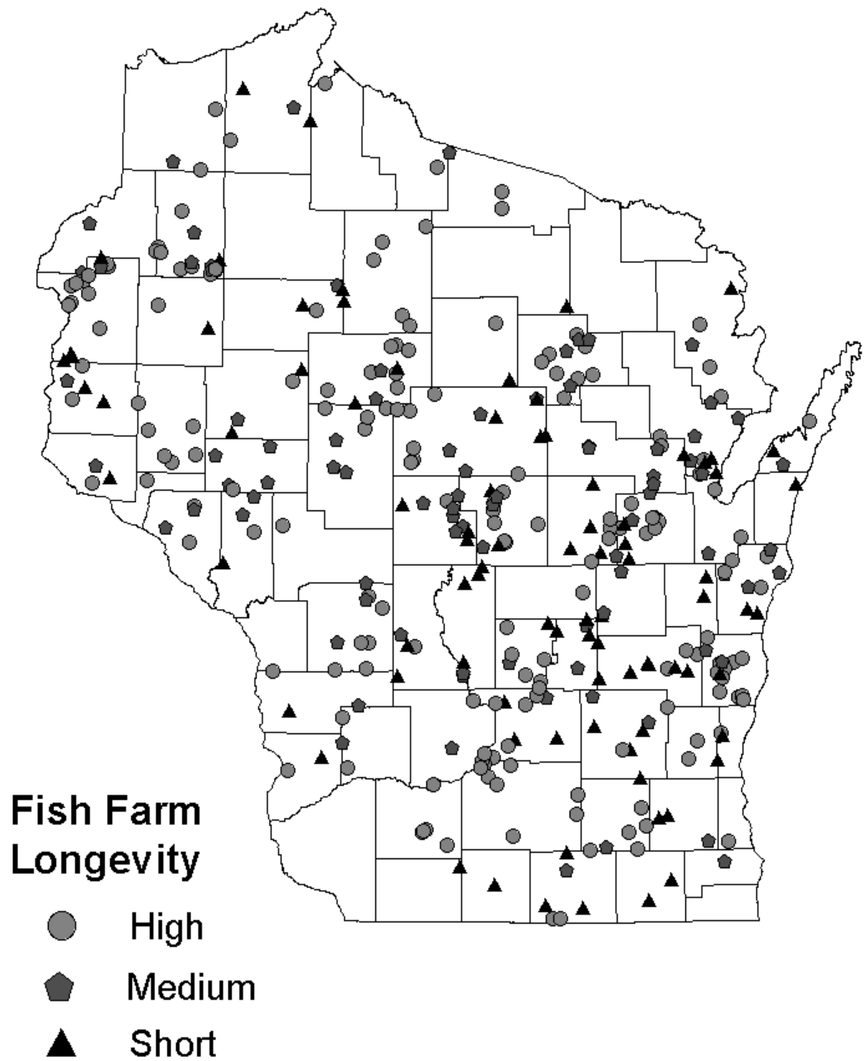

Figure 2.4: The three different longevity groups for fish farms in the state. These longevities were used to help determine which landscape characteristics were more important for fish farms. The longevity groups were also used to determine the number of farms to be removed for sensitivity testing of the second objective's predictive model. High longevity fish farms were in operation for seven or more years, medium longevity fish farms had operational years from four to six years, while short longevity fish farms were only in operation for three or less years.

number changed but location did not, the farm was considered to be in operation for 6 years.

A stratified random sample of all fish farm locations was removed with the plan to use the selected farms to test the sensitivity of the final predictive model. The entire fish farm dataset consisted of 357 different fish farm location points. The predictive model sample size for sensitivity testing was 12% of the entire fish farm location dataset and consisted of 43 fish farm locations, leaving the evaluative fish farm model with 314 farm locations (Figure 2.5). The stratified random sample was based on the geographic regions of the state, which was divided into five areas. Within each of these regions, 12% of each longevity class was randomly chosen for sensitive testing. This meant that 12% of the short longevity, 12% of the medium longevity, and 12% of the high longevity in each of the 5 regions were removed from evaluation. Unfortunately the sensitivity testing was not able to be completed due to research logistical problems. A predictive model was completed by Koeller et al. (*in progress*) and a summary review is found in Appendix D. The 43 selected sensitivity fish farm locations were not used during the evaluation of fish farm locations.

Using ArcMap 10.2 software (ESRI), the 314 fish farms selected for the evaluative model were individually given a 500-meter buffer to evaluate the area directly around the fish farm. Each buffer had a radius of 500 meters. The buffer enabled the landscape characteristics around the fish farm to be assessed and identified. This information was then joined or “geo-tagged’ to the fish farm. To go along with evaluating the 500-meter buffer around each fish farm location, the watersheds that contained the fish farms were also identified. The watersheds were examined because

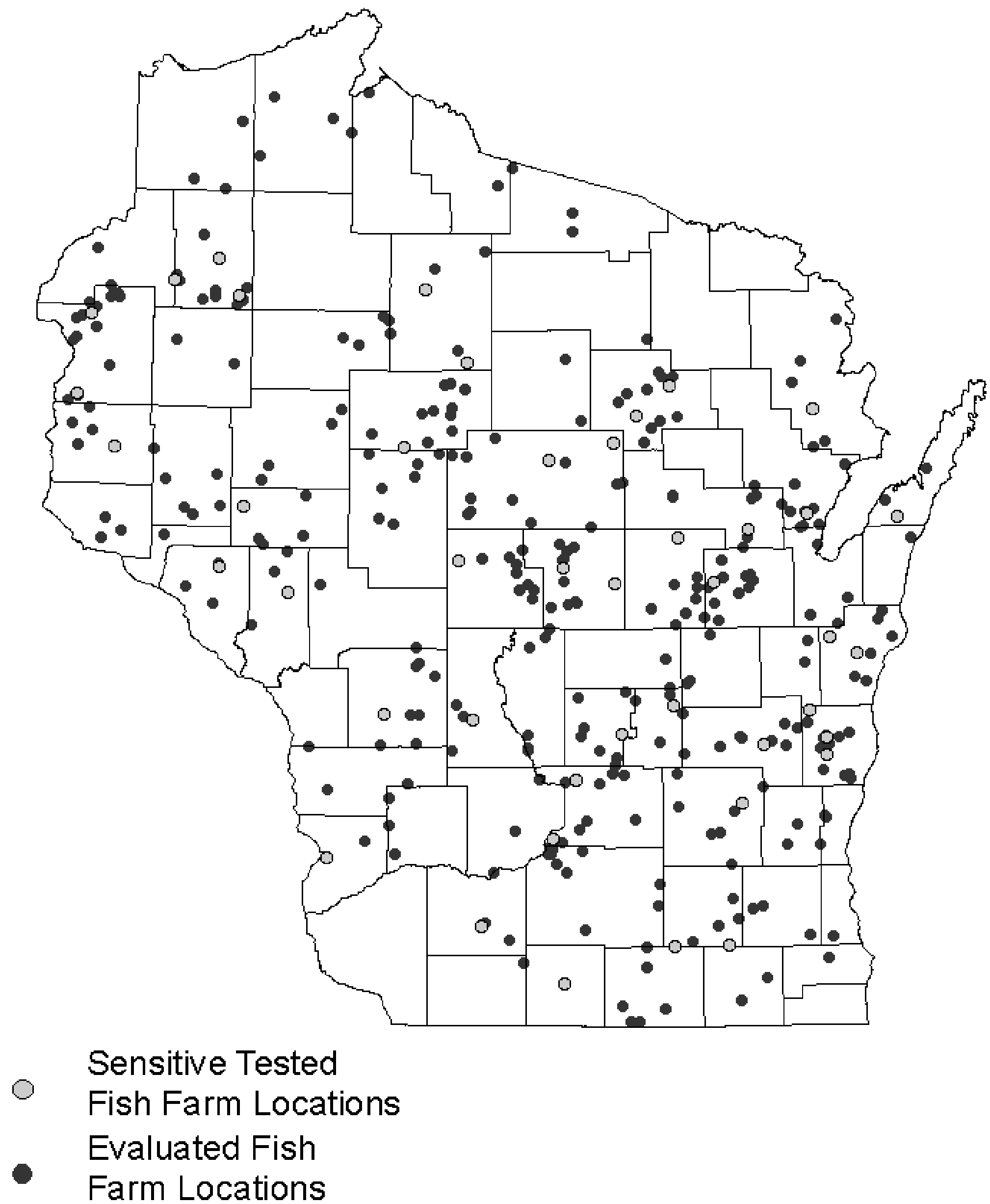

Figure 2.5: Fish farm locations in the state used for the evaluative model and sensitivity testing. The sensitive fish farm locations were removed from five different geographical regions in the state. There were 12% of the total farms removed for sensitivity testing from each of the regions.

of their role with the movement of water, nutrients, and pollutants that could be found in the watersheds containing fish farms. There were 279 watersheds that contained fish farms. There were watersheds that contained multiple fish farms with different longevity classes and some that contained only a single fish farm. Of the 279 watersheds, 253 contained fish farms that were evaluated for landscape characteristics and assessment of fish farm longevity "indicators". The other 26 watersheds which contained fish farms had fish farms that were not evaluated with the hope of using the fish farms for the sensitivity analysis with the predictive model.

An ArcGIS flowchart model template was created to isolate characteristics critical to fish farms (Appendix B). The model was modified for usage with the fish farm buffered locations, and then modified again to examine the critical watershed areas. The major difference in the results of the two flowchart models was the size of the area being evaluated. An individual fish farm buffer only encompassed 194.1 acres, while an individual watershed area tended to be around 23,000 acres. Consequently all of the individual fish farm buffers were less than a 1/3 of a square mile (square mile being 640 acres). The essential algorithmic component of each of these two models is the same, but the land area encompassed for fish farms and watersheds is vastly different.

Model Operations

The evaluative model template began with using the Iterate Feature Selection tool that instructs the model to run an evaluation for each different feature in the dataset such as a single watershed based on a set value (attribute). The same method was used on a single fish farm buffer. This set attribute (value) was the name of the individual watershed and street address name for the individual fish farm buffer. After the Iteration Feature Selection tool which achieved a single watershed/fish farm buffer, a feature class layer was created for just that watershed/buffer using the Make a Feature Layer tool. The explanation of the methodology is for an example with a watershed that contained a fish farm. This newly created watershed feature layer was temporary and needed to be made permanent. The Copy Features tool was then used to save the new the watershed feature layer made the layer permanent. This section of the model using the Make a Feature Layer Tool and Copy Features tool was done in the model as it was found to work and kept. Upon looking at the model, this process could have been removed by having the files sent to a geodatabase or use shape files. This would have eliminated the need to copy the features and would have made a more efficient model.

Once an individual watershed/buffer feature layer was made, each different indicator could then be ran through their respective portion of the model to gather the information which would be later evaluated. This was done by taking the taking the indicator and extracting by a mask of the watershed area. The Extract by Mask tool extracted all the cells of a raster that correspond to the areas defined by the mask. The watershed area was considered the area defined by the mask. The Extract by Mask was performed on all raster data layers. The raster layers evaluated were the DEM, land cover, alkalinity, hardness, and pH. The Clip tool which extracts the input features (watershed area) that overlay with the clip feature was used to extract the state soil and temperature data that were in a vector format.

After the raster data layers (DEM, land cover, alkalinity, hardness, and pH) were clipped (using the Extract by Mask tool) to the watershed area, they were converted to polygons using the Raster to Polygon tool. This tool converted the raster datasets to polygon features. This was done as all the layers needed to be in vector format as raster format was not able to be used. The raster data layers were converted to polygons after the Extract by Mask because when the model had the data converted to polygons before the data were clipped the model would fail from the size of the data layer being extracted to a smaller size. The reason for the model failing when the layers were converted to polygons at the state level before being clipped was from the database being to larger and it exceed the memory capacity of the program to complete the clip. One raster layer, state DEM was also used to create an additional layer, slope. The creation of the slope layer was done using the Spatial Analyst-Surface-Slope tool which took the DEM extraction for an individual watershed and created a slope of the landscape for the watershed. The slope tool identified the slope of each cell of a raster surface. The slope was determined by the change in elevation values from each cell to one another, and was calculated as a percent change. The slope for each cell was then converted to a single integer value to allow summary statistics. Once the slope was calculated for the raster dataset, it was converted to a polygon to be in a consistent format.

The five data layers in polygon format of slope, land cover, alkalinity, hardness, and pH, each had a new field attribute, labeled ‘grid code’ added that identified the layer type. After the fields were added each grid code identifier was created through the use of the Calculate Field tool. These feature polygons were then run through the Make Feature Layer tool again to make sure they were a feature layer. And once again this feature was just temporary so it was run through the Copy Features tool to make a permanent feature layer. The end result of this left feature layers for slope, land cover, alkalinity, hardness, pH, soil, and temperature.

The next step was to determine the frequency of each different layer value found at the watershed. This was done using the Frequency tool. The Frequency tool was able to read a table and a set of fields and created a new table containing unique field values and the number of occurrences of each unique field value. The Frequency tool looked at a stated attribute value for each data layer. It returned the values of the attribute and the frequency for each different value.

The final step in the evaluative model was to combine the individual data layers into one data layer that contained information on each different indicator. This was done using the Intersect tool. This tool took each different feature layer and overlaid them with each other, areas in common with each other were combined together to make the final feature layer. The Intersect tool was chosen for use over other tools based on it being able to work with all the polygons at once and would also make sure the data was clipped to each other.

After the indicator feature layers were combined with each other to make one single feature layer for each watershed, a dissolve command was used to eliminate any information not needed in the final analysis. This was performed using the Dissolve tool to remove any of the remaining unnecessary attribute columns and only contained relevant data for the fish farms evaluations.

Output and Statistical Analysis

The result of the running this evaluative model was individual data layers for each fish farm and watershed that contained information on water quality, land cover, slope, and soil (Table 2.2 and 2.3). Comparisons and statistical testing were then performed to determine which landscape indicators are the most influential to the longevity of fish farms. To begin the comparisons, each value for the indicators were exported by entering the data by hand to a Microsoft Excel spreadsheet for each corresponding fish farm or watershed (Table 2.4). The information for each landscape indicator was found using the *ArcGIS Arc Catalog program*. In this program, individual frequency tables were generated for a single fish farm or watershed. These frequency tables were created using the Frequency tool. There were frequency tables for soil, slope, alkalinity, hardness, pH, and land cover. Each table contained information on what was located in each evaluated area. A frequency example using a slope frequency table included details on the different percent slopes that were found in the individual area, along with how many times that each different percent slope appeared. The percent slope value that had the most appearances in the area was recorded as the most common (frequent) in that specific area. This information was recorded in the Excel spreadsheet. The most frequent indicator value for each different evaluated landscape characteristic (slope, alkalinity, hardness, pH, soil texture, soil pH, and Ksat) was recorded for each fish farm and watershed. This process created Excel spreadsheets which contained the most frequent value for each landscape indicator for the individual fish farm buffer and watershed. The most frequent value was found by taking the most common indicator value and was done to determine the most common value found in the specific area. If there were multiple indicators

Table 2.2: A frequency table for an individual watershed taken from *Arc Catalog*. The table shows the alkalinity of water for a watershed in Wisconsin. The three most frequent values were recorded. In this case, they were 156, 153, and 154.

OBJECTID*	FREQUENCY	Alklnty
4	2	156
1	1	153
2	1	154
3	1	155

Table 2. 3: A frequency table for an individual watershed taken from *Arc Catalog*. The table shows the percent slope of the landscape for a watershed in Wisconsin. The three most frequent values were recorded. In this case, they were 2, 3, and 1.

OBJECTID*	FREQUENCY	Slope
3	59	2
4	46	3
2	39	1
1	36	0
5	26	4
6	15	5
7	11	6
8	5	7
9	4	8
11	3	10
10	2	9

Table 2.4: Example of the frequency data for fish farm buffered locations in Excel. The means for the indicators have already been calculated and are shown. The mode for land cover (LUC) is shown.

Name	Ksat	ph_soil	texture	texdesc	unidiedcl	Slope	LUC	Temp	pH	Alk	Hard	Species	System	Successfu	Reg_Num	Longevity
Plu	28.2287	5.5	LS	Loamy Sar	SP-SM	0	90	52	7	33	36	Mix-Cold,	Pond	N	112209	H
ALP	9.1743	6.5	Sil	Silt Loam	CL	3	81	53	8	215	322	Mix-Cold,	Pond	Y	112210	H
Fif	9.1743	6.2	L	Loam	CL	1	82	50	8	97	124	Cold	Flow-thru	Y	112212	H
Shi	9.1743	6.7	L	Loam	SC-SM	1	82	52	7	292	337	Mix-Cool,	Mix-Pond	Y	112220	H
Sil	9.1743	6.2	SIL	Silt Loam	CL	1	41	51	7	218	359	Mix-Cold,	Mix-Pond	Y	112225	H
Tre	9.1743	7.2	SIL	Silt Loam	CL-ML	1	82	51	7	334	339	Mix-Cool,	Mix-Pond	Y	112230	H
Ced	28.2287	5.5	LS	Loamy Sar	SP-SM	1	42	51	8	92	86	Cold	Mix-Pond	Y	112240	H
Ele	9.1743	6.5	SIL	Silt Loam	CL	12	82	50	7	56	101	Mix-Cold,	Mix-Pond	Y	112241	H
Har	9.1743	7.2	L	Loam	CL	2	82	51	7	308	349	Cool	Pond	Y	112242	H
Stc	9.1743	6.7	SIL	Silt Loam	CL	1	82	51	7	322	328	Cool	Pond	Y	112243	H
Sch	9.1743	5.5	SIL	Silt Loam	CL-ML	1	81	51	8	175	168	Cool	Pond	Y	112244	H
Val	9.1743	5.9	SL	Sandy Loa	SC-SM	1	81	58	7	91	87	Cool	Pond	Y	112246	H
Lit	28.2287	6.5	FSL	Fine Sand	SC-SM	0	90	49	8	165	118	Cool	Pond	Y	112247	H
Riv	9.1743	6.5	SL	Sandy Loa	SC-SM	0	81	50	8	259	312	Mix-Cold,	Mix-Pond	Y	112251	H
Ont	9.1743	5.9	SIL	Silt Loam	CL	2	41	49	7	226	258	Mix-Cold,	Mix-Pond	Y	112257	H
Ste	9.1743	7	SIL	Silt Loam	CL	0	81	51	7	311	367	Warm	Pond	Y	112260	H
ATH	91.7432	5.5	LS	Loamy Sar	SP-SM	0	90	48	7	88	93	Cold	Pond	Y	112262	H

Name (abbreviated name)
Texture (soil texture)
Texdesc (soil texture description)
Unidiedcl (relates to soil properties)
LUC (land cover /land use)
Alk (alkalinity)
Hard (hardness)

values (up to three) that had the same frequency number they were recorded and a mean was found.

Along with the recording of the different indicator values for each fish farm, the longevity year, production system, water supply, and species type were included. For the watersheds only the longevity type of the fish farms located in the watershed were noted. All the information was entered in to a spreadsheet and the different categories shown for each fish farm were: longevity years, production system, water supply, species type, land cover, slope, alkalinity, hardness, pH, soil texture, soil ksat, and soil pH.

Fish farms buffered evaluations were then broken up by their longevity group. There were 157 farms with high longevity, 79 farms with medium longevity, and 78 with short longevity. The average value was then calculated for each different indicator within the longevity group. This made it easier to compare indicator values across the groups. There was no feasible way to compare water supply or species types among the longevity groups. The reason for this was a lack of information from the acquired fish farm datasets. High longevity farms tended to contain very detailed information on these categories while medium and short had poor information or none at all. This was most likely a result of added privacy for fish farms in 2007. Nevertheless, at a minimum the production systems were divided into pond production systems and raceway production systems. There were a total of 24 farms with raceway production systems, but only seven of those operated purely as raceway systems (the other 17 farms also had ponds in conjunction with raceways). There were a total 307 farms which utilized pond production systems with 32 of these have a mixture or ponds, tanks, raceways, and RAS for production. I included farms that used both ponds and raceways into each category to create a large sample size for raceways. This allowed for comparing between only pond systems and raceway systems. One possible reason for the limited number of raceway production systems could be from the lack of information given during registration by the fish farmer, error in entering the registration data, data hidden for privacy reasons, or data misinterpretation. All fish farm locations were verified using aerial imagery and it was not possible to see if the body of water was a flow-through pond/raceway or just a pond.

The watershed evaluations were also divided into three longevity categories, even though individual watersheds contained multiple longevity class. There were 124 watersheds that contained only fish farms with high longevity. There were three watersheds that contained all three longevity groups while 11 watersheds contained both high and medium longevity along with 5 watersheds with high and short longevity. There were 59 watersheds which contained only medium longevity fish farms and nine watersheds with both medium and short longevity. The remaining 68 watersheds contained only short longevity fish farms.

General observations were made between the indicator means (Ksat, soil pH, slope, water temperature, alkalinity, hardness, and pH) across the three longevity groups for the fish farm buffers and watersheds. Differences in means were noted and evaluated whether there was a noticeable difference in the values. These observations were done by comparing the means for the different longevity groups across the pond and raceway production systems. These comparisons looked for significant differences between the three longevities, and inferred that the greater the difference the more likely that indicator has an influence on the overall longevity.

An analysis of variance (ANOVA) was performed to determine if there were statistically significant differences between each evaluated indicator for the fish farm areas (buffered locations) of either production system across the three longevity groups. The ANOVA tests were performed for soil Ksat, soil pH, slope, water pH, water alkalinity, and water hardness. The ANOVA was performed to determine the possible effects the indicators had on the overall longevity of the fish farm. An ANOVA uses a null hypothesis that all the variables (indicators) are random samples in the population (fish farm longevity) and the means are equal to each other (Gotelli and Ellison 2004). The research hypothesis states that the means across the variables are not the same. By rejecting the null hypothesis, it means there is a different in the effect on the longevity for an indicator. The null is rejected if the p value ≤ 0.05 and/or the F-statistic is greater than the F-critical. The F-statistic represents how much variable among the means exceeds that expected due to random change.

A separate set of statistical tests, based on Chi-Squared (χ^2) were performed on the evaluated data values for both watersheds and fish farm buffered areas to further determine which landscape indicators have a statically significant effect on longevity. There were three Chi-Squared (χ^2) tests performed on the fish farm buffers evaluative data. There were results for the farms with pond production systems, raceway production systems, and one that included either system. The evaluative data were grouped based on what each indicator should be for a fish farm based on literature for aquaculture. Each different indicator for each longevity group was categorized based on 3 classes of suitability for fish farms. The Chi-Squared tests were then able to be performed on these classifications and significance was indicated at $p \leq 0.05$ for each indicator. The Chi-Squared tests were performed in Microsoft Excel.

The evaluation data for the fish farm buffers were able to be evaluated a third way. The evaluative data were examined using multiple regression to further determine which indicators had the largest effect on longevity. This was done because the fish farm buffers had a large difference in the longevity years ranging from 1 - 11 years. In this analysis, the dependent variable was longevity years and the independent variables were the landscape indicators. I originally tried using the three longevity groups but did not end up with understandable results as the difference in the three variables was so small, being 1 - 3; with one representing short longevity, two being medium longevity, and three for the long longevity group. By changing the dependent variable to 11 possible options I was able to get results that could be interpreted. The 11 options were determined based on the number of years the fish farm was in business. Table 2.5 is an example of the data that was used for the Akaike Information Criteria (AIC). AIC models were created and ran with program R to determine which model had the largest effect on the longevity (R-project.org).

These AIC models were created *a priori* based only on knowledge of fish farm operations (Burnham and Anderson 2004). A null model was created with no indicator affecting the longevity. This represented the null hypothesis: landscape does not have an effect on fish farm longevity. There were models created which looked at a single indicator and its effect on the longevity and negated cross variable effects. This would be the case if only water pH had an effect on longevity and all the other indicators do not matter. Some models grouped indicators together based on similarities to take into

Table 2.5: Example of the data that was used to complete the AIC Models.

Reg_Num	Years	Longevity Score	Ksat	Soil Score	Slope	Temp	pH	Alkalinity	Hardness
112209	10	3	28.2287	0	0	52	7	33	36
112210	8	3	9.1743	2	3	53	8	215	322
112212	11	3	9.1743	2	1	50	8	97	124
112215	2	1	9.1743	1	1	51	7	239	315
112218	6	2	91.7432	0	1	52	8	151	156
112220	8	3	9.1743	2	1	52	7	292	337
112223	6	2	9.1743	2	1	50	8	157	453
112225	8	3	9.1743	2	1	51	7	218	359
112227	6	2	91.7432	0	2	56	7	64	73
112228	6	2	28.2287	0	0	49	6	134	89
112230	11	3	9.1743	2	1	51	7	334	339
112233	6	2	9.1743	2	0	53	8	277	375
112240	11	3	28.2287	0	1	51	8	92	86
112241	9	3	9.1743	2	12	50	7	56	101

consideration cross variable effects. This was the case with water quality which included the alkalinity, hardness, and pH having an effect on longevity regardless of the other indicators. Other models grouped slope and soil to see the possible influence on longevity. There was also a model that included all of the indicators to see if the effect of everything had a large influence on longevity.

Each model gave results that were included in an AIC table. The models gave information about the residual sum of squares (RSS), degrees of freedom and p-values. Using the RSS, with the degrees of freedom, allowed for the calculation of the AIC value for each model. The AIC in turn was used to calculate the Akaike weight for each model. The evaluation of the model looked at the Akaike weight and to determine how close the value was to one. The closer to one the Akaike weight was the more influence those variables had on the dependent variable (Burnham and Anderson 2004). The p-value also aided in determining which model had the largest influence. If the p-value was <0.05, the model had significance and showed which indicators had an effect on fish farm longevity.

The AIC test was not performed on watersheds as there were watersheds that had multiple fish farms that could have affected the overall interpretation of the results. When a single watershed contained a fish farm in each of the three longevity groups the overall evaluation of the results could be influenced by all three farms.

RESULTS

General Observations of Evaluative Means

Mean values for each fish farm indicator that had pond production systems are shown in Table 2.6. Soil pH ranged 5.9 to 6.5, while the soil Ksat varied 16.880 to 22.204 µm/sec. The water quality variable of alkalinity only differed by a difference of 40 mg/L $CaCO_3$ between the three longevity groups, with short longevity having 213 mg/L $CaCO_3$, medium longevity having 173 mg/L $CaCO_3$, and high longevity having 193 mg/L $CaCO_3$. By looking at the means, it appears that alkalinity and hardness could be important indicators for fish farm longevity when using pond systems.

Mean values for the landscape indicators that are found around fish farms that have raceway production systems are shown in Table 2.7. Much like what was found in the general observations for pond system fish farms, alkalinity (range 144 to 275 mg/L $CaCO_3$) and hardness (range 176 to 323 mg/L $CaCO_3$) could be important indicators for fish farm longevity when using raceway production systems.

Mean values for each aquaculture operation indicator that have either pond or raceway production systems are shown in Table 2.8. This table contains the means for all the fish farm locations that were evaluated in the model. From looking at the means, there may be correlation between water quality hardness (range 196 to 263 mg/L $CaCO_3$) and fish farm longevity. The alkalinity tended to not have as much variation between the three longevity groups with the means ranging from 171 to 213 mg/L $CaCO_3$. The soil Ksat values ranging from 16.400 to 21.705 µm/sec were similar to what was found in only pond production systems. A possible reason for the overall fish farm buffer means being so similar to the fish farm pond buffer means is from the fact there were only 24

Table 2.6: The mean values (±SD) for each landscape indicator for fish farm buffers within a pond production system. Values are shown for each different longevity group highlighting subtle differences between years in operation. Ksat is in µm/sec. Temperature is in degree Fahrenheit. Alkalinity and hardness are in mg/L $CaCO_3$.

Longevity	Ksat	Soil pH	Slope	Temperature	Water pH	Alkalinity	Hardness
High	16.9 (17.6)	6.5 (4.5)	1.8 (2.9)	51 (2.6)	7.2 (0.5)	193 (92.1)	217 (112.7)
Medium	22.2 (24.8)	5.9 (0.4)	1.8 (2.1)	49 (2.8)	7.1 (0.6)	173 (97.4)	198 (118.4)
Short	18.1 (20.7)	6.2 (0.6)	1.9 (2.2)	51 (4.5)	7.2 (0.4)	213 (91.2)	263 (122.8)

Table 2.7: The mean values (±SD) for each landscape indicator for fish farm buffers within a raceway production system. Values are shown for each different longevity group highlighting subtle differences between years in operation. Ksat is in µm/sec. Temperature is in degree Fahrenheit. Alkalinity and hardness are in mg/L $CaCO_3$.

Longevity	Ksat	Soil pH	Slope	Temperature	Water pH	Alkalinity	Hardness
High	12.7 (7.3)	6.1 (0.6)	2.6 (4.5)	50 (2.2)	7.2 (0.4)	195 (102.4)	228 (129.5)
Medium	9.1 (0.1)	6.1 (0.3)	7 (7.8)	50 (4.4)	7.0 (0)	275 (104.8)	323 (131.9)
Short	42.9 (43.3)	6.1 (0.6)	1.3 (1.5)	50 (1.5)	7.0 (0)	144 (121.7)	176 (166.9)

Table 2.8: The mean values (±SD) for each landscape indicator for fish farm buffers within either a pond or a raceway production system. Values are shown for each different longevity group highlighting subtle differences between years in operation. Ksat is in µm/sec. Temperature is in degree Fahrenheit. Alkalinity and hardness are in mg/L $CaCO_3$.

Longevity	Ksat	Soil pH	Slope	Temperature	Water pH	Alkalinity	Hardness
High	16.8 (18.5)	6.5 (4.8)	1.8 (2.8)	51 (2.6)	7.2 (0.5)	193 (91.8)	218 (112.0)
Medium	22.2 (25.2)	5.9 (0.5)	1.9 (2.5)	49 (2.9)	7.1 (0.6)	171 (96.6)	196 (117.9)
Short	17.1 (19.2)	6.2 (0.6)	1.9 (2.3)	51 (4.5)	7.2 (0.4)	213 (91.2)	263 (122.8)

farms that utilized some form of a raceway production system with the remaining 290 farms having ponds for production. The large sample of pond production systems likely have strongly influenced the overall means.

In addition to the general observations between fish farm buffered locations and the indicator means, general observations were made on the landscape indicator means for the watersheds which contained fish farms (Table 2.9). This table shows the means for watersheds that contained only a single longevity group and also the means for watersheds that contained multiple longevity groups.

Statistical Analyses

The ANOVA results of the fish farm buffered locations helped gain an initial understanding of what landscape indicators have an influence on the overall longevity of a fish farm. The analysis of variance showed that the effect of water alkalinity and hardness were significant; alkalinity $F(2, 304) = 3.64$, $p = 0.027$ and hardness $F(2, 304) = 6.41$, $p = 0.002$ (Table 2.10). There was no significant difference ($p > 0.05$) seen in the landscape indicators of soil Ksat, soil pH, slope, and water pH (Table 2.10).

The Chi-Squared (χ^2) tests were not performed across the longevity groups but as a whole based on the production types. The pond production system fish farms showed a significant relationship with the indicator of water pH ($p = 0.0009$, $df = 2$) (Table 2.11). The water pH was not originally believed to have much of a factor in the overall longevity, but from what this test showed it is still an important factor in fish farm location ($p = 0.0009$). The fish farms with raceway productions systems did not have any

Table 2.9: The mean values (±SD) for each landscape indicator for watersheds containing a fish farm location. Values are shown for each different longevity group that show subtle differences between years in operation. High Mixture, Medium Mixture, and Short Mixture represent watersheds that contained multiple longevity groups. In these watersheds there may be high, medium and short longevity fish farm locations. Ksat is in µm/sec. Alkalinity and hardness are in mg/L $CaCO_3$. Water temperature data for watershed evaluations were not included because the values varied so widely within each watershed.

Longevity	Ksat	Soil pH	Slope	Water pH	Alkalinity	Hardness
High Mixture	16.2 (18.4)	6.5 (0.9)	2.7 (2.0)	7 (1.0)	197 (90.0)	224 (110.5)
High	16.8 (18.6)	6.6 (0.8)	2.8 (2.04)	7 (0.6)	197 (90.6)	226 (109.9)
Medium Mixture	21.7 (25.2)	5.9 (1.2)	2.7 (2.0)	7 (1.0)	176 (97.0)	205 (117.0)
Medium	23.7 (24.6)	5.9 (1.0)	2.8 (2.0)	7 (1.0)	169 (95.0)	205 (116.0)
Short Mixture	18.1 (19.8)	6.2 (1.0)	2.6 (2.0)	7 (1.0)	211 (94.0)	249 (117.5)
Short	18.7 (20.6)	6.2 (1.1)	2.8 (2.5)	7 (1.0)	216 (96.0)	262 (120.0)

High mixture was comprised of all watershed that contained high longevity fish farms.
High was comprised of all the watershed that contained only high longevity fish farms.
Medium mixture was comprised of all watershed that contained medium longevity fish farms
Medium was comprised of all the watershed that contained only medium longevity fish farms.
Short mixture was comprised of all watershed that contained short longevity fish farms
Short was comprised of all the watershed that contained only short longevity fish farms.

Table 2.10: The analysis of variance for all longevity groups of the seven landscape indicators for the evaluation results for fish farm buffers. If F>F crit and p-value < 0.05, there is a difference in the means of the three longevity groups. There was difference for the mean water alkalinity and water hardness. This may show that these indicators have an effect on the longevity of fish farms. There was no difference for soil Ksat, soil pH, slope, and water pH.

Soil Ksat							
	Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
	Between Groups	830.4761	2	415.2381	0.7563	0.4703	3.0254
	Within Groups	166911	304	549.0493			

Soil pH							
	Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
	Between Groups	22.2780	2	11.1390	0.8008	0.4502	3.0356
	Within Groups	3157.441	227	13.9094			

Slope							
	Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
	Between Groups	0.8128	2	0.4064	0.0614	0.9405	3.0254
	Within Groups	2013.441	304	6.6232			

Water pH							
	Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
	Between Groups	0.8489	2	0.4245	1.5730	0.2091	3.0255
	Within Groups	82.0306	304	0.2698			

Water Alkalinity							
	Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
	Between Groups	63215.13	2	31607.57	3.6395	0.0274	3.0254
	Within Groups	2640107	304	8684.564			

Water Hardness							
	Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
	Between Groups	174525.2	2	87262.59	6.4057	0.0019	3.0254
	Within Groups	4141294	304	13622.68			

Table 2. 11: Results of the Chi Squared (χ^2) tests for fish farms buffers. P-values < 0.05 are considered statistically significant for having an effect on the longevity of fish farms. Degrees of freedom was equal to 2. For ponds production fish farms, water pH and land cover were the indicators that were significant in having an effect on fish farm longevity. For raceway production fish farms, there are no landscape indicators that are significant in having an effect on farm longevity.

Pond System		Ksat	Soil pH	Slope	Land Cover	Water pH	Alkalinity	Hardness
	P-Value (df=2)	0.0727	0.1351	0.2206	0.0102	0.0009	0.1649	0.3367

Raceway System		Ksat	Soil pH	Slope	Land Cover	Water pH	Alkalinity	Hardness
	P-Value (df=2)	0.8526	0.9005	0.5134	0.5239	1	0.2800	0.2713

indicators that were significant in the longevity of the fish farm (p-values ranged from 0.27 to 1 with 2 df; Table 2.11). This may be an artifact of the small sample size as there were a limited number of farms with raceway systems so there was limited evaluative data to analyze.

The watershed data were also tested using Chi-Squared (χ^2) analysis to determine the significance of the relationship these indicators had on the longevity of the fish farms within a given watershed. The tests were performed in the same manner as the production systems and were not done across the longevity groups but as watersheds with fish farms. Water pH and hardness were found to have significant relationship ($p = 0.0026$, $df = 2$ and $p = 0.0484$, $df = 2$, respectively; Table 2.12). The Chi Square tests did not find any significance with land cover as previously found when looking at fish farm buffered evaluations with a p-value of 0.21062. A possible reason for this is the watersheds are so much larger than fish farm buffer and thus more variation in land cover is likely throughout the entire watershed.

The AIC models for the fish farms further supported the results of water quality and having an influence on the overall longevity of fish farms. The purpose of an AIC testing was to find the model that best explains the longevity (Table 2.13) and this was accomplished by looking at the Akaike weights and the p-values (Gotelli and Ellison 2004). The closer the model's Akaike weight was to 1.0 the more positive influence those variables had on the longevity (Burnham and Anderson 2004). The model's p-value was also a consideration for the influence on the longevity. Results showed the AIC model that fit best consisted of all the water quality parameters (hardness, alkalinity, and pH) (Table 2.13). This model had an Akaike weight of 0.120 and a p-value of 0.005.

Table 2.12: Results of the Chi Squared (χ^2) test for watersheds with fish farm locations. P-values < 0.05 are considered statistically significant for having an effect on the longevity of fish farms. For watersheds containing fish farms, water pH, and hardness are significant in having an effect on fish farm longevity. Degrees of freedom was equal to 2.

Watersheds	Ksat	Soil pH	Slope	Land Cover	Water pH	Alkalinity	Hardness
P-Value (df=2)	0.3493	0.1995	0.5687	0.2106	0.0026	0.1049	0.0484

Table 2.13: AIC values for fish farm buffer evaluation. The table shows the various models run to determine which indicators have the largest effect on fish farm longevity. The closer the model's Akaike weight is to 1 the more influence those variables have on the longevity. The model's p-value is also a consideration for the influence on the longevity. P-values < 0.05 are considered statistically significant for having an effect on the longevity of fish farms. AICc is the AIC correction value.

Model	RSS	K	AIC	correction	AIC_C	AIC_{diff}	Exp	Akaike Weight	R Sqrd	R Sqrd Adjust	p-Value
yWQ	3513.5	5	768.3021	0.1948	768.497	-	1	0.1205	0.0405	0.0312	0.0050
yALL	3442.2	9	769.8646	0.5921	770.4567	1.9597	0.9067	0.1092	0.0600	0.0384	0.0080
yALKHRD	3568.2	4	771.153	0.1295	771.2824	2.7855	0.8700	0.1048	0.0255	0.0193	0.0180
yALLTemp	3436	10	771.2985	0.7261	772.0245	3.5276	0.8383	0.1010	0.0616	0.0370	0.0120
ypH	3612.7	3	773.0448	0.0774	773.1222	4.6252	0.7935	0.0956	0.0134	0.0102	0.0405
yHRD	3634.2	3	774.9079	0.0774	774.9853	6.4884	0.7229	0.0871	0.0075	0.0043	0.1256
ySLOPE	3657.7	3	776.9318	0.0774	777.0092	8.5123	0.6534	0.0787	0.0011	-0.0021	0.5616
yALK	3660.22	3	777.1481	0.0774	777.2255	8.7285	0.6463	0.0779	0.0004	-0.0028	0.7217
yText	3660.7	3	777.1892	0.0774	777.2667	8.7697	0.6450	0.0777	0.0003	-0.0029	0.7688
yKsat	3661.7	3	777.275	0.0774	777.3524	8.8555	0.6423	0.0774	2.8E-07	-0.0032	0.9924
ySoil	3660	4	779.1292	0.1295	779.2586	10.7617	0.5839	0.0703	0.0004	-0.0060	0.9327

yWQ(alkalinity, hardness, pH)
yALL(alkalinity, hardness, pH, slope, soil texture, Ksat)
yALKHRD (alkalinity, hardness)
yALLTemp (alkalinity, hardness, pH, slope, soil texture, Ksat, water temperature)
ypH (water pH)
yHRD (water hardness)
ySLOPE (slope)
yALK (water alkalinity)
yText (soil texture)
yKsat (soil Ksat)
ySoil (soil texture and Ksat)

The next best AIC model contained all of the landscape parameters being (alkalinity, hardness, pH, slope, soil texture, and Ksat). This model had an Akaike weight of 0.109 and a p-value of 0.008. The third best model was comprised of alkalinity and hardness and had an Akaike weight of 0.105 and a p-value of 0.02.

DISCUSSION

The longevity of fish farms in Wisconsin has been somewhat sporadic over the last several decades. There have been a fair number of fish farms that enter the business yearly but a similar number leave the business each year. Part of the problem with the short-lived fish farms may be attributed to the site location of the farm. GIS analysis using landscape indicators in the evaluative model identified the factors of water hardness, alkalinity, pH, and land cover as the largest influences on the overall longevity of an aquaculture operation.

Both Analysis of Variance (ANOVA) and Chi-Squared (χ^2) statistics were used to ascertain geographic features that significantly altered fish farm success (based on longevity). The results from the ANOVA showed that water alkalinity and hardness may have an effect on the longevity of fish farms. The effect of alkalinity and hardness appears to positive with the longevity of fish farms. However the ANOVA tests are not able to tell how strong of an effect alkalinity and hardness have on the longevity. The Chi-Squared (χ^2) analysis for fish farm buffers with pond systems found water pH and land cover have a significant positive influence on the longevity of fish farms. There was no statistically significant influence of the indicators for fish farms with raceway production systems. This was slightly different for the watershed evaluations which found that water pH and water hardness to have a significant positive influence on the longevity of an aquaculture operation.

Along with the results of the ANOVA and Chi-Squared (χ^2) tests, an Akaike Information Criteria (AIC) was run on eleven potential models to determine the best model fit. The one which contained all of the water quality characteristics (pH, alkalinity, hardness), was found to be the model which had the best fit in the multiple regression. This idea of water quality having an influence on fish farm longevity is logical since water quality is a critical factor of fish farms. If the water for the fish is poor quailty there would need to be continuous modifications to make it suitable. An example would be if the pH of the water was 5.0, this is too acidic for fish and would need to be raised. If a farm has this water pH and uses flow-through systems, the water pH will have to be raised before being exposed to fish and thus it would require large amounts of time and chemicals to raise the pH. The water quality results were supported by Swann (1992) and McIntosh et al. (2003) which stated normal water pH in fish farms ranges from 6.5 to 9 and alkalinity and hardness range from 120 to 400 ppm. The evaluative means for the high longevity fish farms had a water pH=7.2, alkalinity ranging (193-197 ppm) and hardness ranging (217-228 ppm). Also, these means were within acceptable ranges for fish farm operations.

Along with water quality aspects being an influence on the longevity of fish farms, the land cover found around the fish farm location appears to have an effect on the longevity. The land cover indicator had significant positive influence when examining only pond production system farms as seeing in the results of the Chi-Squared (χ^2) tests. The majority of the land cover was deciduous forest or cultivated crops was similar to what was seen by Hossain et al. (2009) who determined irrigation, natural grass, and fish farming were the most suitable land uses for fish farm locations. Thus, the land practices found around the fish farms should be considered when constructing a new aquaculture facility.

The results showed that the water quality indicators (pH, alkalinity, hardness) appear to have a positive influence on the overall longevity of the fish farm operations. This makes sense as fish farms require water as a major component to a successful operation. Salam et al. (2005) stated water quality and quantity were possibly the most important requirement for aquaculture. The water source of a fish farm should be as close to the farm site as possible (Salam et al. 2005). This in turn, reduces the future costs for the fish farm. McIntosh et al. (2003) looked at the water quality characteristics of pH, temperature, alkalinity, and dissolved solids in the state of Arizona. This study was able to evaluate pH and alkalinity, which were found to be two the indicators with positive influence on the longevity of fish farm.

The soil quality and characteristics did not have a significant influence on fish farm success but still are an import aspect to fish farm locations. The soil pH for the evaluated fish farms were within the acceptable range for fish farms. The soil Ksat values were found to be similar to soils that tend to a loam content which is often preferred for aquaculture operations (Salam et al. 2005). The slope of the landscape was found to range slightly below 2% for pond systems and raceway systems had a slope range from 1.3 to 7% but still within an acceptable range (McIntosh et al. 2003).

Consequently, from past literature and research the acceptable soil quality (pH, Ksat) and slope were found throughout all of the fish farm samples. It is therefore not surprising that those did not reveal themselves as being significant factors- they were already ubiquitous. The variation of water quality (pH, alkalinity, hardness) and land cover though did show significant variation and was an important influential set of factors for the success or failure of fish farms in Wisconsin.

In looking at extending the geographic extent of a fish farm to its associated watershed the effect of the locational (landscape) factors was not seen to have as large of an effect on the longevity of a fish farm. A possible reason for this is from the fact that a single watershed can contain multiple fish farms of differing longevity classes. This did not allow the watersheds to be evaluated the same way as the individual fish farm locations. Even though the watersheds were not able to be fully evaluated, the entire watershed that a fish farm will be located in should be looked at to determine if there could be any unusual influence to the fish farm location that may not be normal for the location.

These results from the evaluative model should be able to aid future aquaculture entrepreneurs in helping with initial site selection. Possible site locations need to consider what the water quality conditions are at the site and take into account the land cover. Knowing what landscape indicators have a significant influence on longevity should aid in reducing the inability to target ideal fish farm location in Wisconsin. There needs to be adequate consideration of the water quality and water source for the possible site location along with the soil quality and characteristics being able to be support the production system. Even with all the landscape indicators being considered there still need to be the human factor on whether the farm will be managed appropriately and raising the correct species of fish for the area.

CONCLUSION

The evaluative model was able to determine the water quality characteristics of pH, alkalinity, and hardness had the greatest influence on the longevity of fish farm operations. Therefore, understanding the water quality where the fish farm is located is paramount when selecting a suitable location to build a fish farm in Wisconsin. The soil characteristics evaluated (soil pH and Ksat) did not appear to have an effect on the longevity of the fish farm operations along with the slope of the landscape not having an effect since most fish farms were within acceptable parameters. The evaluative model sought to serve as a guide for helping future fish farm locations with considering possible locations. Aquaculture entrepreneurs should take into consideration the landscape factors that tend to have a positive influence (water alkalinity, water hardness, and water pH) in the longevity of fish farms. The evaluative results should not be the only guide for choosing a possible future fish farm location, more detailed evaluation at the specific site should be performed to gain more accurate information about the actual site location.

Future Work

The results from the evaluation of fish farms showed which landscape indicators may have the largest impact on the longevity of a fish farm. The next chapter examines a predictive model that was created to show locations throughout the state where there is optimal suitability for fish farm operations. The predictive model generated a state map that pinpoints locations where new aquaculture ventures should consider being placed.

Further Evaluation Upon Review

One interesting note during the creation of the evaluative model was the lack of detailed data throughout the state. These GIS data included more detailed water quality, and fish farm information. If more information on these data layers could be acquired there could be further evaluation of the fish farms and could lead to a better understanding of which landscape indicators have a large effect on the longevity of a farm. Details on other information about socio-economic factors such as distance to markets and overall cost of production would further aid in the evaluation of the fish farms and would in turn aid in a better predictive model for future fish farm locations.

The collection of the county GIS data layers also took more time than originally thought and each county had a different amount of GIS data available. Some of the more rural and low populated counties had a very limited amount of GIS data, while higher populated counties had the most data. Acquisition of parcel data for most of the counties was extremely useful in verifying the location of the fish farms but some counties accessibility was limited or financially prohibitive.

There was also a lack in the amount of useable water quality data, only alkalinity, hardness, and pH were evaluated because those were the only data sets that covered the entire state. Nitrate in water quality was found to be available after the evaluation, but was not included in the evaluation. Yet evaluations for dissolved oxygen, nitrogen, and dissolved solids could have revealed much more on influences to fish farm success. Each of these is likely to play a role in the longevity of fish farms but no statewide data set was able to be gathered for them. Nitrogen only covered a small portion in the middle of the state; while dissolved oxygen covered roughly half of the state.

Thus further data on fish farms would have increased the overall evaluation of the fish farm locations and provided greater insight into the importance of water quality. Complete data on the production systems used to grow fish and the correct species of fish raise at each fish farm would also have helped with being able to pair down the evaluations and determine in more detail what could affect the longevity of the fish farms.

LITERATURE CITED

ArcGIS for desktop. How IDW works. http://desktop.arcgis.com/en/arcmap/10.3/tools/3d-analyst-toolbox/how-idw-works.htm

Boyd, C.E. 1979. Water Quality in Warmwater Fish Ponds. Alabama Agricultural Experiment Station, Auburn.

Boyd, C. E. 1982. Water Quality Management for Pond Fish Culture. Elsevier, Amsterdam.

Burnham, K. P. and D. R. Anderson. 2004. Multimodel Inference: Understanding AIC and BIC in Model Selection. Sociological Methods and Research. 33(2): 261-334.

Childs, C. 2004. Interpolating Surfaces in ArcGIS Spatial Analyst. ArcUser: July-September 32-35.

Cote, P. Ongoing. The GIS Manual. Harvard University, Graduate School of Design. http://www.gsd.harvard.edu/gis/manual/.

Endreny. T. A. 2002. Forest Buffer Strips: Mapping the Water Quality Benefits. Journal of Forestry 100(1) 35-40.

GeoCommunity. 2001. USGS Digital Elevation Models (DEMS). http://data.geocomm.com/dem/.

Gotelli, N. J. and A. M. Ellison 2004. A Primer of Ecological Statistics. Sinauer Associates, Inc. Sunderlanf, Mass., USA, 510 pp.

Hossain, M. S., S. R. Chowhury, N. G. Das, and M. M. Rahaman. 2007. Multi-criteria Evaluation Approach to GIS-based Land-suitability Classification for Tilapia Farming in Bangladesh. Aquaculture International 15:425-443.

Hossain, M. S., S. R. Chowhury, N. G. Das, S. M. Sharifuzzaman, and A Sultana. 2009. Integration of GIS and Multi-criteria Decision Analysis for Urban Aquaculture Development in Bangladesh. Landscape and Urban Planning 90:119-133.

Kapetsky, J. M., J. M. Hill, and L. D. Worthy. 1988. A Geographical Information System for Catfish Farming Development. Aquaculture 68:311-320.

Kapetsky, J., J. Hill, L. Worthy, and D. Evans. 1990. Assessing Potential for Aquaculture Development with a Geographical Information System. Journal of the World Aquaculture Society 21:241-249.

Koeller, C, C. Hartleb, K. Rice, M, Johnson, and A. Brandt. *In Progress.* A Predictive Suitability Model for Pond and Raceway Aquaculture Systems in Wisconsin. University of Wisconsin-Stevens Point.

Li, J. and Heap, A.D., 2008. A Review of Spatial Interpolation Methods for Environmental Scientists. Geoscience Australia, Record 2008:23, 137 pp.

Lowrance, R., L. S. Altier, J. D, Newbold, R. R. Schnabel, P. M. Groffman, J. M. Denver, D. L. Correll, J. W. Gilliam, J. L. Robinson, R. B. Brinsfield, K. W. Staver, W. Lucas, and A. H. Todd. 1997. Water Quality Functions of Riparian Forest Buffers in Chesapeake Bay Watersheds. Environmental Management 21(5): 687-712.

Malison, J. A. and C. F. Hartleb, Editors. 2005. Best Management Practices for Aquaculture in Wisconsin and the Great Lakes Region. Sea Grant Institute.

Mallya, Y. J. 2007. The Effects of Dissolved Oxygen on Fish Growth in Aquaculture. Holar University College. Unpublished.

McIntosh, D., T.K. Baldwin, and K Fitzsimmons. 2003. Aquaculture development potential in Arizona: A GIS-based approach. World Aquaculture Magazine 34:32-35.

Meaden, G.J. and Aguilar-Manjarrez, J., eds**.** 2013. Advances in Geographic Information Systems and Remote Sensing for Fisheries and Aquaculture. CD–ROM version. FAO Fisheries and Aquaculture Technical Paper No. 552. Rome, FAO. 425 pp.

Nath, S.S., J.P. Bolte, L.G. Ross, and J. Aguilar-Manjarrez. 2000. Application of Geographical Information Systems for Spatial Decision Support in Aquaculture. Aquacultural Engineering 23:233-278.

Piper, R. G., I. B. McElwain, L. E. Orme, J. P. McCraren, L. G. Folwer, and J. R. Leonard. 1986. Fish Hatchery Management, 1st edition. American FisheriesSociety, Bethesda, Maryland.

Ross, L.G. 1998. The Use of Geographical Information Systems in Aquaculture: A Review, Institute of Aquaculture, University of Stirling, Scotland, pp. 1 – 19.

Salam M.A, N.A. Khatun, and M.M. Alli. 2005. Carp Farming Potential in Barhatta Upazilla, Bangladesh: a GIS Methodological Perspective. Aquaculture 245:75-87.

Stewart N. T., G. D. Boardman, and L. A. Helfrich. 2006. Treatment of Rainbow Trout (*Oncorhynchus mykiss*) Raceway Effluent Using Baffled Sedimentation and Artificial Substrates. Aquaculture Engineering 35:166-178

Stickney, R. 2009. Aquaculture: An Introductory Text, 2ndedition. Cambridge University Press, Cambridge.

Swann, L. 1992. A Basic Overview of Aquaculture. Illinois-Indiana Sea Grant. Technical Bulletin #102.

Swann, L. 1993. Water Quality Water Sources Used in Aquaculture. Illinois-Indiana Sea Grant. Fact Sheet AS-486.

Timmons, M.B. and J.M. Ebeling. 2007. Recirculating Aquaculture. USDA NRAC Publication No. 01-007.

True, B., W. Johnson, and S. Chen. 2004. Reducing Phosphorus Discharge from Flow-Through Aquaculture III: Assessing High-Rate Filtration Media for Effluent Solids and Phosphorus Removal. Aquacultural Engineering 32: 161–170.

USDA, 2006. Census of Agriculture (2005), U.S. Department of Agriculture. http://www.agcensus.usda.gov/Publications/2002/Aquaculture/AQUACEN.pdf.

Viadero Jr. R.C., J. H. Cunningham, K. J. Semmens, and A.E. Tierney. 2005. Effluent and Production Impacts of Flow-Through Aquaculture Operations in West Virginia. Aquaculture Engineering 33: 258-270.

Wedemeyer, G. A. editor. 2001. Fish Hatchery Management, 2nd edition. American Fisheries Society, Bethesda, Maryland.

Wisconsin Aquaculture Industry: Value and Economic Impact. University of Wisconsin-Extension and University of Wisconsin-Stevens Point Northern Aquaculture Demonstration Facility (WAA). 2009. www.wisconsinaquaculture.com/Docs/2009_WI_Aqua_Industry_brochure_2.pdf.

Wisconsin Department of Agriculture, Trade and Consumer Protection, Division of Animal Health (DATCP). 2011. Fish farming in Wisconsin: What you need to know. http://datcp.wi.gov/uploads/Animals/pdf/2012FishFarmApplicationPacket.pdf.

Wurts, W.A. 2002. Alkalinity and Hardness in Production Ponds. World Aquaculture 33(1):16-17.

Wurts, W. A. and R. M. Durborow. 1992. Interactions of pH, Carbon Dioxide, Alkalinity, and Hardness in Fish Ponds. Southern Regional Aquaculture Center. 464.

Appendix A: Letter sent to Wisconsin counties requesting GIS data

May 11, 2011

Mr. Steven Pointer
GIS Specialist
Wood County Planning and Zoning Department
400 Market St.
Wisconsin Rapids, WI 54494

Dear Mr. Pointer:

The University of Wisconsin-Stevens Point has recently acquired grant funding to research the characteristics of sustainable aquaculture operations in Wisconsin. The research involves extensive use of Geographic Information Systems (GIS) and GIS data resources. I hope to develop a working relationship with your county and department to obtain and share GIS data resources.

The project will utilize GIS spatial analysis techniques to ascertain the physical, economic, and geographic characteristics that lead to the success or failure of fish farming facilities in Wisconsin. Evaluative and predictive models are anticipated to help determine appropriate areas for future development of aquaculture facilities. These models will be shared publicly to help the industry grow and prosper.

I am obtaining data and compiling a list of available data resources from federal, state, and local sources. Public data from your county will be important to conduct this study. GIS data for land use, land cover, cadastral parcels, zoning, hydrography, and elevation are expected to be among the most useful data resources available from Wisconsin counties. I respectfully request a list of any GIS data holdings that your county administers. Would you be able to email me this information?

Please let me know the policy and procedures that I should follow to obtain your county's public data sets in a GIS (ArcGIS) format. If you would like, I will be glad to share with you project information, methods, data, and results. Please don't hesitate to contact me or my faculty advisors with any questions, comments, or to further discuss the project details. I look forward to hearing from you.

Sincerely,

Allen Brandt
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College of Natural Resources
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cc. County Board Chair- John Doe

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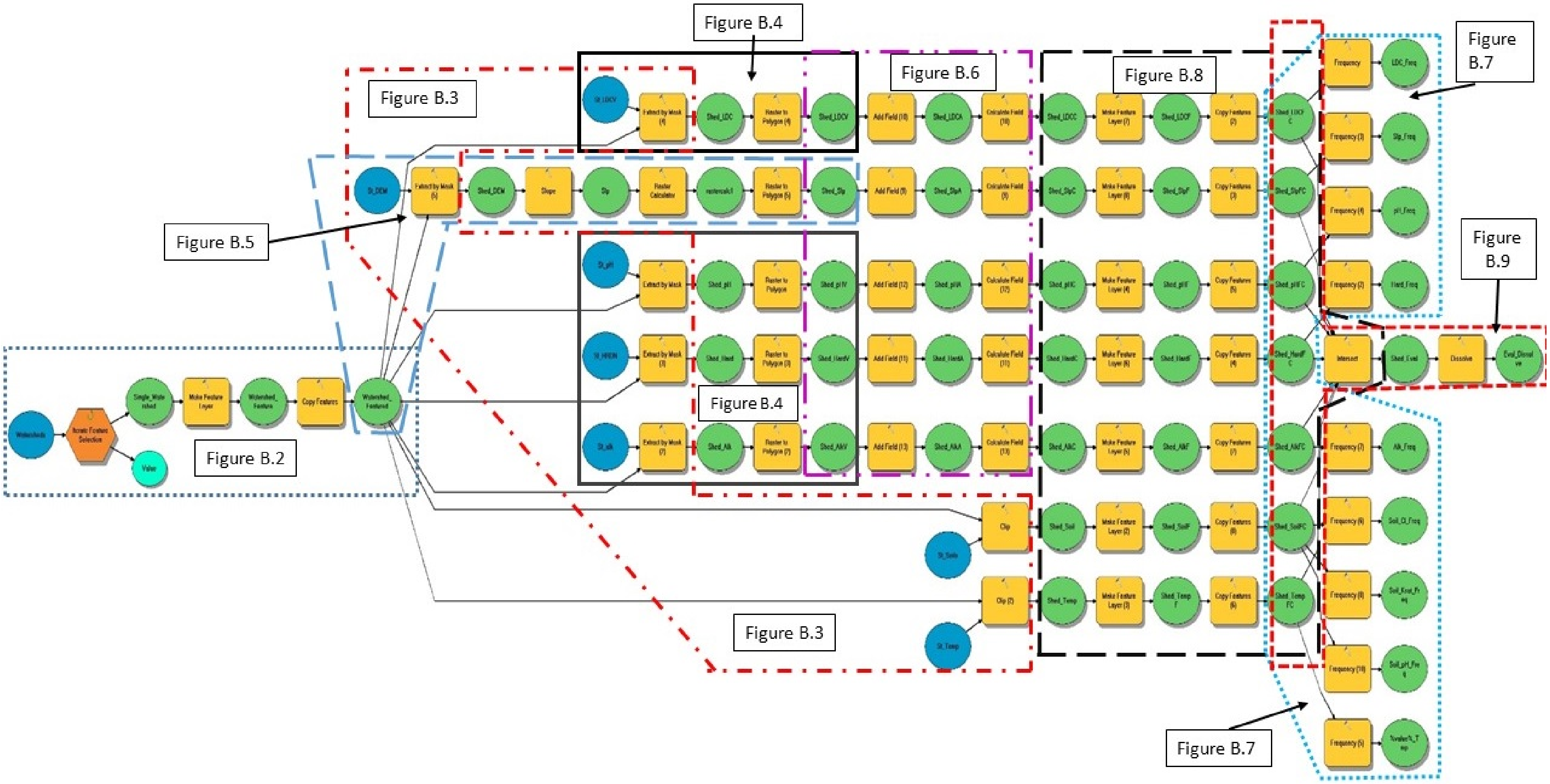
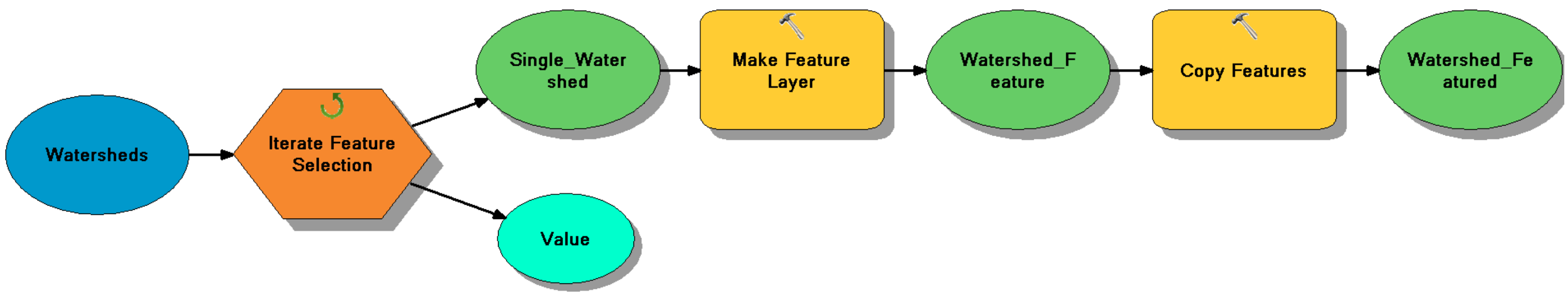
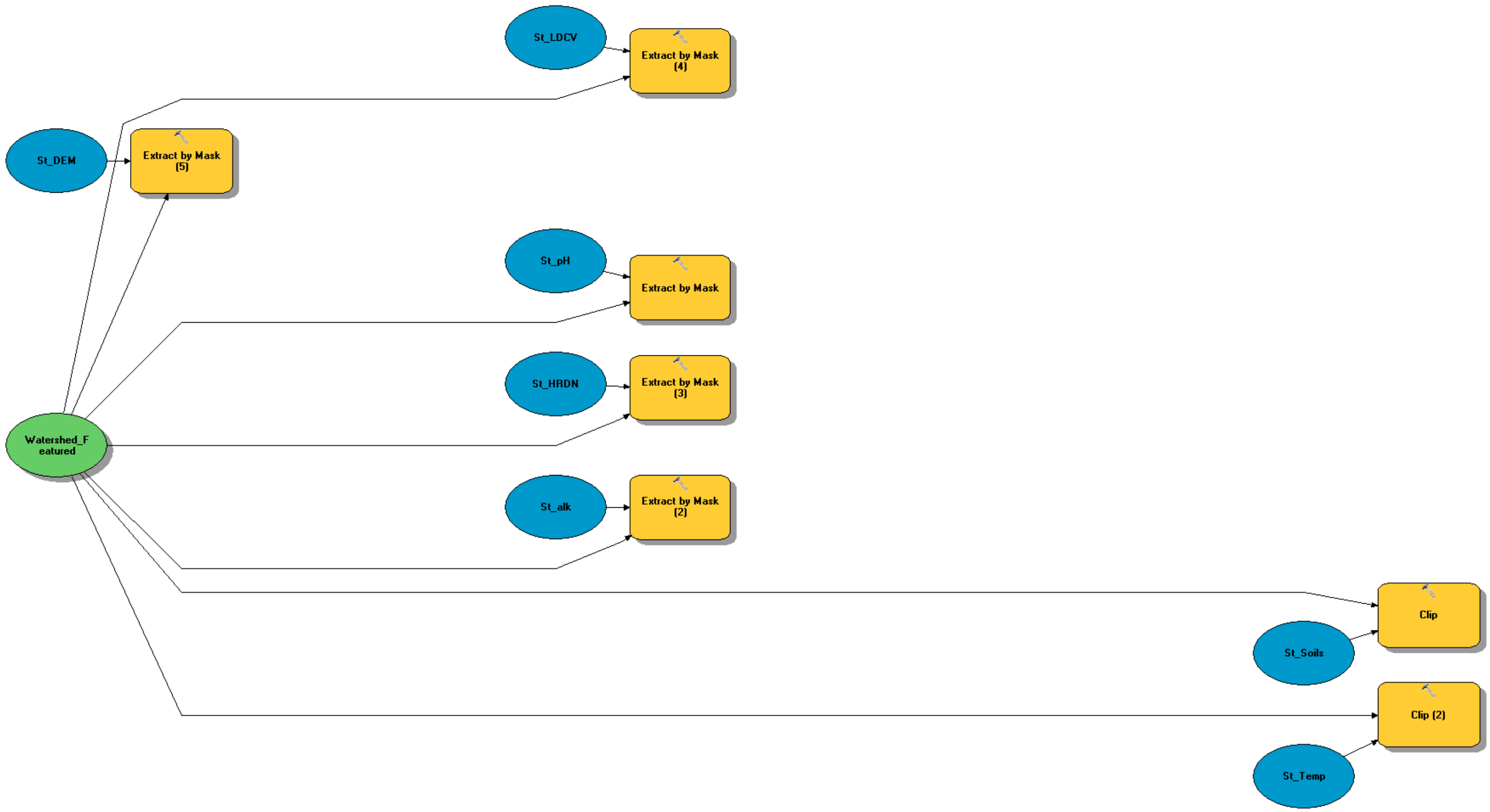
APPENDIX B: Evaluative Model Flow Charts



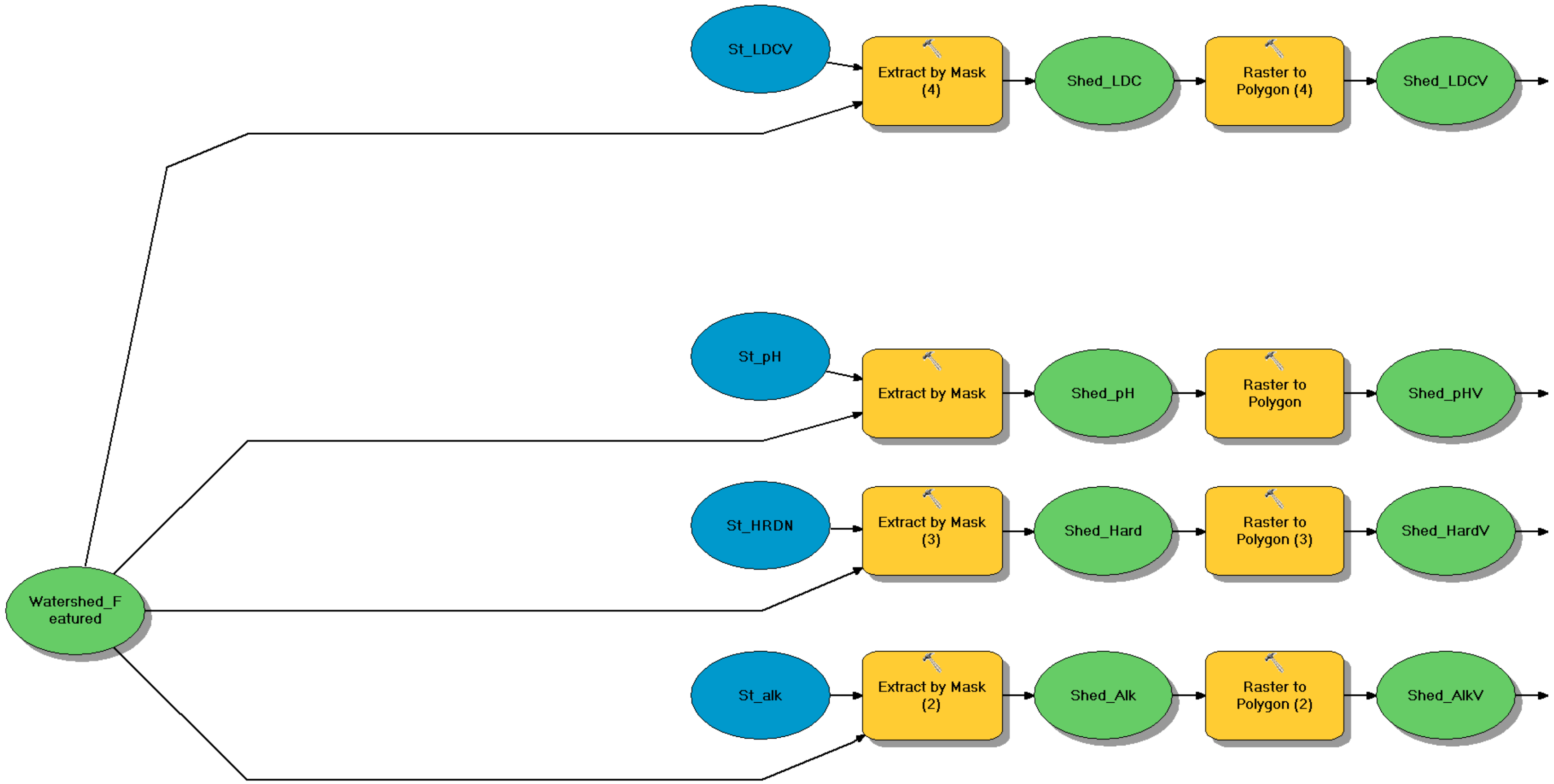
Appendix B Figure 1: The evaluative model used to determine the important landscape characteristics of fish farms in Wisconsin. This represents the entire model as a whole for view of what the completed model looks like. The following figures (Appendix B Figures 2-9) show close-up sections of the evaluative model.



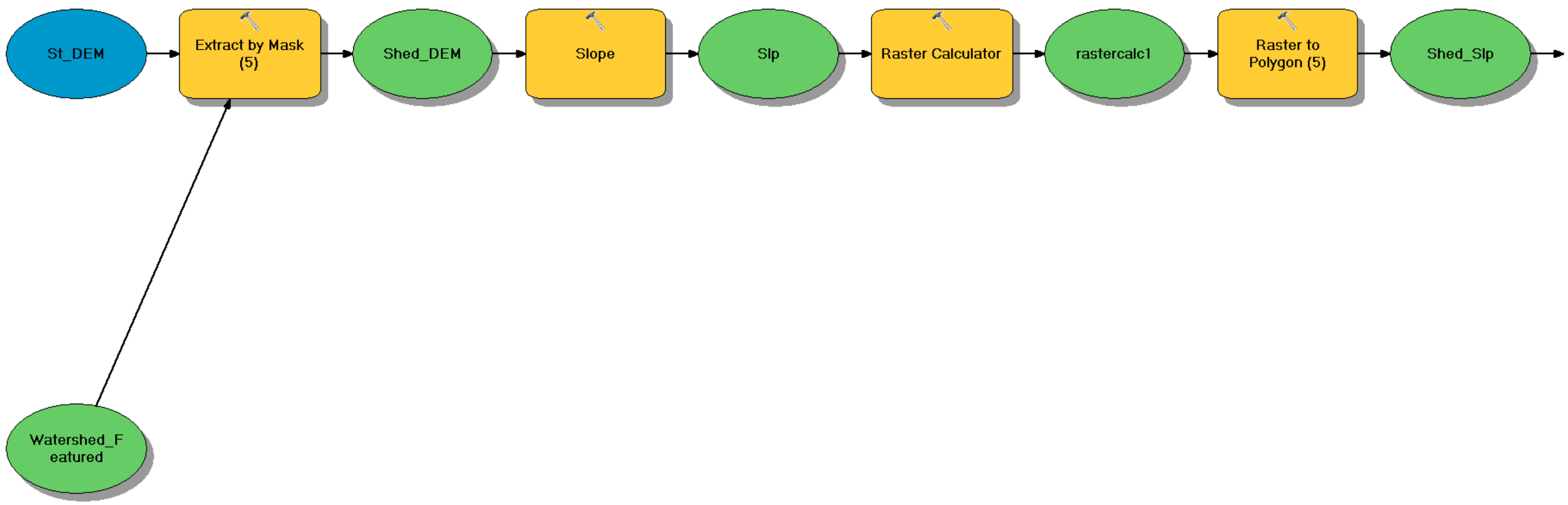
Appendix B Figure 2: The beginning portion of the evaluative model. The Iterate Feature Selection was used to work with only one feature from a dataset at a time. Here the features are for watersheds that contained fish farms. This enabled evaluation for each fish farm and watershed as a single unit. The Make Feature Layer and Copy Features Tools were used to create a permanent feature for the individual farm or watershed. This newly created feature was then used to complete the rest of the evaluation.



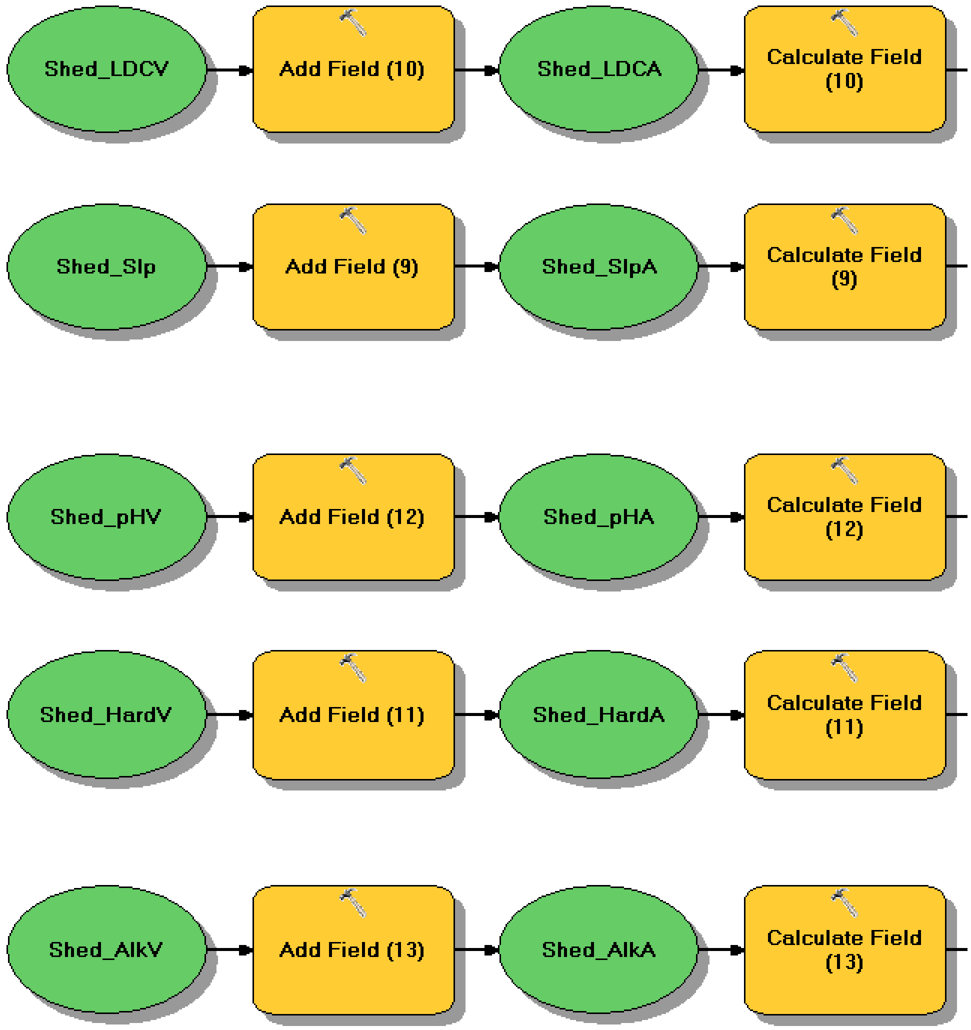
Appendix B Figure 3: The individual feature that was created during the Iteration was used as a cookie cutter to select a portion of the indicator data layers. Each indicator layer was cut to only include the information that was inside the individual feature. This was done using the Extract by Mask and Clip tools. This was done to limit the amount of time need to perform the overall evaluation and to make it easier for evaluating only the areas than contained a fish farms.



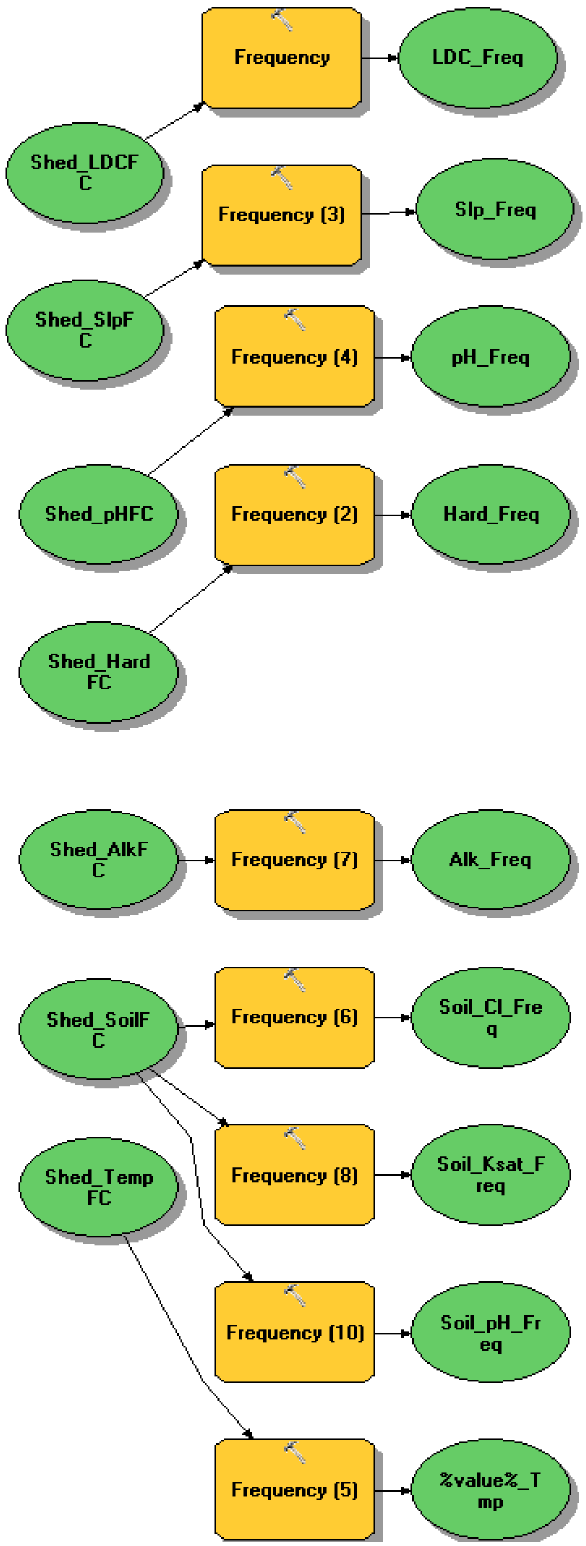
Appendix B Figure 4: This section illustrates what was done to extract the different water quality and land cover indicators to the individual farm or watershed. The Raster to Polygon tool converted the slope data layer that was represented as a raster form into a vector format. The vector format was used as it was the format for the fish farms and watersheds.



Appendix B Figure 5: This portion of the model represents what was done with the individual feature and the state DEM. The DEM was used to calculate the percent slope for the land. The Extract by Mask was performed on the DEM because when this tool was tried on the actual statewide slope the operation failed and was not completed. Thus this is why the slope was calculated at a smaller size to avoid having the model fail. The Raster Calculator tool calculated the percent slope into an integer that could be easily interpreted. The Raster to Polygon tool converted the slope data layer that was represented as a raster form into a vector format. The vector format was used as it was the format for the fish farms and watersheds.

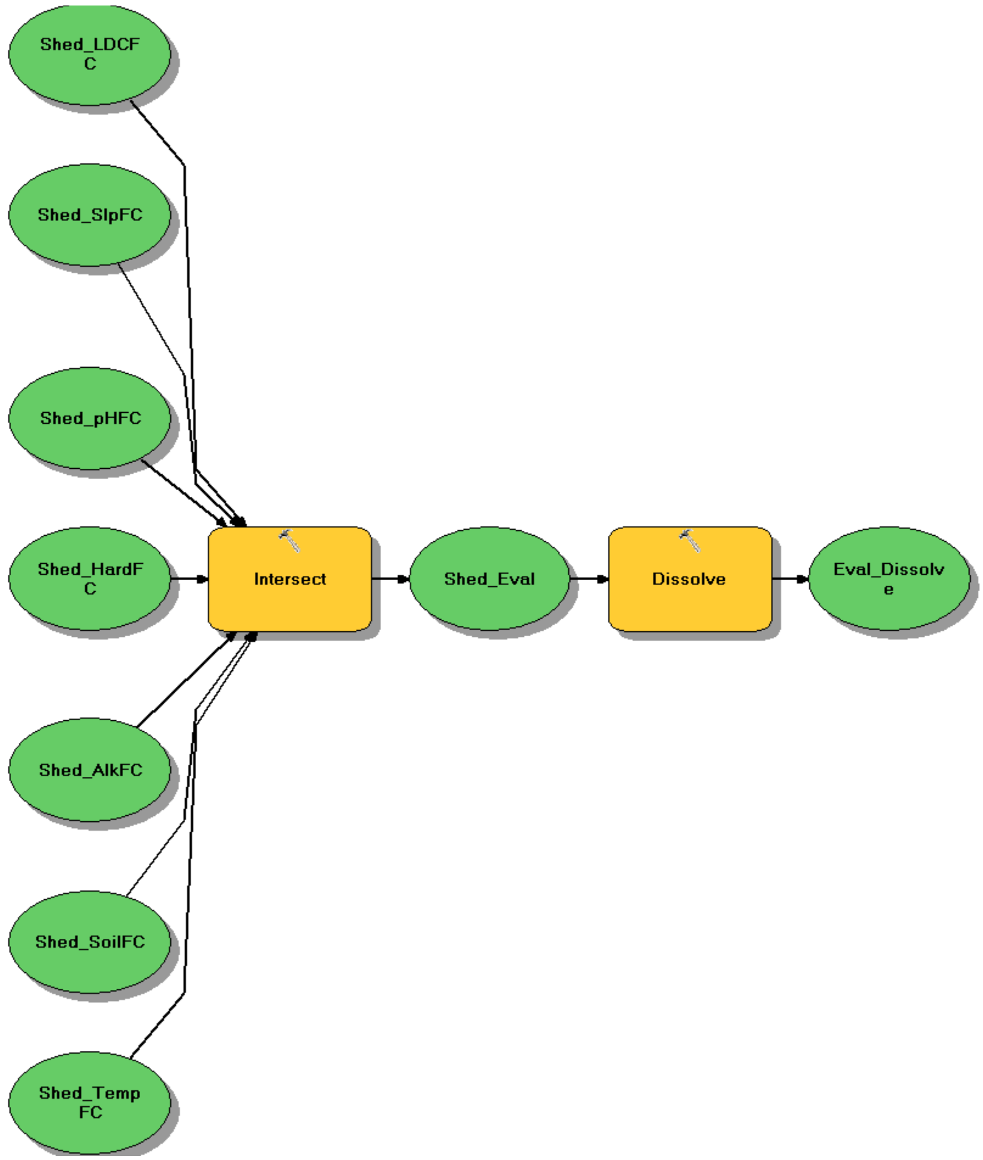


Appendix B Figure 6: The portion of the model where each indicator was made into an individual feature for the given farm or watershed. The Add Field tool was used to create a new field in the data layer that would correspond to the indicator being used. Using the Extract by Mask tool indicator values were placed in a generic named column that could easily be confused with other columns thus the Add Field helped ease the interpretation of the data. The Calculate Field tool filled the newly created field with the known field that corresponded to the correct data.



Appendix B Figure 7: The portion of the evaluative model which performed running the Frequency Tool to determine the most common value for each different indicator. This was done at an individual layer before the features were joined together into on overall layer. Each frequency created a frequency table for the individual indicator layer that was then used to evaluate the fish farms.

Appendix B Figure 8: The portion of the model that creates individual layers for each of the landscaped indicators. The Make Feature Layer tool was used to begin the process of making a permanent feature layer and the Copy Features tool completed the process of making the data permanent. Once each layer was created individually they were joined back together to create a single layer via the Intersect tool.



Appendix B Figure 9: This was the final step in completing the overall evaluation of the fish farm sites and watersheds. Each individual indicator feature was intersected with each other to create one feature that contained all the information about each indicator. A Dissolve was performed to remove any unnecessary information.

Appendix C: Steps for Evaluative Model

Before using the evaluative model one must decide what factor is being evaluated. Is it the fish farm buffers or the watersheds containing fish farms? For this explanation I choose to use the watershed area as was also done in Appendix B.

Step 1: Now that the watersheds with fish farms were the chosen area to evaluate, they were the input for when the Iterate Feature Selection was performed. This tool is intended to be used in ModelBuilder and calls Make Feature Layer (tool) to make a new selection and create two outputs: selected feature (what was used for the model, individual watershed) and value (contains the name of the feature used as an inline variable in the output name of the output table variable). The end result of each iteration was a single individual watershed being selected.

Step 2: The selected feature (individual watershed) was ran through the Make Feature Layer Tool. The watershed was the input and the output was a temporary layer that needed to be made permanent. The output contained the watershed area.

Step 3: The temporary feature layer (input) that was just created was made permanent by being ran through the Copy Features Tool. The output from this was a permanent copy of the select watershed. The process of Make Feature Layer and Copy Features could be by passed by using a geodatabase or shape files. This could make a more efficient model.

Step 4.1: The soil data set and water temperate data needed less manipulation in the model as they were already vector data sets that contained the needed information. The data sets were still for the entire state and had to be made the size of the selected watershed. This was completed using the Clip Tool, which used the soil or temperature data sets as the input features with the clip feature being the selected watershed. The output feature class was then only the soil or temperature data for the selected watershed and contained only that information. This was done to both soil data and temperature data. Then next six steps involve the data sets that were in raster format.

Step 4.2: With an individual watershed the Extract by Mask Tool was used to extract the cells of the raster data sets (land cover/land use, DEM, and water pH, alkalinity, and hardness) to correspond to the area of the watershed. The input raster was each raster data set for the entire state. The input feature mask data was the selected (individual) watershed area. And the output raster was the new data set that only contained information within the watershed area. This step was performed for each of the five raster data sets. The extract by mask was performed before converting the raster to polygon to reduce the size of the raster dataset. The raster to polygon was done tried before and the computer would freeze up from the size of the data being used and not having enough memory to run the operation.

Step 4.2.1: Once the DEM was extracted to the selected watershed it was then needed to determine the slope the area. This was done by using the Slope Tool with identifies the slope from each raster cell. The input raster was the created DEM for the selected watershed and the output raster contained the newly calculated slope. The output measurement was Percent_Rise.

Step 4.2.2: The slope feature which was created contained the percent rise for each cell over the entire selected watershed. The Raster Calculator Tool was then used to calculate the percent slope into an integer for easier interpretation.

Step 5: Now the five of the raster data sets for the selected watershed are ready to be ran through the Raster to Polygon Tool. This tool converts raster data sets to polygon features (vector data sets). The input raster was each of the five data sets for the select watershed and the output polygon features were the created polygon features for selected watershed. This step was done for each individual raster data set. The raster to polygon feature gave polygon features that allowed it easier to understand the attributes of the data.

Step 6: After the raster data had been converted to polygon features the Add Field Tool was used to add a new field for each of the polygon features for the selected watershed. This was done to help with the final interpretation of the data. Each polygon feature had a field added that was unique to its own feature and made sense. Each feature of land cover, slope, pH, alkalinity, and hardness had a field added.

Step 7: The newly created fields then needed to be calculated. This was done by using the Calculate Field Tool. The input table was used for each polygon feature and the field to be calculated was the newly added field. The expression used set the new field to equal the previous field already in the feature but not easily interpreted by the way the previous field was name. Steps 6 and 7 were performed to make the interpretation of the data easier by creating and calculated a new field with and easier to understand name.

Step 8: The polygon features for selected watershed were ran through the Make Feature Layer Tool. The polygon features were the inputs and the outputs were a temporary layer that needed to be made permanent. This was done to make sure the polygon features were for sure feature layers and was used to help direct to the location for where the final feature layers were to be stored. This was performed on land cover, slope, pH, alkalinity, hardness, soil, and temperature.

Step 9: The temporary feature layers for each polygon feature which were just created were made permanent with the Copy Features Tool. The output from this were permanent copies of the polygon features for the select watershed. This was performed on land cover, slope, pH, alkalinity, hardness, soil, and temperature.

Step 10: Before the individual polygon features were joined together for the selected watershed, the Frequency Tool was used to determine the frequency of values for each polygon feature. The polygon features were the landscape indicator variable of land cover, slope, pH, alkalinity, hardness, soil, and temperature. The Frequency Tool read each table and set of fields and created a new table containing unique field values and the number (frequency) of occurrences for each field value. The polygons of land cover, slope, pH, alkalinity, hardness, and temperature had one frequency to look a single variable. The soil polygon had three frequencies which looked at the variables of texture, ksat, and pH.

Step 11: Once the individual layers were created and the frequencies were performed the Intersect Tool was use to join the polygons back into a single feature layer. Each of individual polygons were the input and the output was all the information in a single layer for the selected watershed.

Step 12: The last process of the model was to perform a dissolve. This was done using the Dissolve Tool. The input feature was the polygon layer that contained all the variable information for the selected watershed. The dissolve was used to remove any unnecessary information from the data layer. The fields that were left were the ones added earlier in the model and ones that contained the variable values for soil and slope and ones that contained information on the individual watershed.

Appendix D: Predictive Model Summary Review

INTRODUCTION

There has been an aquaculture industry in Wisconsin since 1856 (WAA 2009). This industry raises a wide variety of fish species for uses of bait, stocking, and food. The fish species are raised in ponds or raceway production systems. Over the last several decades the longevity of aquaculture businesses has been sporadic. One possible reason for this problem centers on the inability to target ideal farm locations as well as ascertaining key factors in operating a profitable fish farm. An issue with the expansion of the aquaculture industry is the difficulty to isolate and ascertain geographic factors that promote fish farm success

Using modern technology like Geographic Information Systems (GIS), these ideal locations and factors can be more easily identified and tested (Kapetsky et al. 1990). A GIS can be defined as an "integrated assembly of computer hardware, software, geographic data and personnel designed to efficiently acquire, retrieve, analyze, display, and report all forms of geographically referenced information geared towards a particular set of purposes" (Nath et al. 2000). A GIS can be used to look at multiple aspects of the landscape to locate areas with high suitability for future aquaculture ventures (Meaden and Aguilar-Manajarrez 2013). It is the utility of this tool in conjunction with an integrated geospatial database of fish farms that could provide Wisconsin a needed boost in the aquaculture industry.

A suitability model was created with a GIS to locate suitable locations in Wisconsin for fish farms that utilize either pond or raceway production systems (Koeller et al. *in progress*). This study, undertaken by Koeller et al. (*in progress*), took into consideration many different criteria to aid in predicting suitable locations for fish farms. The criteria was formulated from previous studies that determined suitable fish farm locations were influenced by water quality, site quality, and infrastructure (Hossain et al. 2009; Karthik et al. 2005, McIntosh et al. 2003; Salam et al 2005). But, the majority of the previous studies only looked at individual fish species grown in a single production system.

A study by McIntosh et al. (2003) used the variable of soil clay content and water alkalinity and pH along with the factors of land slope and water temperature and dissolved oxygen. Hossain et al. (2009) took into consideration the water quality factors of pH, temperature, and dissolved oxygen along with soil quality factors of slope, texture, pH, and organic matter content. Soil pH and soil texture were factors considered in a multi-criteria evaluation done by Salam et al. (2005) but did not look at individual water quality parameters.

The objective of the study by Koeller et al. (*in progress*) was to create site suitability models for both pond and flow-through (raceway) aquaculture systems in Wisconsin based on physical landscape differences, such as, water quality, soil characteristics, and physical site criteria. These criteria, as previously examined, were considered and selected from available statewide data by aquaculture industry experts. The results of the subsequent pond and raceway site suitability models will be used in the future by potential fish farm entrepreneurs in choosing an ideal fish farm location in Wisconsin.

In the present study, the water quality criteria used included alkalinity (mg/L $CaCO_3$), ammonia (NH_3), hardness (mg/L as $CaCO_3$), pH ($-\log_{10}[a_{H+}]$), iron (Fe), manganese (Mn), and chloride (Cl). The soil characteristics included factors on both physical and chemical characteristics. Soil characteristics considered included organic matter content, clay content, soil permeability, and soil pH. The physical site criteria looked at the land use/land cover of the location. Areas designated as open water by the Wisconsin Department of Natural Resources hydrography database (hydro 24Kv6) were restricted from suitability scoring as a fish farm can't be constructed on/in open water.

METHODS

The study by Koeller et al.(*in progress*) used the model criteria for water quality of alkalinity, chloride, hardness, iron, manganese, and pH; soil factor of organic matter, clay content, permeability, and pH; and land use areas designated as open waters. These model criteria were chosen because they were available for the entire state and were relevant to the success of aquaculture operations. The criteria for the model was weighted using a multi-criteria decision making approach to organize factor weights using an analytical hierarchical process (AHP) (Saaty 1990). This is similar to the methods of several other studies that determined the weights of suitability model criteria (Hossain et al 2007; Hossain et al 2009).

To determine how to properly weight the criteria for a pairwise comparison matrix for the model criteria of water quality and soil/land use was done asking seven Wisconsin aquaculture industry experts were asked to evaluated water quality, soil and land use factors. They were asked to rank (pairwise comparison matrix) the relative importance of one factor against another based on a scale of 1/9 (extremely less important) to 9 (extremely more important) for each factor. Each reviewer weighted the criterion from each category against all other criterion from the same category. These experts were then asked to weigh the importance of water quality against soil and other physical criteria. Reviewers rated pH, alkalinity, and hardness highest for water quality factors, while clay content, Ksat, and soil pH scored highest for soil criteria. In total, weighted criteria was scored the highest for water quality factors representing 70% of the overall score for the factors that can influence fish farm success. Hossain et al. (2009) had water quality factors being the second highest weight behind infrastructure and socio-economic factors. These factors, infrastructure and socio-economic, were not examined in the study by Koeller et al (*in progress*).

After the factors were weighted, the multi-criteria decision model was executed and classified as unsuitable, low suitability, acceptable, and optimal locations in the state. This was done for each water quality factor (pH, alkalinity, hardness, iron, manganese, and chloride) as well as the soil and land use characteristics (soil pH, clay content, ksat, organic carbon, and land cover). Once the individual factors were completed for the state they were combined to create four preliminary suitability models for the state of Wisconsin. These were pond water quality, raceway water quality, pond soil and land use &, and raceway soil and land use.

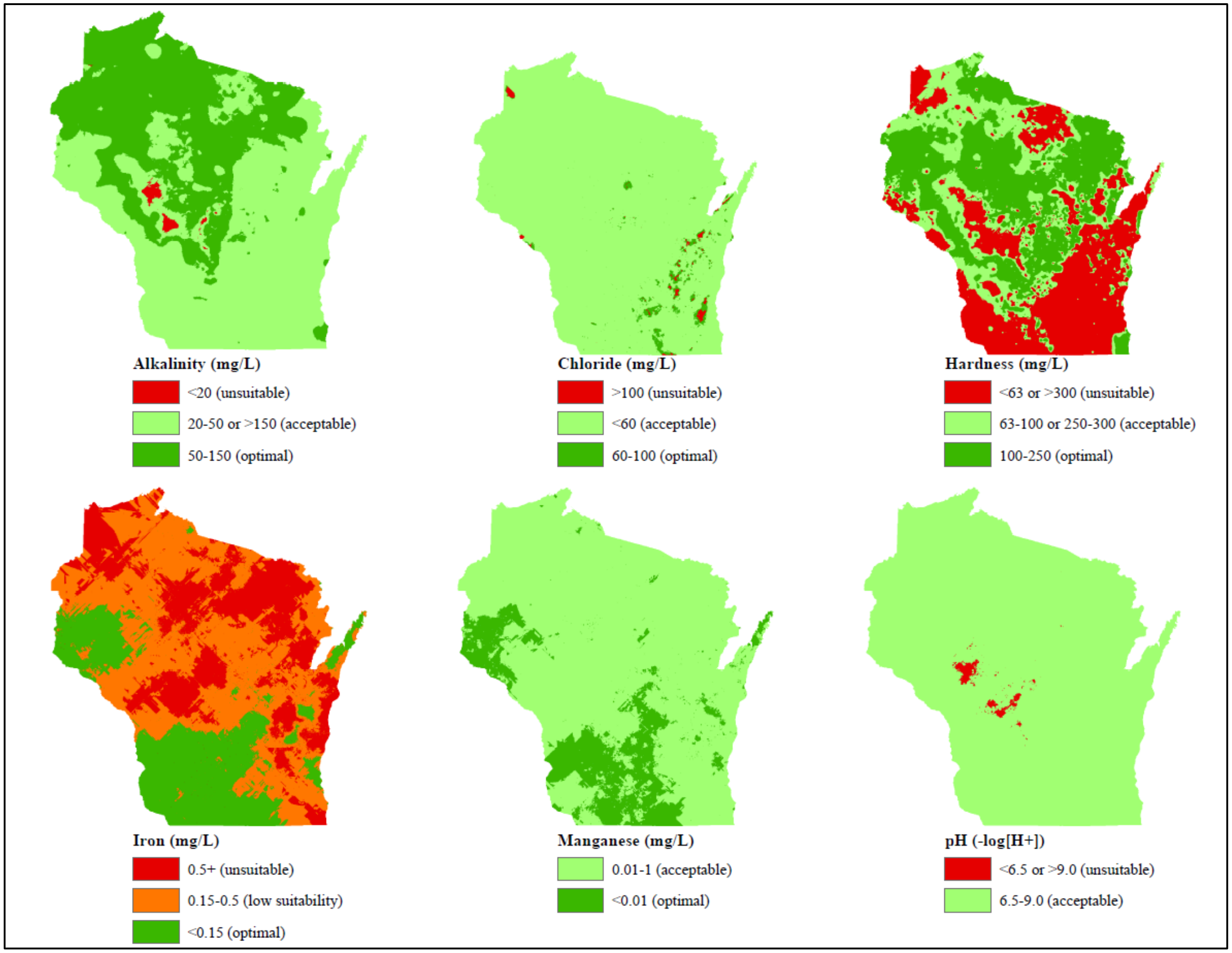
An overall suitability was then determined by combining the water quality, soil and land use suitability layers for both pond and raceway production systems that produced classified levels ranging from optimal suitability to unsuitable. If any geographic area on any of the layers were classified as unsuitable then this negated its suitability on the combined final model. Any geographic gaps in the final model were filled in by statistically averaging nearby cells to determine likely values. This technique was performed using ArcGIS Geostatistical Analyst and associated tools involving cross-validation and interpolation.

RESULTS

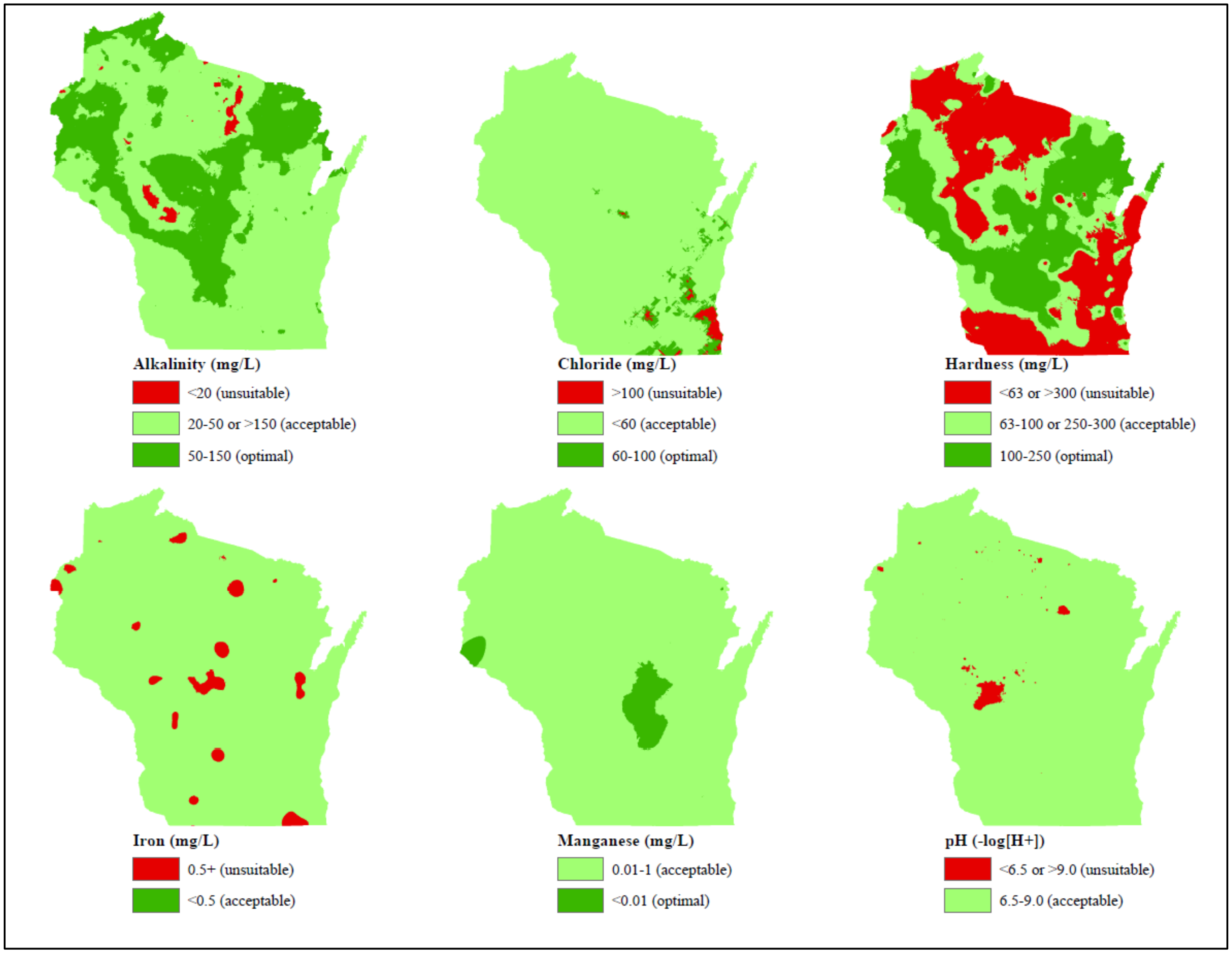
Water hardness and iron concentrations were the most limiting factors in determining the site suitability for both pond and raceway production systems. The majority of the areas with unsuitable water hardness for raceway production systems were in the southern and eastern portions of the state along with a portion in the west central region of the state and small areas of unsuitable hardness in the northern region of the state (Appendix D Figure 1). The water hardness for pond systems was unsuitable in the north central and eastern portions of the state along with the areas along the southern border of the state (Appendix D Figure 2).

Water iron concentrations for raceways had optimal suitability in the southwestern region of the state while the majority of the unsuitable locations were in the north and east regions of the state, along with an area in the west central region. Unsuitable iron concentration for pond systems was well dispersed, yet the majority was located in the central portion of the state. Water alkalinity and pH for raceway systems were found to have acceptable or optimal suitability throughout most of the state with only small areas being unsuitable in the west central portion of the state. Pond systems also had similar areas with acceptable or optimal suitability throughout most of the state with an area in the West Central portion being unsuitable and a small area in the northeast region.

Chloride concentrations were mainly unsuitable in the southeastern regions of the state near areas with large population centers. Manganese did not have an unsuitable location in the state and was found at optimal levels in the west and southwest regions of the state for raceways, while pond systems were optimal in the east central and a small area along the western border of the state.



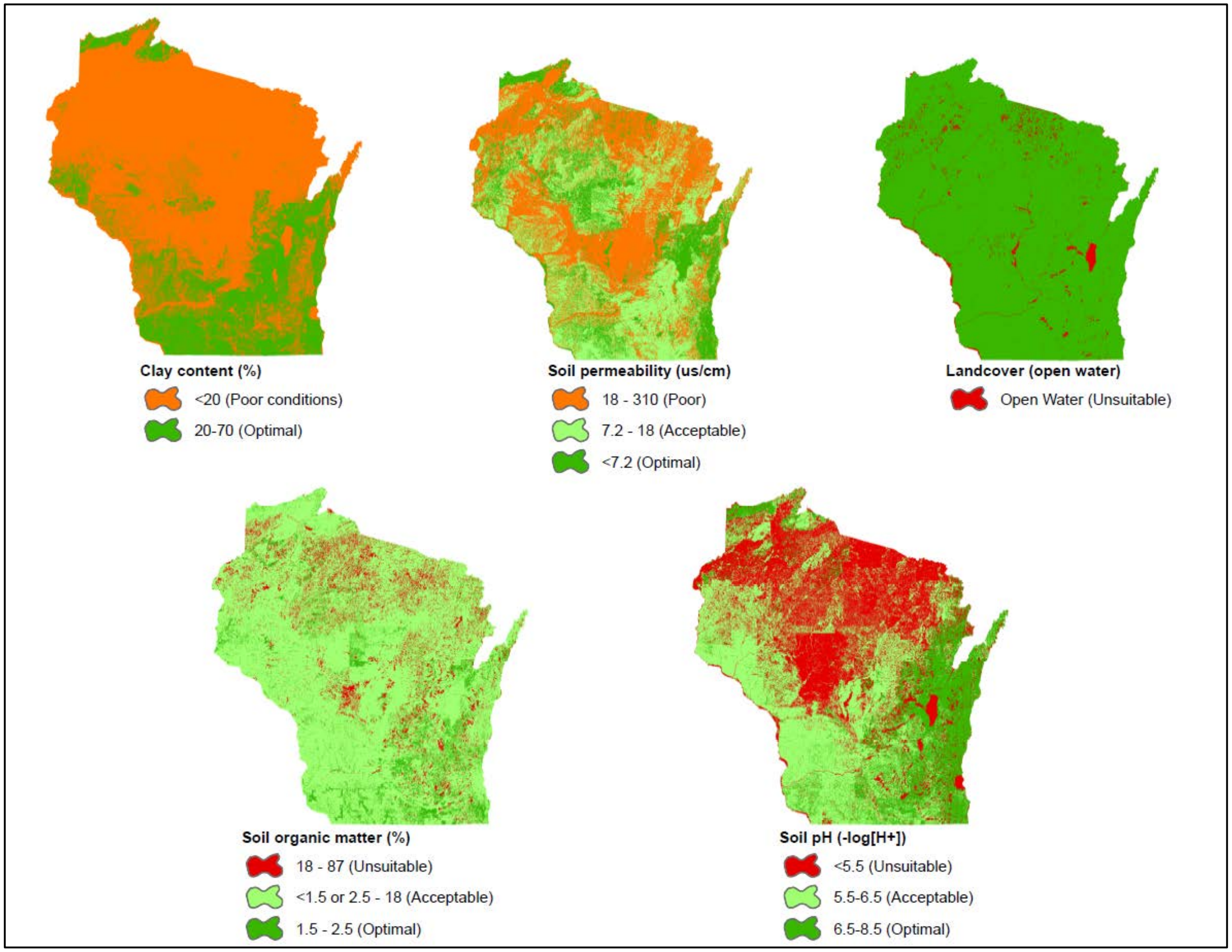
Appendix D Figure 1: Interpolated ground water quality parameters for raceway aquaculture site suitability modeling. Parameters include alkalinity (mg/L), chloride (mg/L), water hardness (mg/L), iron (mg/L), manganese (mg/L), and water pH (-log[H+]). (Taken from Koeller et al. *in progress*)



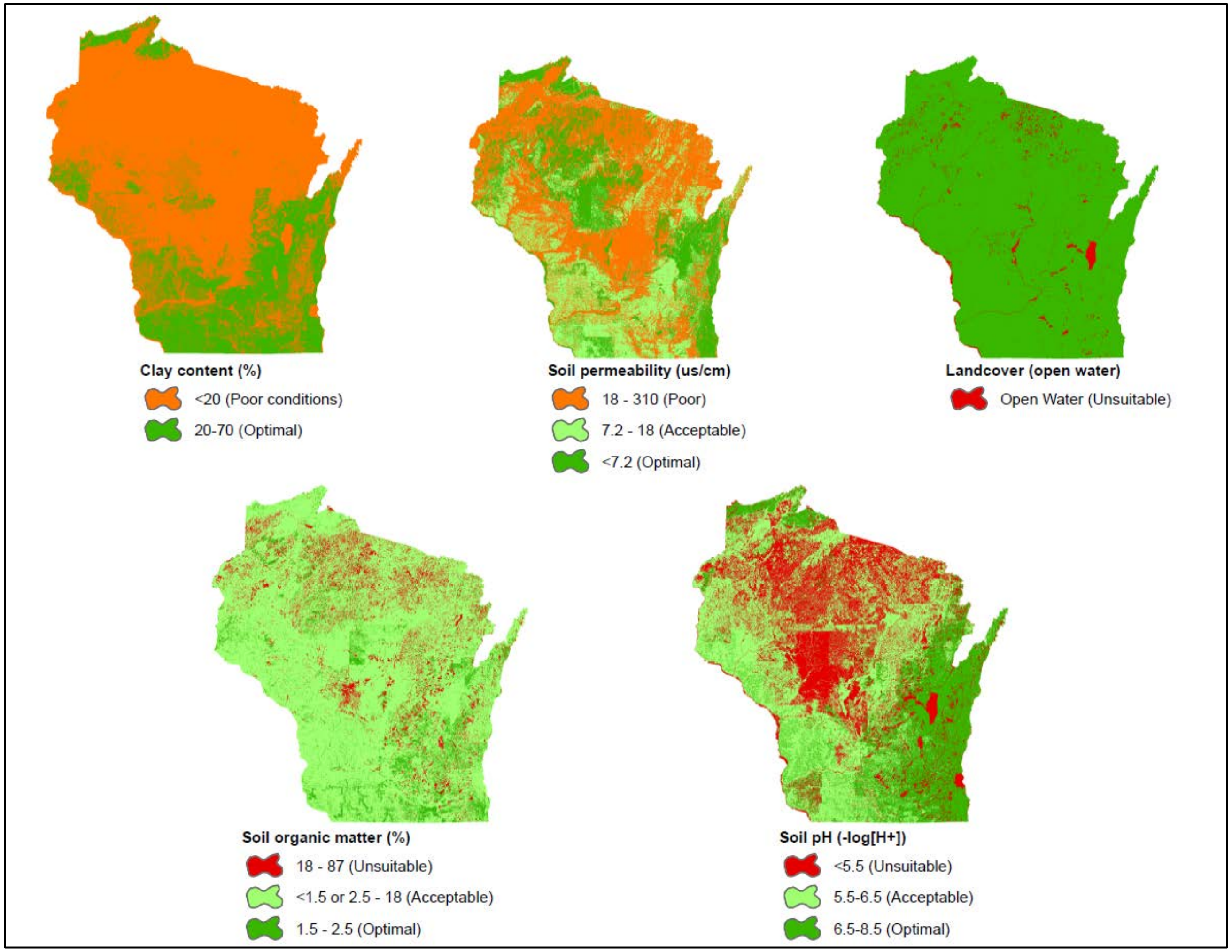
Appendix D Figure 2: Interpolated surface water quality parameters for pond aquaculture site suitability modeling. Parameters include alkalinity (mg/L), chloride (mg/L), water hardness (mg/L), iron (mg/L), manganese (mg/L), and water pH (-log[H+]). (Taken from Koeller et al. *in progress*)

The suitability layers for soil characteristics and land use appeared to be more similar for raceway and pond production systems. The most limiting factors in Wisconsin were soil pH and organic matter for both raceway and pond production systems. Soil pH tended to be unsuitable in the northern half of the state for raceway systems and for pond systems was more centralized in the central portion of the state along with the northern regions (Appendix D Figures 3 and 4). Soil organic matter was well dispersed within the areas of unsuitable levels for both production systems. The western portion of the state tended to have more acceptable locations for both raceway and pond systems. The soil clay content tended to be optimal in the southern and eastern portions of the state, along with small areas along the south shore of Lake Superior for both raceway and pond production systems. Poor conditions for clay content were found throughout the northern and central regions of the state for raceways and ponds systems. Soil permeability was found to be poor mostly in the central portion of the state along with areas in the northern half of the state for both production systems. Land use/land cover was only found to be unsuitable in open water.

The suitability locations for water quality, soil and land use characteristics were combined to show the areas within the state which were suitable for fish farm operations utilizing either raceway or pond production systems. The raceway site suitability model had 73.8% of the state found in unsuitable locations (Appendix D Table 1), while the pond site suitability was unsuitable for 58.7% of the state (Appendix D Table 2). The suitability for raceway systems was highly effected by the water quality with 55.4% of the state being unsuitable while soil and land use were 39.5% unsuitable. Pond systems



Appendix D Figure 3: Soil PCC and LULC parameters for raceway aquaculture site suitability modeling. Parameters include clay content (%), soil permeability (us/cm), open water LULC, soil organic matter (%), and soil pH (-log[H+]). (Taken from Koeller et al. *in progress*)



Appendix D Figure 4: Soil PCC and LULC parameters for pond aquaculture site suitability modeling. Parameters include clay content (%), soil permeability (us/cm), open water LULC, soil organic matter (%), and soil pH (-log[H+]). (Taken from Koeller et al. *in progress*)

Appendix D Table 1: Raceway aquaculture suitability model criteria including water quality criteria (alkalinity, chloride, hardness, iron, manganese, pH) and Soil and LULC criteria (clay content, soil permeability, land use/land cover, organic matter, soil pH) and combined suitability surfaces (overall suitability, groundwater quality suitability, soil PCC and LULC suitability) listed as percent cover in the state of Wisconsin. (Taken from Koeller et al. *in progress*)

Suitability Surface	**Unsuitable (%)**	**Low Suitability (%)**	**Moderate Suitability (%)**	**High Suitability (%)**
Overall Suitability	73.8	12.8	10.6	2.8
Groundwater Quality Suitability	55.4	25.1	17.3	2.2
Soil PCC and LULC Suitability	39.5	30.2	15.6	14.7

Water Quality Criteria

Criteria	**Unsuitable (%)**	**Low Suitability (%)**	**Moderate Suitability (%)**	**High Suitability (%)**
Alkalinity	0.7	-	58.6	40.7
Chloride	0.6	-	97.2	2.2
Hardness	36	-	26.2	37.8
Iron	28.1	46.8	-	25.1
Manganese	-	-	82.5	17.5
pH	0.9	-	99.1	-

Soil PCC and LULC Criteria

Criteria	**Unsuitable (%)**	**Low Suitability (%)**	**Moderate Suitability (%)**	**High Suitability (%)**
Clay Content	-	74.3	-	25.7
Soil Permeability	-	44.6	34.4	21.0
Landuse/Landcover	3.5	96.5	-	-
Organic Matter	9.6	-	80.4	10.0
Soil pH	36.8	-	42.4	20.8

Appendix D Table 2: Pond aquaculture suitability model criteria including water quality criteria (alkalinity, chloride, hardness, iron, manganese, pH) and Soil and LULC criteria (clay content, soil permeability, land use/land cover, organic matter, soil pH) and combined suitability surfaces (overall suitability, groundwater quality suitability, soil PCC and LULC suitability) listed as percent cover in the state of Wisconsin. (Taken from Koeller et al. *in progress*)

Suitability Surface	**Unsuitable (%)**	**Low Suitability (%)**	**Moderate Suitability (%)**	**High Suitability (%)**
Overall Suitability	58.7	10.6	15.9	14.8
Groundwater Quality Suitability	41.4	17.9	21.7	19.0
Soil PCC and LULC Suitability	33.0	36.5	17.5	13.0

Water Quality Criteria

Criteria	**Unsuitable (%)**	**Low Suitability (%)**	**Moderate Suitability (%)**	**High Suitability (%)**
Alkalinity	1.3	-	66.1	32.6
Chloride	1.1	-	95.3	3.6
Hardness	38.2	-	29.7	32.1
Iron	3.2	-	96.8	-
Manganese	-	-	95.5	4.5
pH	1.2	-	98.8	0

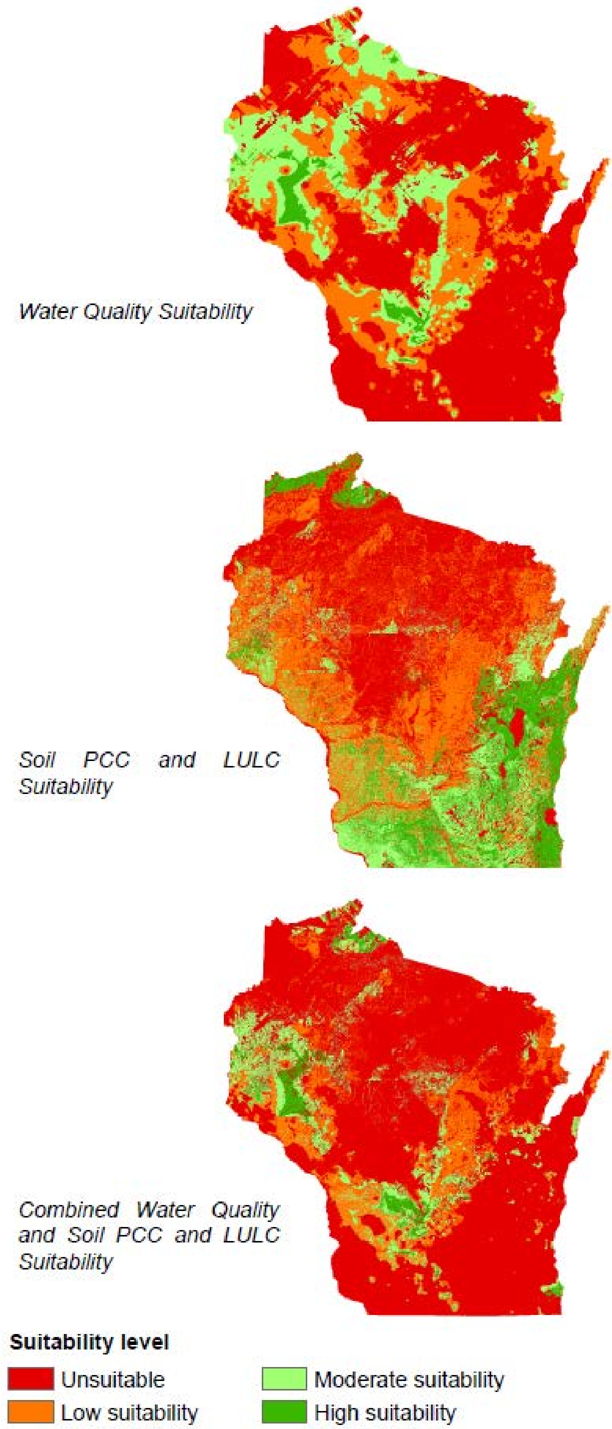
Soil PCC and LULC Criteria

	Unsuitable (%)	**Low Suitability (%)**	**Moderate Suitability (%)**	**High Suitability (%)**
Clay Content	**-**	**76.7**	**-**	**23.3**
Soil Permeability	-	49.6	25.8	24.6
Landuse/Landcover	3.5	96.5	-	-
Organic Matter	9.5	-	83.1	7.4
Soil pH	30.3	-	44.1	25.6

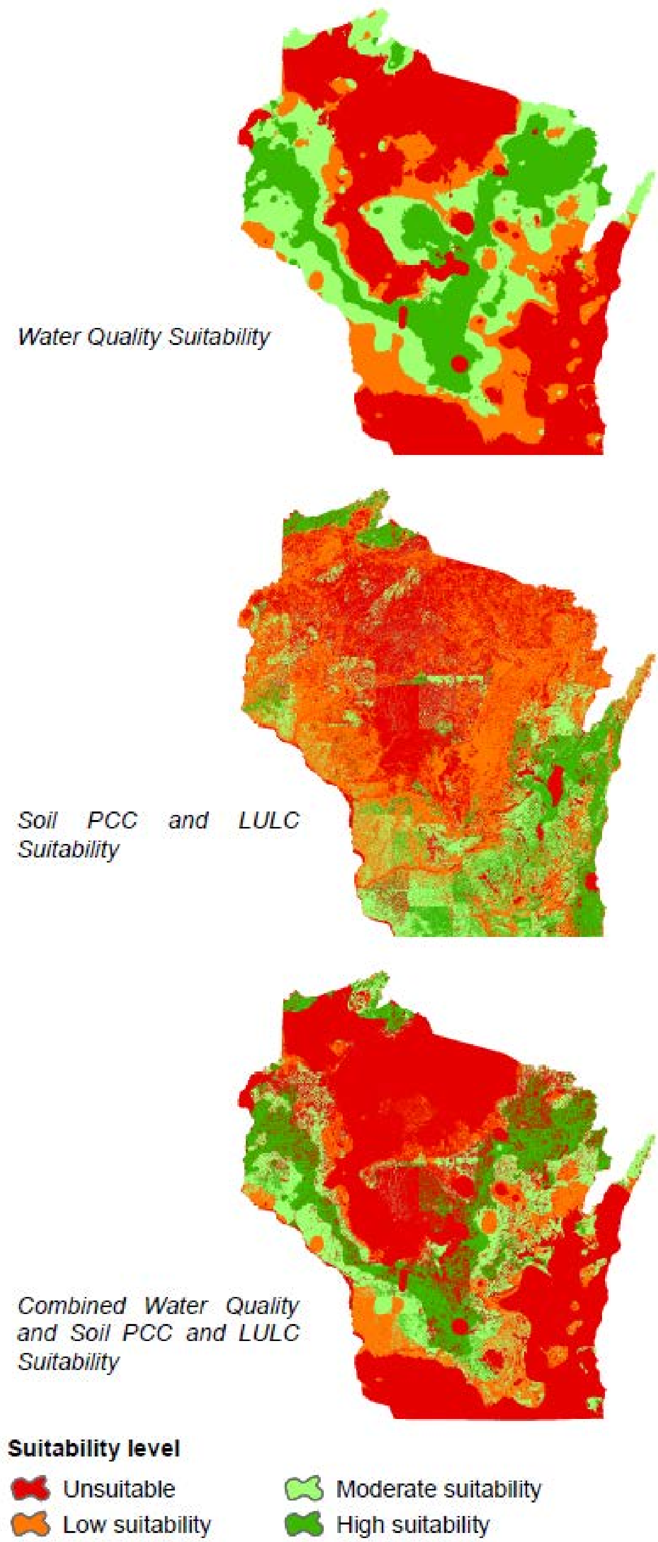
had 41.4% unsuitable location for water quality and 33% unsuitable land based on soil and land use.

The overall suitability for raceway systems combining the soil and land cover quality factors favor the southern and eastern regions of the state. Water quality suitability was found mainly to occur in the western and southwestern portions of the state (Appendix D Figure 5). There were also relatively small areas in the central region of the state, as well as areas near Ashland and Milwaukee. The combined weighted model of water, soil, and land cover characteristics though illustrates the best suitability in the western and southwestern portions of the state.

The combined suitability for pond production systems found a larger portion of the state to be suitable for fish farms (Appendix D Figure 6). The overall combined suitability for ponds appeared to follow the areas where water quality suitability was high. The main areas stretch from western Wisconsin to the south central and then up to the northeastern portion of the state. There were also small regions near the Bayfield Peninsula, upper Door County, Superior, and Green Bay with high and moderately high suitability scores.



Appendix D Figure 5: Weighted sum site suitability results for raceway systems categorized using natural breaks into four categories (unsuitable, low suitability, moderate suitability, and high suitability). Suitability surfaces include overall water quality site suitability, overall soil PCC and LULC site suitability, and combined water quality and soil PCC and LULC site suitability. (Taken from Koeller et al. *in progress*)



Appendix D Figure 6: Weighted sum site suitability results for pond systems categorized using natural breaks into four categories (unsuitable, low suitability, moderate suitability, and high suitability). Suitability surfaces include overall water quality site suitability, overall soil PCC and LULC site suitability, and combined water quality and soil PCC and LULC site suitability. (Taken from Koeller et al. *in progress*)

DISCUSSION

The outcome of the study by Koeller et al. (*in progress*) was to create an online, interactive web-mapping application for use with the planning of future pond and raceway production systems in Wisconsin. This system allows users to determine the most suitable locations for a new aquaculture venture and to see which key factor or factors may limit the longevity of the fish farm. The web site also allows for further exploration of unsuitable locations to determine if the entrepreneur is willing to work with particular limiting factors, ad whether or not these factors could be mitigated and brought to levels within a tolerable range. The various criteria used in the interactive predictive models can also be adjusted by the user to investigate assuaging conditions. This would allow entrepreneurs to balance these factors between optimal location and the cost to alleviate mitigating factors in their final decision.

There are some limitations with using the suitability models generated by Koeller et al. (*in progress*). The primary limitation is the availability of data for creating the models. There are water quality factors such as ammonia, nitrate, and nitrite concentrations that can influence fish production that were not available for the entire state and, thus, were not included in the final models. This necessitates potential fish farmers to further examine chosen sites (i.e. field checking) to determine their compatibility. Furthermore, water quality factors can vary throughout time as conditions in the environment change, and these models do not take into account the change over time.

These models were created to aid users in locating areas in the state where an aquaculture operation would be suitable. However, further investigation of the site should be done to gain more information on the water and soil quality before financial investment begins. The entrepreneur should also take into consideration the infrastructure around the possible fish farm site such as cost to run electricity and distance to markets to selling the fish.

The pond and raceway aquaculture suitability models are available online for users interested in learning more about their location. To access the Raceway and Pond Aquaculture Suitability site, visit: http://www.uwsp.edu/cols-ap/nadf/Pages/GIS-based-analysis.aspx. The web map is configured for use on desktop, tablet or mobile devices with a cellular or Wi-Fi connection. Users can interact with data layers for each water quality and soil quality and land use criteria as well as view models showing overall water quality site suitability, overall soil quality and land use site suitability, and combined water quality and soil quality and land use site suitability.

CONCLUSION

The idea of creating suitability models has been done before by various aquaculture researchers. Salam et al. (2005) created suitability maps for carp farming in Bangladesh. McIntosh et al. (2003) created species specific models for the state of Arizona and found the models to have an overall accuracy of 56% for suitable fish farm location in the state. These models looked at water quality, soil clay content, slope, and land ownership and fish types such as bass, catfish, tilapia, and trout. McIntosh et al. (2003) hoped to include infrastructure (roadways, power, towns, etc.) into the model but did not have a way to predict those variables with the success of fish farm locations. Water quality, soil quality, and infrastructure and socio-economic factors were the primary components for a suitability model created by Hossain et al. (2009). This study looked at the urban development of aquaculture in Bangladesh and found slope and infrastructure to have a negative effect on the suitability of fish farms.

In contrast to these, Koeller et al.'s (*in progress*) predictive model that showed areas and regions within the state of Wisconsin where there is suitable land for future aquaculture site locations. These models were created by weighing the various landscape factors (water quality, soil quality, land cover) based on their overall importance to the success of a fish farm. The predictive models serve as a guide for helping future aquaculture entrepreneurs who wish to build an aquaculture operation within Wisconsin. However, the predictive models should not be the only piece of information used when determining a site location. Physical site visits should be conducted prior to creation of production system to verify the water quality, soil quality, and other important factors for fish farms.

Future Work

The predictive model could be expanded on if other data sets were available, such as, information on infrastructure and distance to possible markets for the fish farm locations. This data is not readily available and was not evaluated with the current fish farms and was not used as a factor in the predictive models.

A sensitivity test of the predictive models should be done to ascertain the accuracy of the predictive models with current operational fish farms. It is likely that accuracy of the model will be lower for raceway production systems since there are very few aquaculture operations of this type. Conversely, there would be enough pond production system farms that would be able to accurately determine the predictability for the pond suitability model.

LITERATURE CITED

Hossain, M. S., S. R. Chowhury, N. G. Das, and M. M. Rahaman. 2007. Multi-criteria Evaluation Approach to GIS-based Land-suitability Classification for Tilapia Farming in Bangladesh. Aquaculture International 15:425-443.

Hossain, M. S., S. R. Chowhury, N. G. Das, S. M. Sharifuzzaman, and A Sultana. 2009. Integration of GIS and Multi-criteria Decision Analysis for Urban Aquaculture Development in Bangladesh. Landscape and Urban Planning 90:119-133.

Kapetsky, J., J. Hill, L. Worthy, and D. Evans. 1990. Assessing Potential for Aquaculture Development with a Geographical Information System. Journal of the World Aquaculture Society 21:241-249.

Karthik, M., J. Suri, N. Saharan and R.S. Biradar. 2005. Brackish Water Aquaculture Site Selection in Palghar Taluk, Thane District of Maharashtra, India Using the Techniques of Remote Sensing and Geographical Information System. Aquacultural Engineering 32: 285-302.

Koeller, C., C. Hartleb, K. Rice, M. Johnson and A. Brandt. *In Progress*. A Predictive Suitability Model for Pond and Raceway Aquaculture Systems in Wisconsin.

McIntosh, D., T.K. Baldwin, and K Fitzsimmons. 2003. Aquaculture Development Potential in Arizona: A GIS-based approach. World Aquaculture Magazine 34:32-35.

Meaden, G.J. and Aguilar-Manjarrez, J., eds. 2013. Advances in Geographic Information Systems and Remote Sensing for Fisheries and Aquaculture. CD–ROM version. FAO Fisheries and Aquaculture Technical Paper No. 552. Rome, FAO. 425 pp.

Nath, S.S., J.P. Bolte, L.G. Ross, and J. Aguilar-Manjarrez. 2000. Application of Geographical Information Systems for Spatial Decision Support in Aquaculture. Aquacultural Engineering 23:233-278.

Saaty, T.L. 1990. How to make a decision: The Analytical Hierarchy Process. European Journal of Operational Research 48:9-26.

Salam M.A., N.A. Khatun, and M.M. Alli. 2005. Carp Farming Potential in Barhatta Upazilla, Bangladesh: a GIS Methodological Perspective. Aquaculture 245:75-87.

Wisconsin Aquaculture Industry: Value and Economic Impact. University of Wisconsin-Extension and University of Wisconsin-Stevens Point Northern Aquaculture Demonstration Facility (WAA). 2009. www.wisconsinaquaculture.com/Docs/2009_WI_Aqua_Industry_brochure_2.pdf.