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Operationalizing Resilience in the Face of Water Conflict: Linking Social and Ecological Systems

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OPERATIONALIZING RESILIENCE IN THE FACE OF WATER CONFLICT:

LINKING SOCIAL AND ECOLOGICAL SYSTEMS

by

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ABSTRACT

OPERATIONALIZING RESILIENCE IN THE FACE OF WATER CONFLICT: LINKING SOCIAL AND ECOLOGICAL SYSTEMS

by

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Under the supervision of Dr. Timothy J. Ehlinger

This dissertation investigates the possibility of linked surface-groundwater governance through the application of a social-ecological systems lens to the Lake Beulah Conflict over a high capacity well in Walworth County, Wisconsin. Potential adverse impacts the loss of Ca^{2+} rich groundwater would have on Lake Beulah's water quality was modeled through an ex-ante assessment method using the U.S. Army Corps of Engineers lake and reservoir model BATHTUB, the U.S. Geological Survey geochemical model PHREEQC and a Ca^{2+} mass balance equation. The utility of this information in a management setting was also analyzed. Reduction of Ca^{2+} through groundwater withdrawal revealed a eutrophication threshold and a drastic change in Ca^{2+} concentration in the downstream basins of Lake Beulah, uncovering the need for monitoring how groundwater withdrawal affects the interdependent basins in the lake. Currently, scientific information is used to generate results-based legitimacy, a hallmark of the model-as-mediator management paradigm. Utilization of these findings would best inform governance and management of linked surface-groundwater resources as a boundary object to generate consensus and initiate process development.

The analysis revealed that water policies favoring state level development interests threaten the water quality of groundwater dependent ecosystems and spark resistance at the community level. Conflicts are resolved through the court system affecting state level water governance, but local control over decision making regarding linked surface-groundwater resources is still lacking. Centralization of power over linked surface-groundwater resources fails to acknowledge the context dependency of local level conflicts and places power in the hands of state scale players like development and agricultural interests. Community and watershed non-governmental organizations focus on local issues of concern within their watershed such as invasive species management when conflicts over linked surface-groundwater resources are resolved, when state level interests pursue other avenues to influence the decision-making process. For the sustainable governance of LSGW resources, the Public Trust Doctrine must be integrated within a participatory governance process to resolve future conflicts.

The legal separation of groundwater and surface water has created independent institutions that now require new scales of collaborative adaptive governance to manage linked surface-groundwater resources. Identifying the opportunities and barriers to this collaborative adaptive governance is necessary to institutionalize practices that lead to sustainable water resource use. Application of Panarchy theory to analyze local, regional and state development in Wisconsin placed Lake Beulah and East Troy in their historical contexts. An understanding of cross-scale interactions outlined crises, opportunities and barriers operating within the Lake Beulah-East Troy Social-Ecological System. Opportunities for collaborative governance are largely based on current conditions of the system while barriers are rooted deeply in historical system development. For collaborative governance to be institutionalized in the Lake Beulah-East Troy Social-Ecological System, the barriers must be addressed before opportunities can be seized.

To
My Mother Ruth and my Wife Hannah
Your courage, strength and understanding made this possible

And to My Son Gabe
Your announcement was the swiftest kick in the pants a student could ask for

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Chapter 1: Opportunities and challenges for incorporating threshold effects in the governance of linked surface and groundwater systems

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Abstract

The accelerating impacts of landuse changes driven by development in areas outside of urban centers have highlighted the imperative for integrated management of surface and groundwater resources. Although judicial rulings have provided government agencies authority to utilize the potential impacts of groundwater reduction on surface waters to inform management decisions, these agencies are not equipped with standardized processes to gather the information necessary to exercise their authority. This gap has created regulatory uncertainty and fostered conflict around linked surface and groundwater resources (LSGR) management. Lake Beulah is a multi-basin marl lake in Walworth County, Wisconsin where concerns over the potential impact of groundwater withdrawal on lake water quality resulted in a lengthy legal battle between lake residents, local government, and the Wisconsin Department of Natural Resources (WDNR). In this study, we first employed the US Army Corps of Engineers reservoir/lake model BATHTUB in combination with geochemical model PHREEQC to identify an impact threshold value for groundwater reduction for Lake Beulah. Groundwater withdrawal increases the vulnerability of Lake Beulah to nutrient loading through a reduction in the Ca^{2+} - P co-precipitation mechanism, with the magnitude of the effect varying among sub-basins in the

lake. It remains to be seen as to whether state agencies in Wisconsin will utilize decision frameworks in making management decisions in LSGR systems. Ongoing challenges to court rulings and interpretations of agency authority continue to obfuscate whether WDNR will be allowed to consider the cumulative effects of multiple wells in assessing significant adverse impacts. A critical discussion of the utility of decision support frameworks outlines the need for trans-disciplinary boundary work to identify how evidence can be used effectively in the stewardship of LSGR.

Introduction

Growth and development in areas outside of urban centers have increased stress on surface water (Bennett et al., 2001; Carpenter et al., 1999; Carpenter, 2008) and groundwater resources (Llamas and Martínez-Santos 2005, Llamas et al. 2003). Concerns over negative impacts of decreased groundwater flow on surface waters increasingly spark conflict between environmental and agro-industrial interests over water rights and the authority of regulatory agencies (Bergquist, 2016a; Evans and Evans, 2014; Moore et al., 1996). In the State of Wisconsin, multiple court cases have expanded the authority of the Wisconsin Department of Natural Resources (WDNR) through interpreting the public trust doctrine to incorporate effects of groundwater reduction on surface waters (Kobza 2011, Scanlan 2012). However, these court rulings do not provide the WDNR a process to exercise their newly granted authority and recent political interpretations now constrain their ability to act (Wis. Att'y Gen. 01 2016).

Calcareous marl lakes are rare and resist eutrophication by the co-precipitation of phosphorus with calcium through the mechanism of marl formation (Otsuki and Wetzel, 1972; Robertson et al., 2007; Wiik, 2012). Marl lakes are dependent on groundwater input to remain in a clear water state, both as a diluting agent and as a source of Ca^{2+}. This dual dependence bolsters the biogeochemical resilience of marl lakes (Robertson et al., 2007) and contributes to their overall lower sensitivity to anthropogenic nutrient pollution compared to non-marl lakes. However, this does not mean that they are not vulnerable to human impacts. The complex inter-dependence of linked surface and groundwater resources (LSGR) in marl lakes requires more in-depth analysis of how groundwater reduction can increase vulnerability to declines in lake water quality.

This study uses the multi-basin Lake Beulah in Walworth County, Wisconsin as a case study to identify an eutrophication threshold for groundwater reduction using the US Army Corp of Engineers (USACE) reservoir/lake modeling software BATHTUB (Walker 1999) and the US Geological Survey (USGS) hydro-geochemical modeling software PHREEQC (Parkhurst and Appelo, 2013). We identify an eutrophication threshold using these models to conduct an ex ante assessment of groundwater reduction on water quality in Lake Beulah. Reduction of groundwater from the uppermost basin in Lake Beulah reduced both water quality and Ca^{2+} levels in the downstream cells making them vulnerable to disturbance. However, given the increasing political influence affecting water resources policy, the utility of this scientific information is dependent upon the role it plays in the decision-making process. Boundary work (sensu Clark et al., 2011; Mollinga, 2010) is needed to identify concepts, objects and settings that will allow communities to make informed management decisions and generate consensus.

Materials & Methods

Study Site

Lake Beulah is a 338-hectare dimictic drainage lake located in northeast Walworth County Wisconsin (Figure 1). It has a maximum depth of 17.7 meters, a mean depth of 5.2 meters and a volume of 1.76 million cubic meters. Lake Beulah is composed of three lakes (Long Lake, Crooked Lake and Mill Lake) which are connected through artificially raised water levels by a flow over dam (Ecological Research Partners, 2013). Lake Beulah is positioned in the glacial outwash region of the Southern Kettle Moraine, which is dominated by porous sandy soils (Borman, 1976). Water bodies in this region are defined by high spring activity, biological diversity and calcium-rich water due to their position in the landscape (Thornton et al. 2013). Marl lakes in southeastern Wisconsin can withstand up to twice the amount of nutrient loading of non-calcareous lakes resulting in exceptional water quality (Robertson et al. 2007), which is desirable for lake residents (Kashian et al. 2006). What is most astonishing about this high-quality ecosystem is its proximity to the large urban centers of Chicago, Madison and Milwaukee.

Land use surrounding Lake Beulah was historically agricultural (Walworth, 2012). Over the past several decades the population in the surrounding counties has increased (SEWRPC 2002, Thornton et al. 2013) and the accompanying land use change has sparked concerns in the Lake Beulah community about the future of the lake's water quality. That interest spiked in 2003 when the nearby Village of East Troy placed a high capacity well within Lake Beulah's watershed.

After performing a groundwater study and creating a lake management plan it was understood that the high capacity well drawing from Lake Beulah's watershed would not significantly affect lake levels. However, the potential to impair the lake's water quality could not be determined (Nauta, 2010). This is because Lake Beulah receives a significant amount of Ca^{2+} rich groundwater. High amounts of Ca^{2+} in lake water acts as a buffering agent against nutrient loading (Hamilton et al. 2009, House 1990). Reducing the amount of Ca^{2+} in the water column will make Lake Beulah more vulnerable to eutrophication (Hamilton et al., 2009) but the level at which a eutrophication threshold will be crossed has not been identified. This study identifies the threshold where reduction in Ca^{2+} and groundwater input will result in Lake Beulah becoming eutrophic.

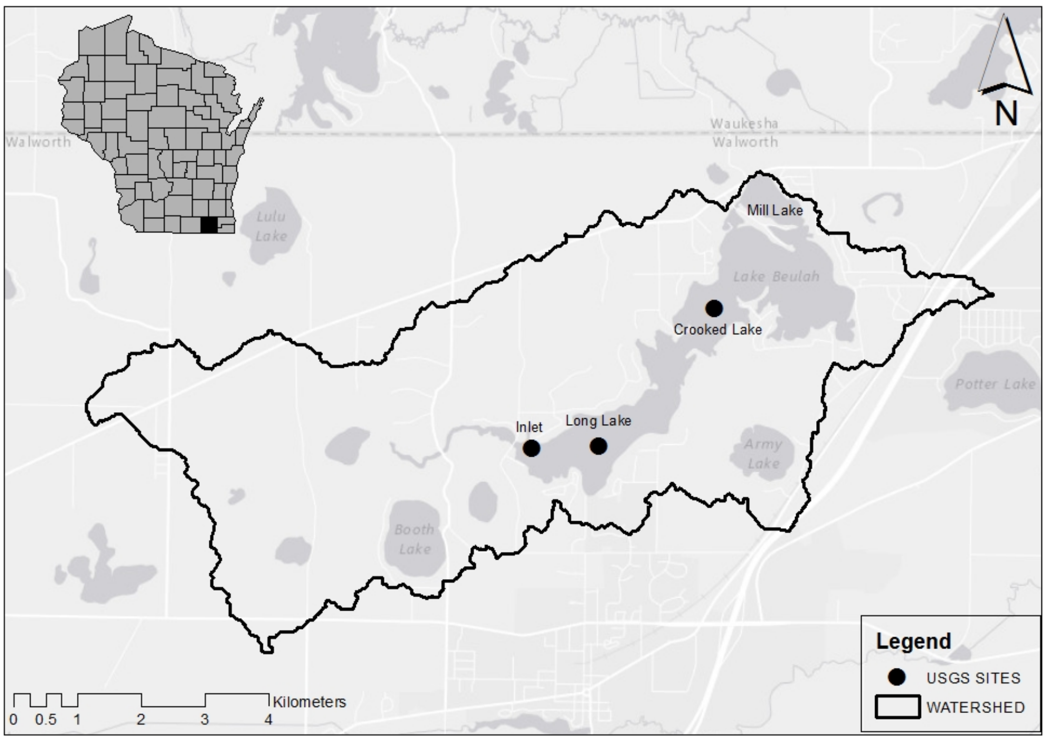


Figure 1: Geographic representation of the study area, along with USGS sampling locations and basin names

Data collection and analysis

Historical Data

The United States Geological Service (USGS) has been monitoring water quality in Lake Beulah since 2007, with a total of 7 sites sampled of which 3 have been sampled every year. In order from upstream to downstream these sites are: The Inlet, Long Lake and Crooked Lake (Figure 1). Samples were collected and sent to the Wisconsin State Lab of Hygiene for measurement of a suite of water quality indicators. This data are freely available as part of the USGS National Water Information System (https://waterdata.usgs.gov/nwis).

BATHTUB Software and Model Development

BATHTUB is a steady state reservoir modeling software developed by the USACE (Walker 1999). The purpose of BATHTUB is to understand how complex reservoirs respond to nutrient loading and to estimate the impact of potential management actions (Muhammetoglu et al., 2005). Typical lake eutrophication models treat waterbodies as one pool (Panuska and Kreider, 2003). This is unsatisfactory for lakes and reservoirs with complex morphology like Lake Beulah that have multiple connected, semi-independent basins and changes in the water budget will not occur uniformly across Lake Beulah due to its multiple basin structure (Dunkle, 2008). BATHTUB addresses this problem through dividing the waterbody into separate limnological cells that flow into and out of each other. To develop the BATHTUB model for Lake Beulah, a bathymetric chart of the lake was divided into 3 cells starting from the upstream: Long Lake, Crooked Lake and Mill Lake (Figure 2). These cells were chosen because they coincide with the USGS sampling locations, except for Mill Lake which was added because of its standalone nature (see Figure 1). The area for each depth category in each cells was calculated using a planimeter. USGS historical sampling data was used for model water quality inputs.

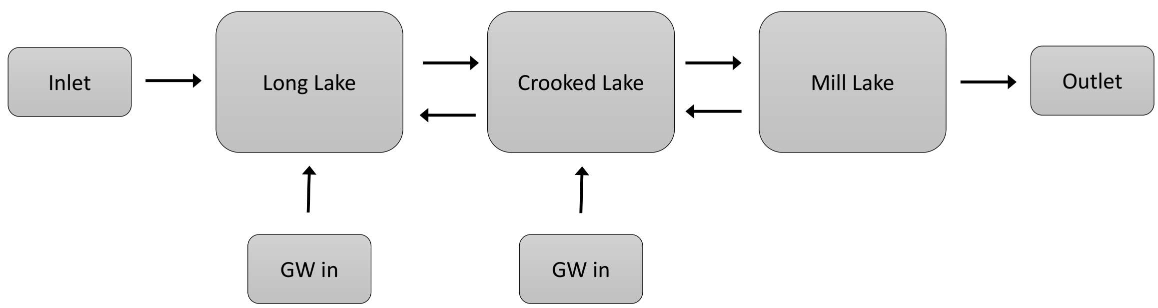


Figure 2: Model scheme for Lake Beulah used in the BATHTUB modeling software. The three cells: Long Lake, Crooked Lake, and Mill Lake have independent limnological characteristics. Groundwater flow is represented by stream inflow.

Table 1: Physical Characteristics of Lake Beulah and BATHTUB Cells

Attribute	Whole Lake	Long	Crooked	Mill
Watershed Area (km2)	26	-	-	-
Shorline (km)	24.1	-	-	-
Surface Area (km2)	3.38	1.1	1.8	0.3
Max Depth (m)	18	18	15	14
Mean Depth (m)	7	7.3	4.6	6.4
Mixed Depth Layer (m)	5.8	5.8	4.2	5.4
Residence Time (yr)	1.96	0.97	0.82	0.17
Cell Length (km)	-	2.1	2.5	0.8
Hypolimnetic Thickness (m)	-	11.3	8.67	7

BATHTUB allows the modeler to add stream inputs and outputs in any cell (Walker 1999). This gives modelers the ability to put detailed hydrologic information into the model and account for multiple inputs and outputs that occur in complex reservoir systems. Stream inputs were put in the Long Lake and Crooked Lake cells to represent groundwater input into Lake Beulah (Hunt et al., 2003). Proportion of groundwater inflow into each cell was determined using Darcy’s Law (Hubbert, 1956), a detailed water table map (Dunkle, 2008), soil porosity data (Borman, 1976) and a groundwater budget (Nauta, 2010).

During model simulations, the Vollenwieder eutrophication model was used to generate predicted TP (µg/L) values (Vollenweider, 1971). Global variables included precipitation, stream inflow, evaporation, outflow, external nutrient loading and atmospheric nutrient loading. Precipitation, stream and groundwater inflow/outflow and external nutrient loading values were taken from the 2010 Lake Beulah Management Plan. Evaporation rate was taken from the Marshfield Experimental Station in Marshfield, WI and atmospheric nutrient loading values for Iowa (representing the Upper Midwest) were used (Anderson and Downing 2006). The watershed delineation program L-Thia (http://lthia.agriculture.purdue.edu/) was used to determine the area and land use for each cell. L-Thia uses 2006 land use data, which is considered current enough for use in this study. Land uses were aggregated from the National Land Cover Database (NLCD) categories (Homer et al. , 2011)to comply with model inputs. Export coefficients for land use (Lin, 2004) were accounted for in the BATHTUB model. Since the well would only reduce groundwater flow into the Long Lake cell, groundwater flow was decreased by 30%, 60%, and 100% from the Long Lake cell to simulate its effect on water quality and [Ca^{2+}] within and across basins.

PHREEQC Model and Calcium Concentrations

The hydro-geochemical modeling software PHREEQC (Parkhurst and Appelo, 2013) was used to examine how reductions in calcium load would affect Ca^{2+}- P co-precipitation, an important process affecting water quality in Lake Beulah. Total phosphorus values from BATHTUB were coupled with USGS water quality data to model the relationship between Ca^{2+} and TP in PHREEQC, which takes the chemical components of a water sample and calculates the concentrations of major elements and the resultant species present at equilibrium. Reduced Ca^{2+} values (mg/L) from load calculations were used along with BATHTUB TP values (µg/L) and changes in pH and alkalinity (as mg/L CaCO3). Concentrations of P species unbound to Ca^{2+} were summed as available P (µg/L) at each step in the reduction process. Using the equations for Southern Wisconsin stratified drainage lakes (Lillie et al., 1993), available P concentrations from the PHREEQC reactions were converted into resulting CHL-A (µg/L) and secchi disk depth (m) values.

Calcium load (kg/yr) to Lake Beulah was derived from the average Ca^{2+} concentrations measured (mg/L) at spring turnover (U.S. Geological Survey, n.d.) and the Ca^{2+}-settling rate taken from a paleoecological study of Lake Beulah sediment cores (Garrison, 2000). Sediment cores were taken in the Long Lake cell and due to Lake Beulah's multi-basin nature this Ca^{2+}-settling rate only pertains to Long Lake. The resulting Ca^{2+} load (kg/yr) was then divided into surface water and groundwater loads based on the lake's water budget (Nauta 2010). The surface water inflow value was attributed to stream inflow due to the highly porous soils in the region reducing runoff and the high spring activity in upstream Pickerel and Booth Lakes (SEWRPC, 2010). The groundwater Ca^{2+} load (kg/yr) was divided into 80% and 20% proportions flowing into Long Lake and Crooked Lake respectively. No groundwater flows directly into Mill Lake.

Groundwater inflow and groundwater Ca^{2+} load to the Long Lake cell were reduced by 30%, 60% and 100%. Because of the placement of the well, the reduction in groundwater input to the Lake Beulah system in this study was expressed entirely in Long Lake (Dunkle, 2008). To measure changes in water column Ca^{2+} concentrations (mg/L) in the downstream cells, Ca^{2+-} settling rates were determined for each cell independently. The simulated loss of groundwater to the Lake Beulah system created a gradient between P and Ca^{2+} that was used for threshold identification.

Results

Simulations modeled the impacts of pumping by reducing groundwater flow into the Long Lake cell by 0, 30, 60 and 100 percent. These reductions in groundwater inflow resulted in concomitant increases in TP concentrations ranging from 31.8 µg/L (with no groundwater loss) to 36 µg/L (Table 2). However, because BATHTUB does not consider the co-precipitation relationship between Ca^{2+} and TP documented in the literature (Robertson et al 2007), as expected TP values were consistently higher than empirically observed in the lake (Figure 3).

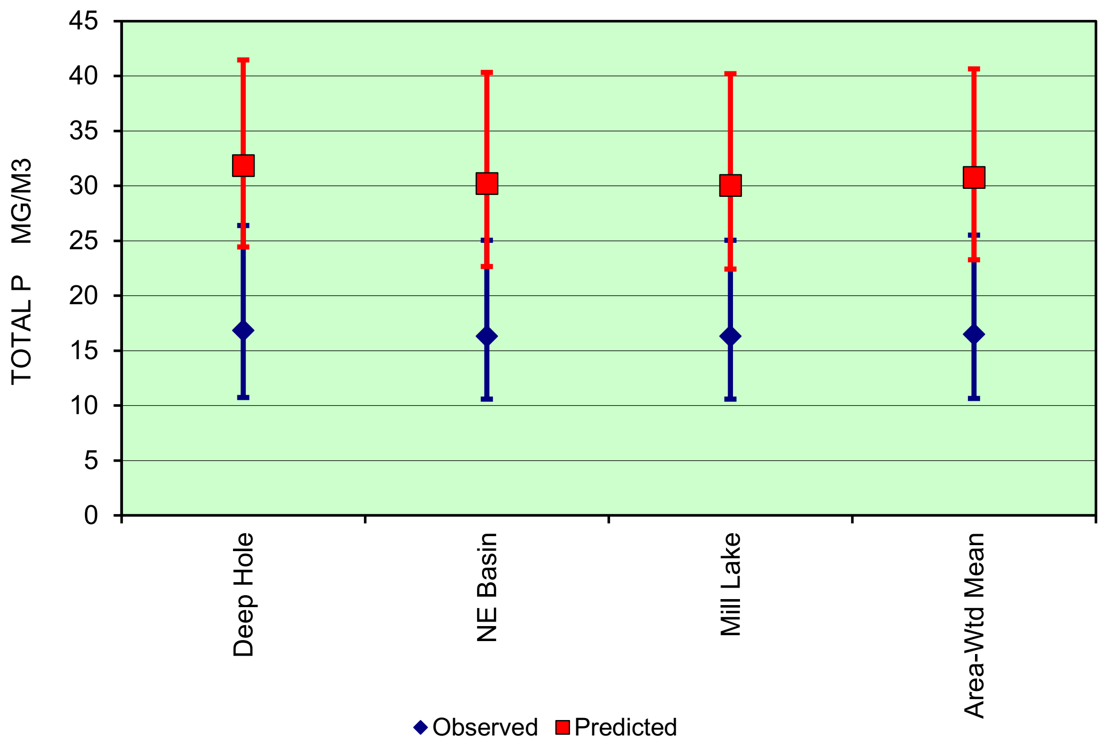


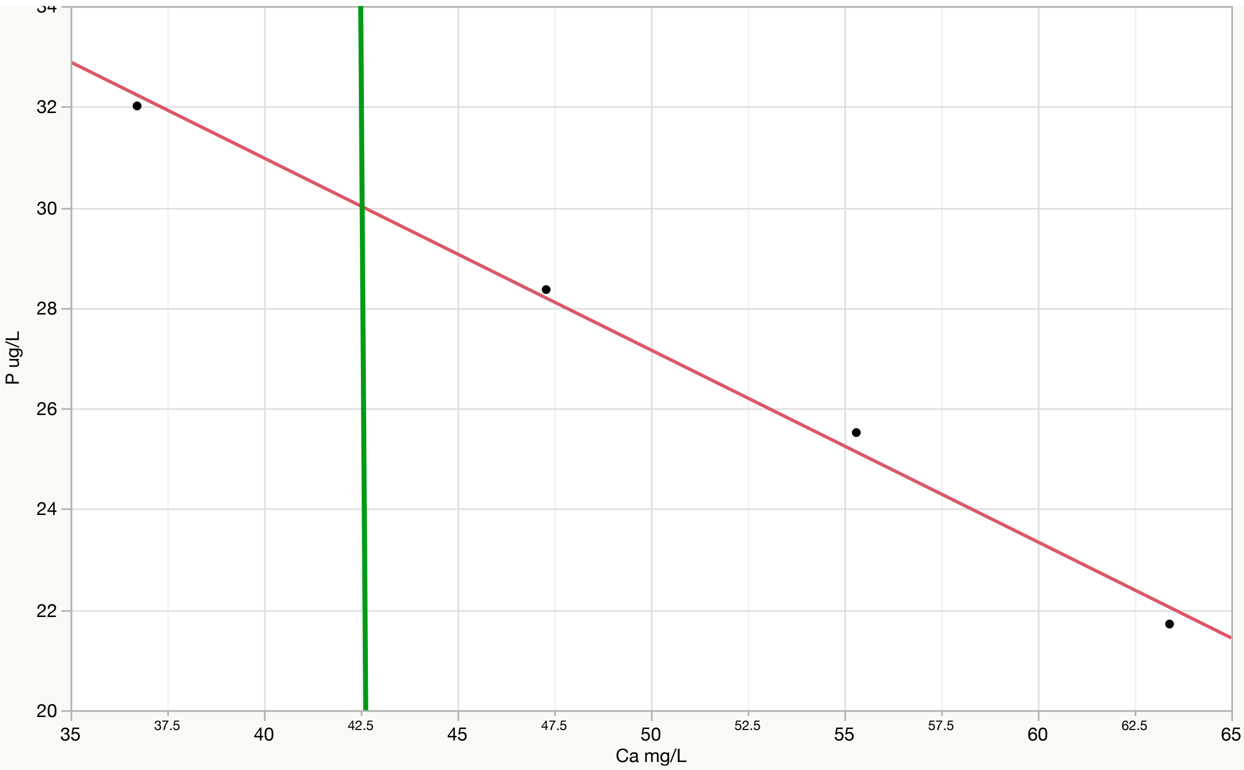
Figure 3: Observed and predicted values of total phosphorus (µg/L) for the basins of Lake Beulah: Long Lake, Crooked Lake and Mill Lake using the BATHTUB modeling software.

An annual Ca^{2+} load of 5.64e5 kg/yr to Long Lake was determined using a mass balance equation (EQ 1) where Lin is the load of calcium coming into the Long Lake cell (kg/yr), S is the mass of CaCO3 that settles out of the water column (mg/m2/yr) and [Ca^{2+}] is the concentration of calcium in the water column (mg/L). Average [Ca^{2+}] at spring and fall turnover (63.4 mg/L) and the settling rate for CaCO3 (63,00 mg/m2/yr) for the Long Lake cell were used (Garrison, 2000). The resultant load was then separated into surface and groundwater inputs using established water budget values (Nauta, 2010) and average inlet Ca^{2+} (mg/L) provided by the USGS dataset to model the effect of groundwater reduction on water column [Ca^{2+}] (mg/L). The [Ca^{2+}] (mg/L) of the cell directly upstream was converted into the surface water Ca^{2+} load (kg/yr), the same mass balance equation was used to calculate changes in [Ca^{2+}] (mg/L) in Crooked and Mill lakes.

$$L_{in} - S = [Ca^{2+}]$$

Equation 1: Water column calcium concentration at spring turn over (in mg/m^2 /yr) is equal to the calcium load (L_{in}) to Lake Beulah (in mg/ m^2 /yr) minus the settling rate (S in mg/ m^2 /yr).

Reducing groundwater to the Long Lake cell by 30%, 60% and 100% resulted in a decrease of [Ca^{2+}] from 63.4 mg/L to 36.7 mg/L Ca^{2+} in Long Lake (Table 3). These values were accompanied by the TP concentrations predicted using BATHTUB and run in the PHREEQC model. Through summing up P species unbound to Ca^{2+}, available TP was found to increase from 21.7 µg/L to 32 µg/L when groundwater inflow was decreased from the Long Lake cell (Figure 4). TP values generated in PHREEQC (Parkhurst and Appelo, 2013) were used to calculate both Secchi disk depth (m) and Chl-a concentration (µg/L) using the Wisconsin Trophic State Index (WTSI) equations. Secchi disk (m) decreased from 2.09 m to 1.75 m and Chl-a increased from 8.17 to 10.53 (µg/L) (Table 3).



Linear Fit

P ug/L = 46.245659 - 0.381669*Ca mg/L

Summary of Fit

RSquare	0.994172
RSquare Adj	0.991258
Root Mean Square Error	0.407889
Mean of Response	26.90243
Observations (or Sum Wgts)	4

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	56.764386	56.7644	341.1867
Error	2	0.332747	0.1664	**Prob > F**
C. Total	3	57.097133		0.0029*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	46.245659	1.066882	43.35	0.0005*
Ca mg/L	-0.381669	0.020663	-18.47	0.0029*

Figure 4: Eutrophication threshold identified for a marl lake calculated using PHREEQC modeling software. As calcium rich groundwater is reduced from the water budget, the efficiency of the Ca^{2+} - P co-precipitation mechanism is also reduced. At a Ca^{2+} concentration of 42.6 mg/L TP concentrations surpass the 30 µg/L biophysical and regulatory eutrophication threshold.

Table 2 : Water Quality Effects of Groundwater Withdrawal in Lake Beulah

Parameter	No Withdrawal	30% Withdrawal	60% Withdrawal	80% Withdrawal
% Withdrawal Long Lake Cell	0	38	75	100
Groundwater Inflow (m3/yr)	2,100,000	1,470,000	840,000	420,000
Long Lake Residence Time (yr)	0.965	1.04	1.14	1.22
Long Lake Ca^{2+} (mg/L)	63.4	55.4	47.4	36.7
Long LakeTP (µg/L) BATHTUB	31.8	33.9	34.2	36
Long Lake TP (µg/L) PHREEQC	21.7	25.5	28.4	32
Long Lake Secchi (m)	2.09	1.93	1.79	1.75
Long Lake CHL-a (µg/L)	8.17	8.96	10.24	10.53

Downstream effects of groundwater withdrawal were pronounced (Figure 5). The sedimentation rate for Ca^{2+} increased in the Crooked Lake cell to 256,000 (mg/m2/yr) and decreased in the Mill Lake cell to 1,000 (mg/m2/yr). When groundwater input was reduced for Long Lake, Ca^{2+} levels decreased from 49 (mg/L) to 7.24 (mg/L) in the Crooked Lake cell and from 39.2 (mg/L) to 5.65 (mg/L) in the Mill Lake cell.

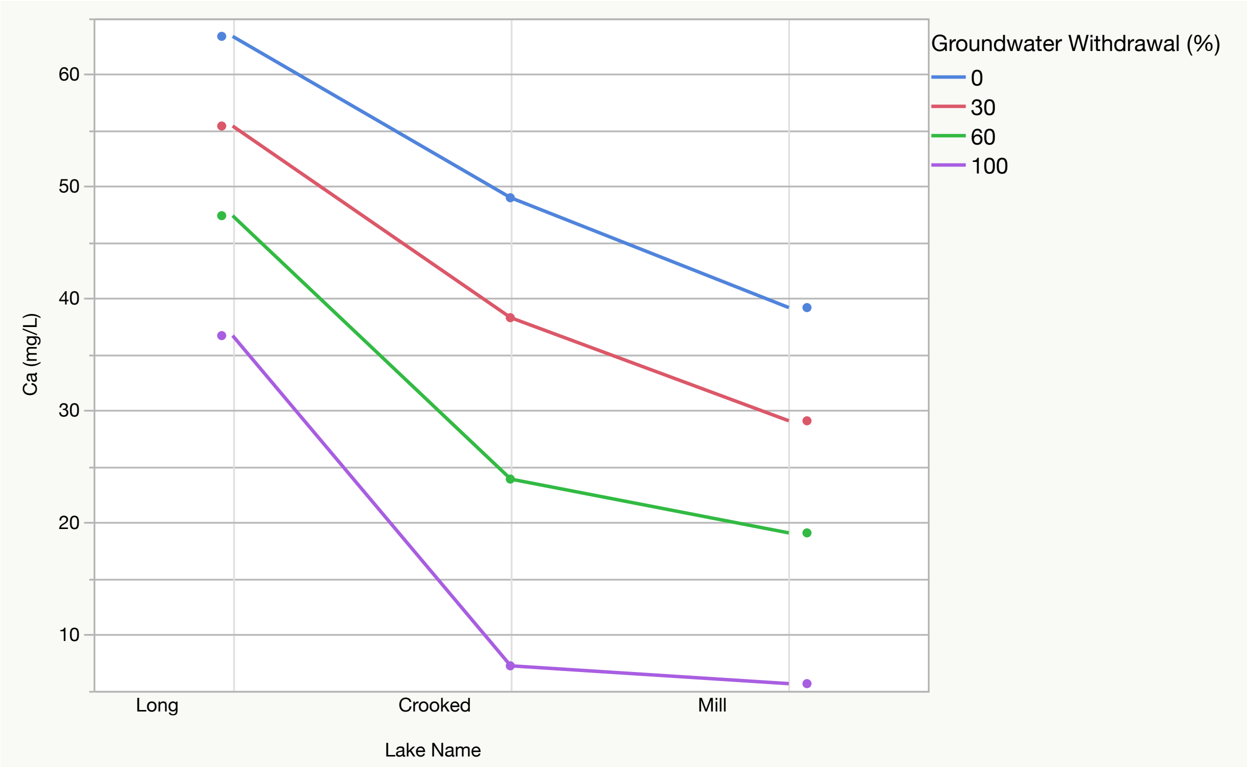


Figure 5: [Ca]lcium concentrations across basins in Lake Beulah and the effects of groundwater withdrawal.

Discussion

The analyses in this paper demonstrate that the input of calcium through groundwater plays a significant role in creating and maintaining high quality water resources in Lake Beulah. For example, without reductions in TP caused by TP/Ca^{2+} co-precipitation the Long Lake cell would be out of compliance for TP (Wis. Stat. § 102.06(4)) and at risk of crossing a eutrophication threshold (Liu et al., 2015). TP (µg/L) and CHL-a (µg/L) both increase while secchi disk depth (m) decreases with reduced groundwater input, indicating a reduction in water quality in the Long Lake cell. The linear regression equation of the relationship between TP and Ca^{2+} identifies a threshold value where Lake Beulah would no longer be in compliance with Chapter NR 102 of the Wisconsin State Statues (Wis. Stat. § 102.06(4)) (EQ 2). Ca^{2+} (mg/L) would have to decrease to 42.6 mg/L or a reduction of groundwater flow by 78% to pass this regulatory and biophysical eutrophication threshold. These results indicate that currently the Long Lake cell is resilient to groundwater withdrawal because of the Ca^{2+} input from surface water flow through the inlet. However, direct groundwater inflow is necessary for Lake Beulah as a whole to remain in a clear state because it supplies Ca^{2+} to the basins downstream.

$$P = 46.2 – 0.38*Ca$$

Equation 2: Linear regression equation used to identify the eutrophication threshold of a marl lake where P is total phosphorus in the water column (in µg/L) and Ca is calcium in the water column (in mg/L).

For Lake Beulah as a whole, reduction in groundwater input from pumping would result in an overall increase in TP and decrease water quality. For example, removal of groundwater decreased secchi disk depth from 2.09 (m) to 1.75 (m) changing the lake’s trophic status from mesotrophic to eutrophic (Lillie et al., 1993). This is due to low TP in the region’s groundwater (Robertson et al., 2002). Groundwater inflow is therefore acting as a diluting agent in addition to being a source of Ca^{2+}. The removal of groundwater also increased the residence time of the Long Lake cell, and called for more runoff to fill in the basin.

Loss of groundwater to the Long Lake cell is magnified in the downstream basins because of their dependence on delivery of Ca^{2+} via surface water flow. With the large Ca^{2+} sedimentation rate in Crooked Lake (256,000 mg/m2/yr) even slight reductions in Ca^{2+} can result in substantial changes in water quality. For instance, removing groundwater flow from Long Lake's water budget results in a 42% decrease in water column Ca^{2+} (mg/L) in the Long Lake cell but an 85% and 86% decrease in water column Ca^{2+} in the Crooked and Mill Lake cells respectively. This drastic decrease in Ca^{2+} from a seemingly small reduction in groundwater flow can dramatically hinder the downstream basins in Lake Beulah from benefiting from the Ca^{2+} - P removal mechanism.

Changes in the overall water budget could push Lake Beulah past an eutrophication threshold due to the lake's direct and indirect dependence on groundwater. The stream feeding Lake Beulah relies on spring activity and supplies much of the Ca^{2+} present in the water column (Nauta 2010, SEWRPC 2010). Reduced groundwater flow from springs upstream could cause an additional reduction in water column Ca^{2+} and push Lake Beulah past the eutrophication threshold. This could also occur due to external causes such as drought and changing climate patterns as well as internal ones like the cumulative impacts of current and future groundwater utilization in the watershed. To properly manage Lake Beulah's water quality into the future, monitoring of wells that have the potential to affect direct and indirect groundwater flow is necessary.

Application to other lakes

It is important to note that the threshold identified in this study is specific to Lake Beulah and the process for its identification using the BATHTUB and PHREEQC models is specific to multi-basin marl lakes. Through incremental increases in modeled phosphorus loading, Lake Nagawicka, another marl lake in southeastern Wisconsin, was found to withstand a two-fold increase in TP loading before becoming eutrophic (Robertson et al., 2007). Neither this nor our study consider nonlinear effects of groundwater withdrawal on water quality and as such, managers should work to keep Ca^{2+} levels comfortably above the identified threshold (Rockström et al., 2009). Experimental studies involving increased phosphorus loading in large lake enclosures (Hamilton et al., 2009) found that lake sediments are a major sink for TP in calcareous Michigan lakes. Studies like these are necessary to identify and characterize the nonlinear effects of groundwater withdrawal on marl lake water quality. It is also important to mention that Lake Beulah has a mean Ca^{2+} concentration of 63.4 mg/L, much higher than the average lake in southeastern Wisconsin (Lillie and Mason, 1983) (Figure 6). Other lakes may already be closer to their eutrophication threshold.

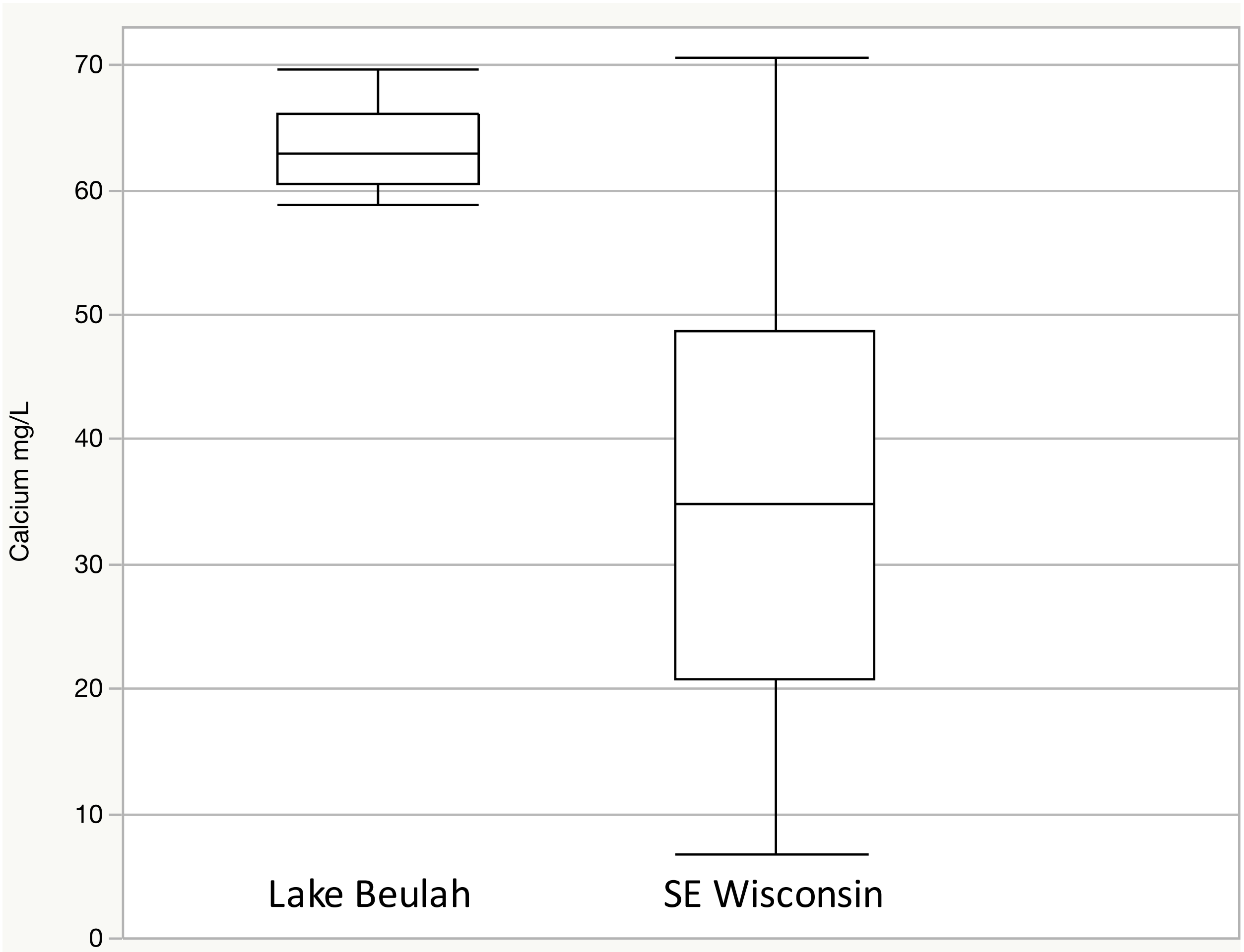


Figure 6: Comparison of Ca^{2+} (mg/L) between Lake Beulah and lakes in southeastern Wisconsin.

Broader Implications

Ecological Importance of Calcium

The ecological implications of decreased Ca^{2+} go well beyond water quality. Recent studies have shown that reductions in Ca^{2+} lead to near extirpations of keystone herbivorous zooplankton like *Daphnia* species Keller et al. 2001). Crayfish have exhibited reduced exoskeletal rigidity in more acidic (less calcareous) waters (Jeziorski and Smol, 2016). Other crustaceans have exhibited increased concentrations of divalent metals at membrane binding sites increasing toxicity in higher trophic organisms. These declines have also alluded to indirect effects both within and outside the waterbody itself (Jeziorski et al., 2008). Eggshell thickness of piscivorous raptor species have shown declines correlated with the decline of lake Ca^{2+} levels (Jeziorski and Smol, 2016). Given the fact that Lake Beulah and the Mukwonago is home to a diverse community of mussel species, including the state endangered rainbow clam (SEWRPC 2010), stress from declines in Ca^{2+} should be avoided.

Governance Considerations

Decision support tools for natural resources management are frequently generated but seldom used for reasons including: disciplinary obstacles, existing management paradigms, and institutional settings (Mollinga, 2010). Processes developed to assess potential adverse impacts of groundwater reduction will not be useful without significant work to identify how science can inform integrated surface and groundwater governance.

To effectively govern integrated surface and groundwater resources multiple disciplinary barriers need to be overcome. These include barriers within resource management agencies, between experts and stakeholders, and between research and policy (Berkes et al. 2000, Clark et al. 2011, Mollinga 2010, Walker and Salt 2012). These different management silos develop their own nomenclature and common practices when interacting with water resources. For example, the issues concerning groundwater flow to surface waters tend to focus on the effects of reduced water quantity, something that can be easily quantified using current hydrogeological modelling practices (Hayashi and Rosenberry 2002, Hunt et al. 2003, Sophocleous 2002). Little if any work has been conducted on understanding how groundwater reduction could affect lake water quality. This is because most managers who are asked to make decisions on groundwater resources do so through a hydrogeological lens. Managers understand the ecological importance of groundwater resources for surface waters, but stop short of seeking out the ecological perspective when making management decisions. Terms like groundwater dependence and adverse environmental impacts can serve as boundary concepts to generate shared understanding across disciplines, stakeholders and policy actors.

Consideration of management paradigms is critical to proper decision making in any kind of natural resources governance (Halbe et al. 2013, Rockström et al. 2014, Sendzimir et al. 2008). The United States' management paradigm centers around reliance on quantitative modelling to provide unbiased decision support (Mollinga, 2010).These models have become increasingly complex, reinforcing the barriers between disciplines and stakeholders. The problem is that models are developed and utilized within a context, which inherently subscribes them to a political ideology (Mollinga, 2010). This leads stakeholders with conflicting interests to pick and choose models that they agree with to give their argument scientific legitimacy (Ropeik, 2012). Studies have been conducted to increase the transparency between modelers and stakeholders in water conflicts (Olsson et al., 2007; Tidwell et al., 2004; Tidwell and Van

Den Brink, 2008). These studies attempt to lower the barrier between stakeholders and managers, but still operate with this “model as mediator” paradigm. Knowledge created through meaningful stakeholder participation in integrated surface and groundwater governance can act as a boundary object to properly address conflicts over water resources.

The institutional setting (both formal and informal) in which management of surface and groundwater resources occurs determines the nature of water governance (Ostrom, 1990; Rockström et al., 2014). The model as mediator management paradigm, for example, is inherently centralized because of the complexity and technical know-how involved (Mollinga, 2010). Stakeholders are informed of decisions made by managers based on quantitative modeling without support from meaningful stakeholder engagement and knowledge co-generation (Stern and Baird, 2015). Centralized state governance is typical for valuable and exhaustible natural resources like groundwater (Lemos and Agrawal, 2006), exposing the regulation of LSGR to political sovereignty driving regulatory uncertainty and conflict (Bergquist, 2016a; Scanlan, 2012). The WDNR’s legitimacy in the eye of the public has eroded overtime due to factors outside of its control (Bergquist 2016a, Scanlan 2000) and an assessment process on its own will not satisfy the stakeholders involved in linked surface and groundwater conflicts. Institutions must be crafted that allow for public participation, consensus generation and overall adaptive co-management (Berkes 2009, Carlsson and Berkes 2005) to properly govern integrated surface and groundwater resources.

The findings in this study provide a foundation for interested managers, stakeholders and policy actors to start a conversation about how to govern integrated surface and groundwater resources. The Lake Beulah decision, given by the Wisconsin State Supreme Court in 2011, set the precedent that the effects of high capacity wells on adjacent surface waters falls under the Public Trust Doctrine (Lake Beulah Management District v. DNR, 2011). To come to this decision, both the Village of East Troy and the Lake Beulah Management District had to spend considerable amounts of time and resources defending their positions in court. The analysis above was not performed at the time of the initial conflict, but could be used to inform other communities dealing with linked surface and groundwater issues.

Individual wells may not pose an immediate threat to the integrity of surface waters, but the cumulative effects of multiple high capacity wells must be considered to properly assess potential environmental impacts. Like other types of natural resource conflicts, the case dependency in linked surface/groundwater conflicts makes it difficult for a centralized authority like the WDNR to govern effectively. To address this problem, communities of practice need to be brought into the decision-making process in a meaningful way (Reed 2008, Stringer et al. 2006) to ensure consensus is reached. This is the opposite of what is happening in the State of Wisconsin where, by request from the state's Attorney General, the WDNR will not take into consideration cumulative impacts of high capacity wells on adjacent surface waters during the permitting process (Bergquist, 2016b).

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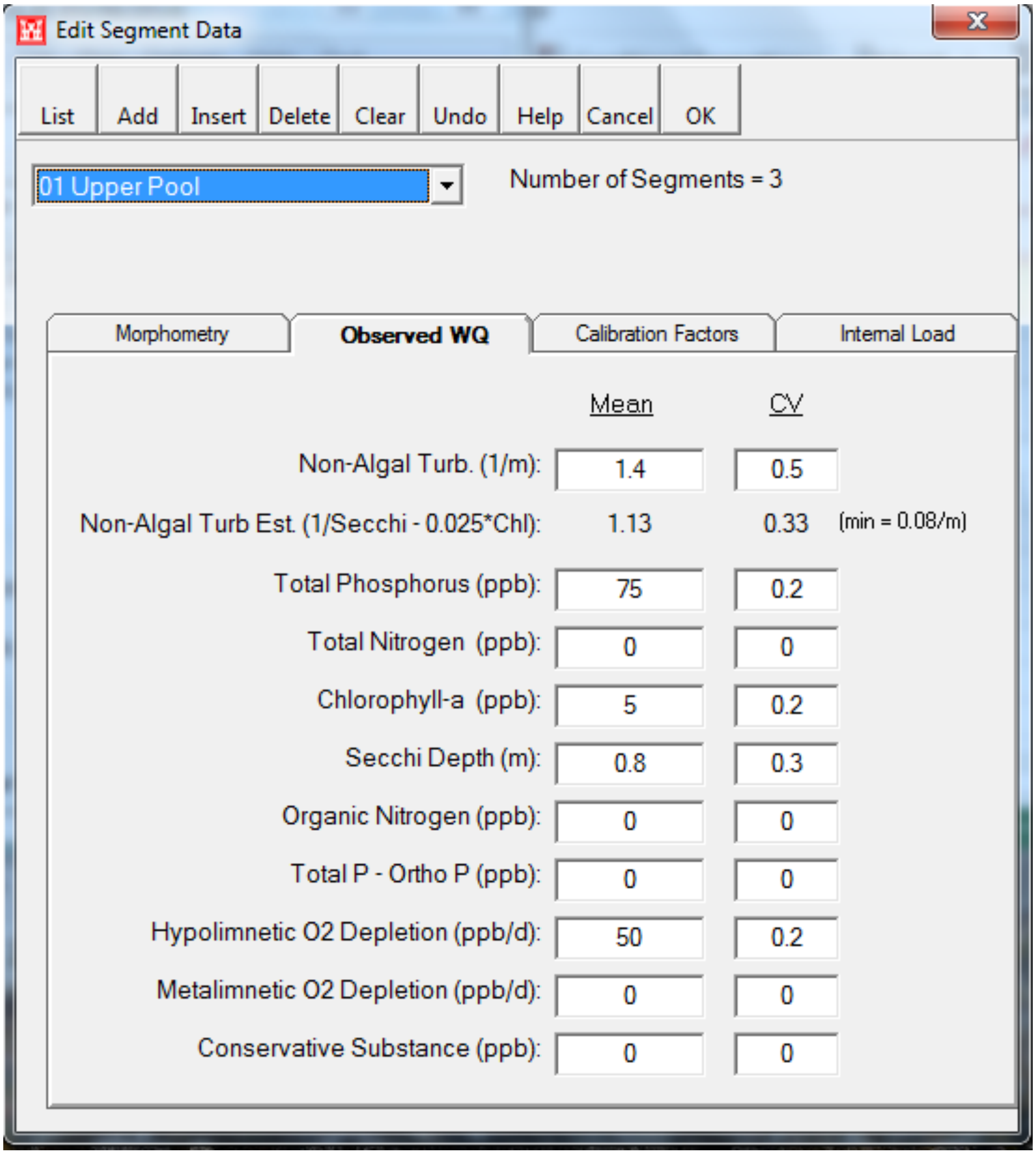
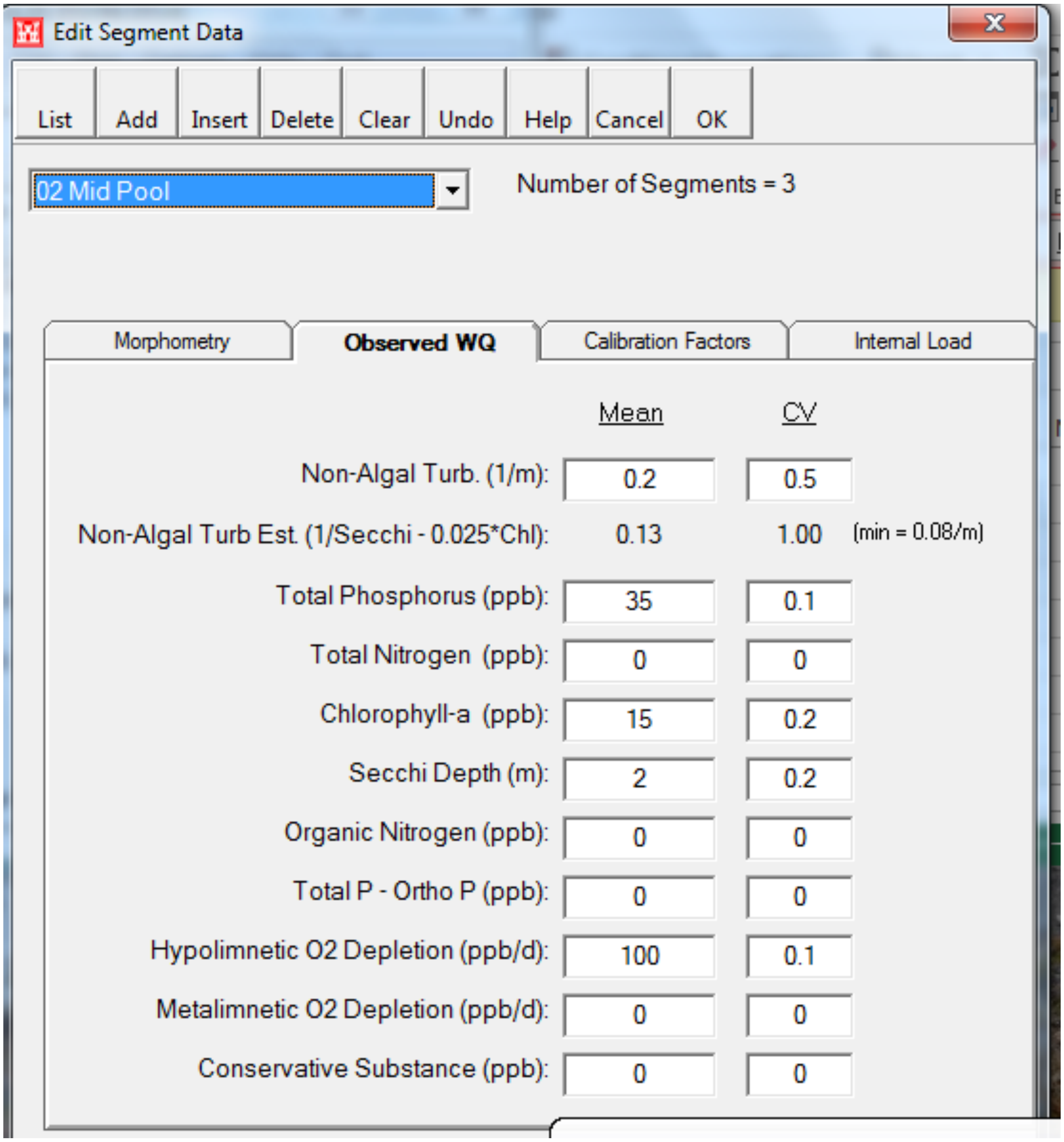
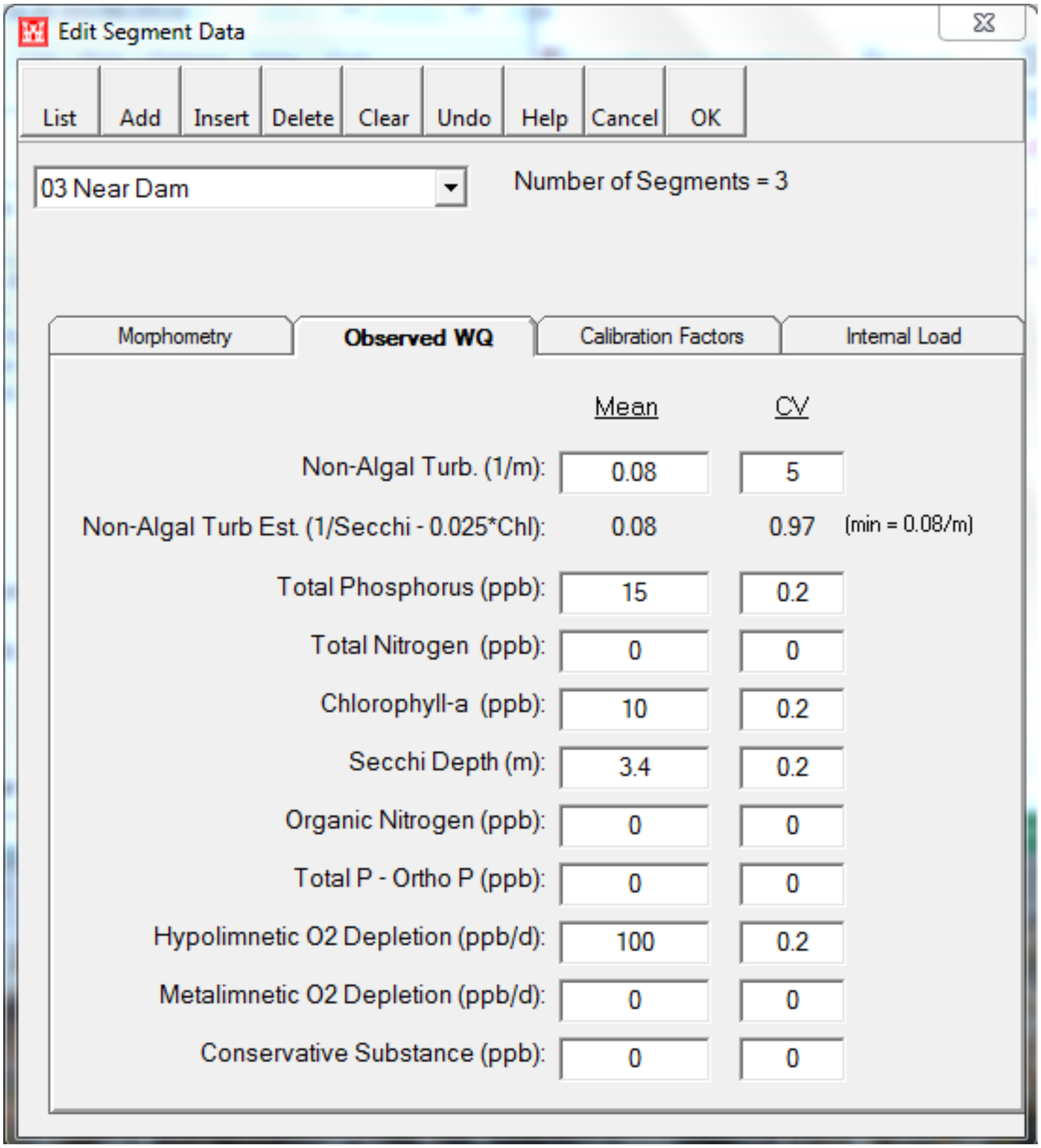
Appendix A: BATHTUB Model Set Up




Edit Segment Data
List
Add
Insert
Delete
Clear
Undo
Help
Cancel
OK
02 Mid Pool
Number of Segments = 3
Morphometry
Observed WQ
Calibration Factors
Internal Load
Mean
CV
Non-Algal Turb. (1/m):
0.2
0.5
Non-Algal Turb Est. (1/Secchi - 0.025*Chl):
0.13
1.00
(min = 0.08/m)
Total Phosphorus (ppb):
35
0.1
Total Nitrogen (ppb):
0
0
Chlorophyll-a (ppb):
15
0.2
Secchi Depth (m):
2
0.2
Organic Nitrogen (ppb):
0
0
Total P - Ortho P (ppb):
0
0
Hypolimnetic O2 Depletion (ppb/d):
100
0.1
Metalimnetic O2 Depletion (ppb/d):
0
0
Conservative Substance (ppb):
0
0


Edit Segment Data
List
Add
Insert
Delete
Clear
Undo
Help
Cancel
OK
03 Near Dam
Number of Segments = 3
Morphometry
Observed WQ
Calibration Factors
Internal Load
Mean
CV
Non-Algal Turb. (1/m): 0.08 5
Non-Algal Turb Est. (1/Secchi - 0.025*Chl): 0.08 0.97 (min = 0.08/m)
Total Phosphorus (ppb): 15 0.2
Total Nitrogen (ppb): 0 0
Chlorophyll-a (ppb): 10 0.2
Secchi Depth (m): 3.4 0.2
Organic Nitrogen (ppb): 0 0
Total P - Ortho P (ppb): 0 0
Hypolimnetic O2 Depletion (ppb/d): 100 0.2
Metalimnetic O2 Depletion (ppb/d): 0 0
Conservative Substance (ppb): 0 0

Appendix B: PHREEQC Model Set Up

```
SOLUTION_MASTER_SPECIES
SOLUTION_SPECIES
PHASES
EXCHANGE_MASTER_SPECIES
EXCHANGE_SPECIES
SURFACE_MASTER_SPECIES
SURFACE_SPECIES
RATES
END
```

Reading input data for simulation 1.

```
DATABASE C:\Program Files (x86)\USGS\Phreeqc Interactive 3.3.7-
11094\database\phreeqc.dat
SOLUTION 1
   temp      16.5125
   pH        7.59
   pe        4
   redox     pe
   units     mol/L
   density   1
   Alkalinity 0.00402
   Ca        0.00138
   P         0.00000106
   water     1 # kg
```

Calcium and alkalinity were reduced and phosphorus increased based on output of the BATHTUB model.

Chapter 2: Analysis of social-ecological dynamics affecting governance in linked surface-groundwater systems

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Abstract

Governance of water resources cannot solely rely on scientific understanding to inform policy. Social and economic processes operating at multiple scales have the potential to push water systems across thresholds into undesirable alternative biophysical states. A recent and relatively unexplored example is the governance of linked surface-groundwater (LSGW) resources. A conflict over a high capacity well in southeastern Wisconsin was examined through open-ended key stakeholder interviews. Using framework analysis to abstract themes and categories from the interview data, factors affecting the governance of LSGW resources emerged. Using the threshold matrix method, factors were assigned alternative states and linked through narratives describing their trajectories of expected change. A total of 16 factors were identified as linked to surface-groundwater utilization on scales ranging from individual property owners to the state level. These factors also occurred across the biophysical, economic and social domains, revealing social-ecological feedbacks not currently addressed by management authorities. The analysis reveals that state level development interests are met with individual and community level resistance when utilization of LSGW resources are perceived to have the potential to adversely affect surface water quality. The current pathway

for resolution of these conflicts requires interpretation of the Public Trust Doctrine through the court system, which is ill-fitted to address LSGW systems. Furthermore, court rulings regarding individual watersheds do not necessarily facilitate communication and coordination between affected parties outside of the particular region. As such, housing development and agricultural interests work at the legislative level to influence surface-groundwater policy to put limits on court rulings affecting state-wide issues such as evaluation of cumulative impact. Meanwhile, community and watershed non-governmental organizations focus on local issues of concern within their watershed such as invasive species management. For the sustainable governance of LSGW resources, the Public Trust Doctrine must be integrated within a participatory governance process to resolve future conflicts.

Introduction

In stark contrast to their geophysical interdependence, existing frameworks for the governance of surface and groundwater resources operate independently of each other, often creating conflict over water resource use (Moore et al. 1996, Llamas and Martínez-Santos 2005) Although our knowledge of the relationship between surface and groundwater has advanced considerably (Sophocleous 2002, Shaw et al. 2013), laws and regulations continue to address them as separate systems (Sophocleous 2002, Mukherji and Shah 2005, Mitchell et al. 2012). In the State of Wisconsin surface waters are governed under The Public Trust Doctrine (Quick 1994, Scanlan 2012). In spite of the fact that laws to protect groundwater resources have recently been enacted (Lake Beulah Management District v. DNR 2011), efforts to implement the regulatory process have resulted in significant disagreement among environmental and development interests regarding central issues such as what constitutes significant adverse impact (Bergquist 2016c, 2016d). The ensuing regulatory uncertainty in the permit approval process has frustrated all parties involved, necessitating significant resources to be spent on scientific studies and legal counsel.

Even with all of the information accumulated from linked surface-groundwater (LSGW) systems, there remains a lack of understanding regarding the social, economic and environmental drivers and feedbacks underlying conflict. Applying a social-ecological systems lens to the analysis of these problems allows researchers to link resource systems to the social and economic factors that influence them (Galaz et al. 2006, Kinzig et al. 2006, Ostrom 2009, Chapin et al. 2010). The threshold matrix method developed by Kinzig et al. 2006 accomplishes this through identifying and visualizing the social and economic dynamics that influence the biophysical system. The threshold matrix method can be especially useful when managers are dealing with emerging governance problems (Walker and Salt 2012) such as conflicts over LSGW resources.

In this paper the threshold matrix method is applied to evaluate the dynamics of the conflict between the Lake Beulah Management District and Village of East Troy in Walworth County Wisconsin regarding the permitting of a high capacity municipal well. Document analysis of legal proceedings, news articles and development plans, combined with interviews of key stakeholders at the local, regional and state scales provided insights into the social and economic factors influencing the groundwater dependent social-ecological system – from which a threshold matrix was constructed. The matrix was then used to explore the processes for resolving conflicts within the context of the Public Trust Doctrine. Results of this study indicate that in order to properly address LSGW conflicts, the Public Trust Doctrine must be integrated into a broader governance process that includes: knowledge of the resource system, networks of key stakeholders across conflicts, scales and domains, and generation of consensus across conflicting groups over the risks involved in LSGW utilization.

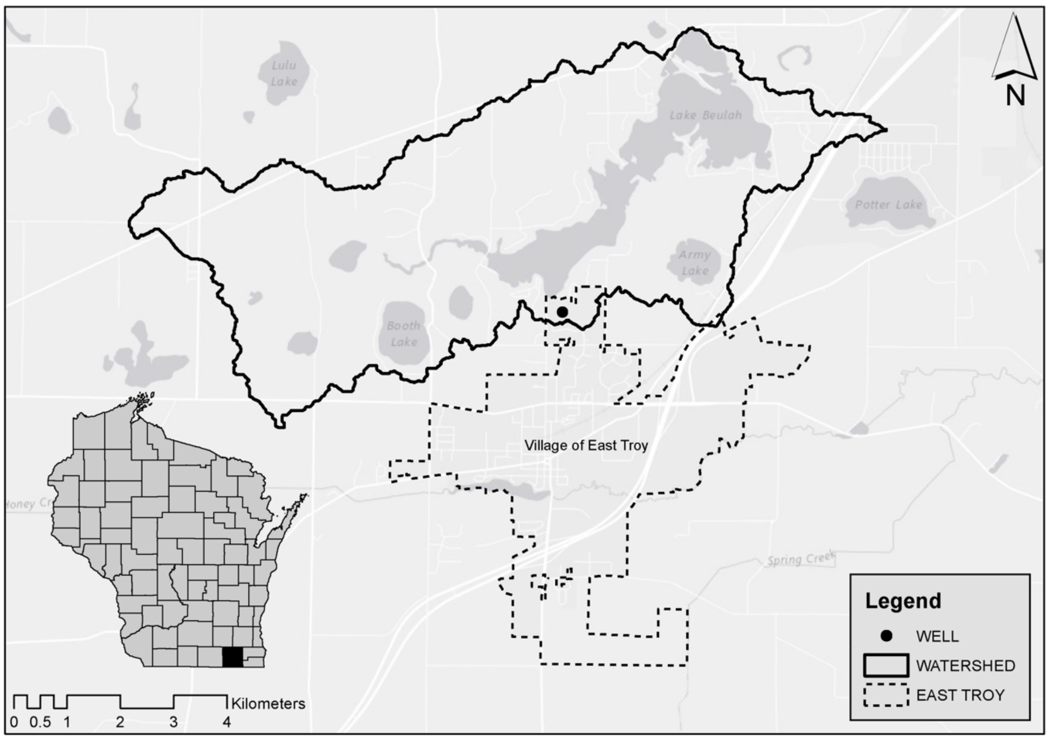

Figure 7: Geographical perspective of the Lake Beulah / East Troy conflict. The high capacity well is located where the East Troy village boarder overlaps with Lake Beulah's watershed.

Study context: The Lake Beulah Social-Ecological System

Lake Beulah is a flow through marl lake in Northeastern Walworth County, Wisconsin (Figure 7) which is located in the Mukwonago River basin. The lake is part of the Mukwonago River Basin, which contains multiple reaches of exceptional resource waters of the state despite being surrounded by two of the state's most populated areas Milwaukee and Madison (SEWRPC 2010, Thornton et al. 2013b). One of the reasons for the high aquatic ecological integrity of the lake is the ample amount of groundwater input from springs into the lake. The subsurface soils in the region are predominantly well-sorted glacial outwash, which allow water to recharge the shallow aquifer and reduce surface runoff. The Mukwonago River is also home to multiple state threatened and endangered species including the long ear sunfish (*Lepomis megalotis*) and the rainbow mussel (*Villosa iris*) (SEWRPC 2010). These attributes of the landscape have cultivated a sense of stewardship in the residents of the watershed. A partnership of the governing bodies in the watershed have also vowed to work together to control future development in the region (Slawski 2013, Thornton et al. 2013b). All of these factors result in one of the most biologically diverse and highest quality riverine ecosystems in Wisconsin.

Lake Beulah was dammed in the late 19th century in order to raise water levels to increase the amount of developable shoreline property. At that time Walworth County was mostly undeveloped, and houses on Lake Beulah were primarily vacation homes for families traveling from Milwaukee, Madison or Chicago. This dynamic still persists today, and property owners having their primary residences as far away as California and Arizona. Typical properties on the lake are valued around $1 million, and based upon interviews conducted by the authors (see below) most property owners characterize themselves as “lake stewards”. This situation different from what exists for residents in much of the surrounding region. Since the 1950s there has been steady population migration in southeastern Wisconsin out from the urban center of Milwaukee into the outlying rural communities, resulting in low density residential development in areas surrounding Lake Beulah including Waukesha, Mukwonago and East Troy (SEWRPC 2002). The population trend has resulted in increased pressure on public resources, including transportation, sanitation, and drinking water quantity and quality.

In late 2002, the Lake Beulah Management District (LBMD) learned that the Village of East Troy planned to install a high capacity well within Lake Beulah’s watershed (Figure 7). The well site was chosen by the village because a developer was creating a residential subdivision in the area and agreed to provide the necessary infrastructure to connect a new high capacity well to the village’s water system. In return, the village would annex the subdivision in accordance with their extraterritorial rights (Author interviews). This came at an opportune time for the village because the Wisconsin Department of Natural Resources (WDNR) had informed them that in order to be in compliance with state water regulations the village needed to increase their water capacity (Author interviews). The Village was also experiencing a period of population growth and had plans for new commercial development.

The LBMD, along with unaffiliated lake homeowners, worked with the village to find an alternate site for the well. Although adequate sites were found outside of Lake Beulah’s watershed, the village moved forward with plans to drill at the primary well site by submitting a high capacity well permit application, which was approved by the WDNR. This sparked a lawsuit by the LBMD filed with the Wisconsin State Supreme Court in 2011 (Lake Beulah

Management District v. DNR 2011). The LBMD argued that the WDNR had the authority under the Public Trust Doctrine to deny the high capacity well permit because the well had the potential to cause adverse environmental impacts on the lake. The Village argued that since groundwater and surface water are regulated under different statues, the WDNR did not have authority under the Public Trust Doctrine because groundwater resources are not "navigable waters". The State Supreme Court Ruled that the WDNR did have the "right and general duty" under the Public Trust Doctrine to take into account the potential adverse environmental impacts a high capacity well poses on adjacent surface waters (Lake Beulah Management District v. DNR 2011). This ruling, however, would not be retroactively imposed on the well installed by the Village. The State Supreme Court also stated that in order for the WDNR's Public Trust duties to be triggered, concrete scientific evidence of the potential adverse environmental impacts must be presented to them (Scanlan 2012).

The Lake Beulah Decision, as it is now known, set precedent in the State of Wisconsin in that it legally linked surface and groundwater resources under the Public Trust Doctrine. This decision has triggered significant ongoing debate about water governance in the state by exposing a gap between legal doctrine and scientific understanding. Behind the scenes, development and agricultural interests are pressuring the legislature to pass policies that will narrow the WDNR's authority regarding high capacity wells. Meanwhile, environmental interests are collaborating to fund and implement studies for monitoring, assessment and modeling how future wells could affect the greater watershed.

The social-ecological dynamics for the Lake Beulah LSGW system are complex and occur across multiple scales and domains. Using the Lake Beulah watershed as our focal scale, this study will utilize the threshold matrix method outlined by Kinzig et al. 2006 to examine the alternate states that could result in Lake Beulah becoming eutrophic due to groundwater reduction.

Methods

Documents pertaining to the development of southeastern Wisconsin (SEWRPC 2002, , 2006, 2010), East Troy and Lake Beulah specifically (Village of East Troy 2008, Lake Beulah Management District v. DNR, 2011), were analyzed to understand the conflict's context. The written decision given by the Wisconsin State Supreme Court provided detailed background about the conflict and the policy arena in which it played out. From these documents the scales of analysis along with a preliminary set of themes and categories were determined using an adapted version of Framework Analysis (Srivastava and Thomson 2009). Domains were determined apriori using the biophysical, economic and social domains outlined in Kinzig et al. (2006). Themes and categories, representing the different subsystems and alternative states in the Lake Beulah Social-Ecological System respectively, were then clustered by the scale and domain at which they occur.

Key stakeholder groups involved the conflict were identified from a list of parties who submitted amicus briefs to the court. Fifteen individuals were selected representing the diversity of stakeholder groups for interviews. This included consultants (3), state regulators (1) regional regulators (3), LBMD members (2), village officials (2) conservation groups (2) and residents on Lake Beulah (2). The study was approved by the University of Wisconsin-Milwaukee Institutional Review Board (IRB) in June of 2015 and interviews were conducted between July and September of that year. Interviews lasted from 30-90 minutes and were recorded for further analysis. Open-ended questions were used to cover the following topics (complete protocol in Appendix A):

- Personal account of the conflict and concerns over water resources
- Water governance in Lake Beulah, East Troy, and the State of Wisconsin
- Sources of scientific and political information pertaining to water resources in Wisconsin
- Individuals and organizations involved in water governance in Wisconsin
- State of information sharing between conflicting parties

Analysis of the interviews was conducted using the Framework Analysis (Rabiee 2004, Srivastava and Thomson 2009), a method developed in social policy studies designed to investigate policies through interviewing individuals involved with and affected by the policy itself. Framework Analysis abstracts, filters and sorts data collected through five steps. First, familiarization involves the researcher immersing themselves in the data. In this study, interview audio recordings and field notes were iteratively reviewed to create transcriptions of key sections for data extraction. Second, framework identification occurs when themes and categories emerge through the familiarization process (Richie and Spencer 1994). The preliminary set of themes and categories were used to identify a thematic framework when reviewing interview material. Themes and categories also emerged from the interviews themselves allowing them to verify and bolster the researchers' understanding of the Lake Beulah Social-Ecological System. Third, indexing requires the researcher to identify portions of the data that correspond to specific themes and categories. Fourth, the process of charting extracts the data identified in the indexing step for each interviewee and organizes them to generate a table for analysis. The results of the charting process provide a detailed analysis of how the themes and categories emerged from the data (Smith and Firth 2011; Appendix B).

Finally, mapping involves analyzing the data extracted from the previous steps to create a "schematic diagram of the phenomenon" (Srivastava and Thomson 2009).

Themes and categories identified from Framework Analysis represent the different subsystems and their alternative states present in the Lake Beulah Social-Ecological System. These subsystems and alternative states were then assigned to their appropriate scale and domain and relationships between them were hypothesized. The resulting threshold matrix, system states and linkages were reviewed and substantiated by a group of independent researchers with knowledge of the Lake Beulah system and governance conflict (Quinn Patton 2014).

The threshold matrix method depicts interactions between system states across scales and domains of a social-ecological system. These interactions are used to generate hypotheses about the cascading effects crossing a threshold has on the entire system. In this fashion, narratives describing the effects a change in state would have across scales and domains connect the alternative states generated through framework analysis. Through linking these subsystems and alternative states across scales and domains, hypotheses can be generated concerning the social-ecological system dynamics present in Lake Beulah. These dynamics can be seen as trajectories of expected change (Chapin et al. 2010) to inform proper management of LSGW systems.

Table 3: Subsystem components identified in the Lake Beulah social-ecological system with their accompanying systems states and scale of occurnace; organized by system domain.

System Domain	Sub-System	System States	System Scale
Biophysical	Surface Water	Turbid / Clear	Watershed/Community
	Aquifer	Productive / Depleted	Watershed/Community
	Water Quality	Attaining / Non-Attaining	Watershed/Community
	Hydrology	Infiltration / Runoff	Region/State
	Landscape	Natural / Human-dominated	Region/State
Economic	Housing Market	Resort / Residential	Individual/Property
	Economic Base	Recreational / Agro-industrial	Watershed/Community
	Development Mindset	Smart Growth / Suburban Sprawl	Watershed/Community
	Economy	Local / Global	Region/State
	Water Policy	Environmental / Developmental	Region/State
Social	Values	Environmental / Development	Individual/Property
	Land Ethic	Conservationist / Utilitarian	Individual/Property
	Identity	Lake People / Townspeople	Watershed/Community
	Watershed Identity	Locally Invested / Bedroom Community	Watershed/Community – Region/State
	Governance	Proactive / Reactive	Region/State

Results and Discussion

Subsystems, States and Tipping Point Dynamics

Framework Analysis revealed a total of 16 subsystems for the Lake Beulah Social-Ecological System and 2 alternative states were identified for each sub-system (Table 3). The subsystems and states were then assigned primary systems domains and system scales (Figure 7). Although most subsystems were assigned a specific scale and domain, several occurred across domains as well as both scales and domains. For example, "Land Ethic" was placed bridging the economic and social domains because both states have economic and social dimensions. Similarly, "Surface Water" connects across individual, watershed, economic and biophysical scales and domains, demonstrating that turbid conditions affect both biological integrity and property values (Kashian et al. 2006). Whether or not Lake Beulah is an attaining water body in "Water Quality" occurs across the watershed and regional scales. This depicts that water quality is not just a biophysical label; it is also dependent on the designated use of the water body that dictates its water quality criteria through the Clean Water Act.

The tipping point matrix (Figure 8A) visualizes how the state of sub-systems at one scale and domain influence across scales and domains. For example, the state of the aquifer occurs at the watershed scale in the biophysical domain. This directly influences the state of the lake's surface water and indirectly influences the state of the housing market on the lake (Kashian et al. 2006) on the individual scale in the economic domain. Narratives allow these relationships across scales and domains to be linked into dynamic loops that portray the cascading effects of a change in state on a social-ecological system. In completing the threshold matrix, researchers were able to compare the current process of protecting surface water resources in Wisconsin, evolving the Public Trust Doctrine, with proposed frameworks for water governance in the social-ecological systems literature. Close examination of the tipping point matrix shows that key dynamics can be characterized as three unique archetypes: General Conflict (Figure 8B), Adverse Threshold Cascades (Figure 8C), and Sources of Resilience (Figure 8D).

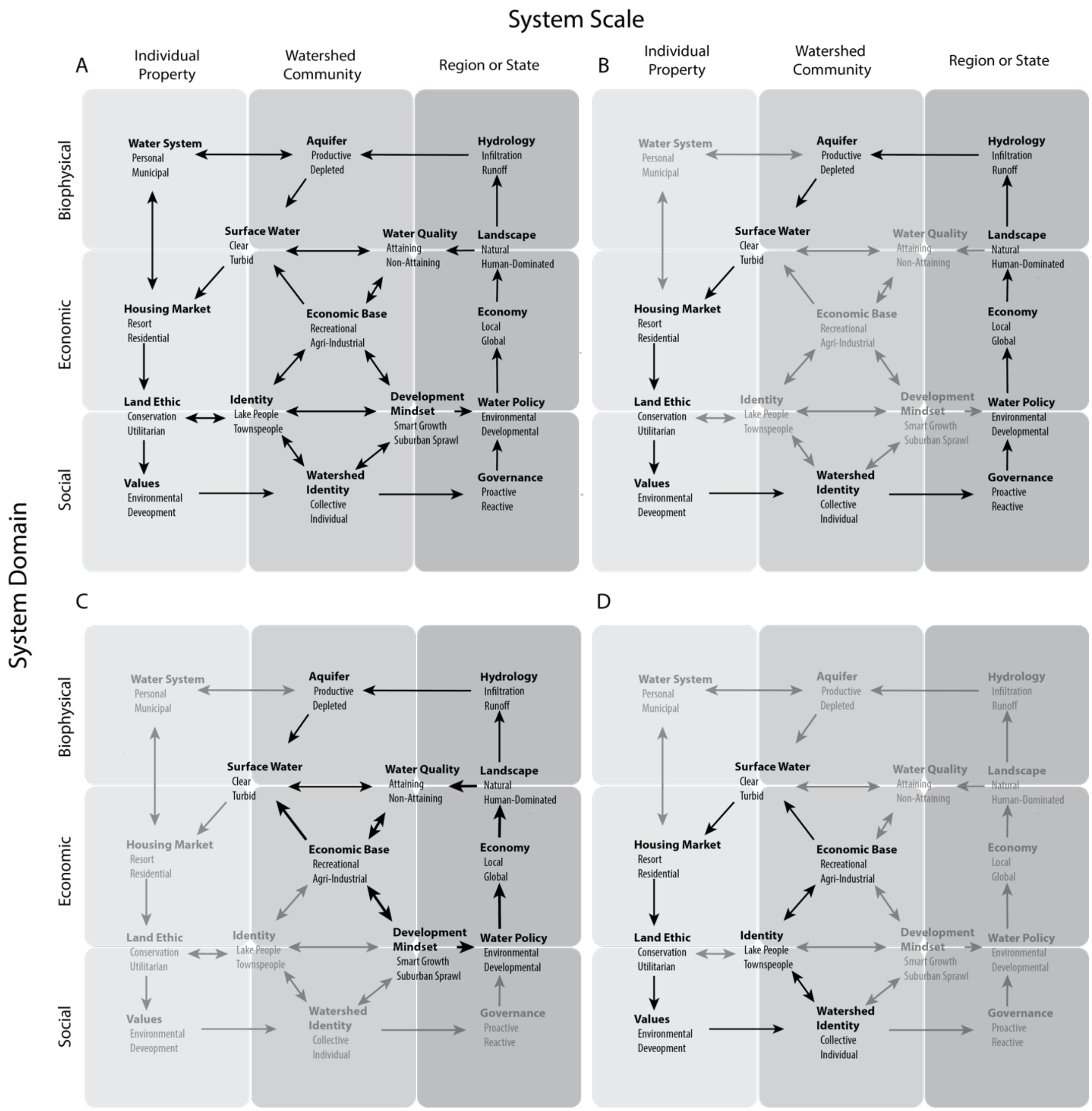

Figure 8: Depiction of narratives present in the Lake Beulah Social-Ecological System using the threshold matrix method. A) Overall systemic view of interacting thresholds hypothesized to be present in the Lake Beulah Social-Ecological System. B) Depiction of subsystems involved in the initial conflict between the LBMD and the Village of East Troy. C) Adverse cascade initiated by Lake Beulah crossing the Surface Water threshold from a clear to a turbid state. D) Source of social-ecological resilience where the lake's clear state is a reinforced by the feedback between Lake Beulah and those who identify with it.

The “General Conflict Dynamic” (Figure 8B) depicts how the conflict over LSGW resources has and continues to play out in the Lake Beulah Social-Ecological System. Water policy favoring developmental over environmental interests sets off a threshold cascade from the social and economic domains at the state scale to the biophysical. Through contributing to the global economy, a more human-dominated landscape is necessary that inherently alters the hydrology of the region. When development driven alteration of regional hydrology began to threaten the aquifer feeding Lake Beulah, concerned citizens began gathering information pertaining to adverse effects of groundwater reduction on surface waters. Upon understanding the relationships between aquifer productivity, surface water quality and property value, citizen groups and the LBMD organized collectively at the watershed scale to influence the governance process at the state scale.

The “Adverse Cascades” dynamic (Figure 8C) illustrates how current state water policies undercut local governance through changing the economic base (Stern 1993, Mavrommati et al. 2014). Lake Beulah becoming turbid through these cascades explained in the general conflict dynamic will cause the lake to become a non-attaining waterbody under the Clean Water Act and placed on the 303(d) list. With recreational activities limited because of reduced water quality other economic interests (i.e. agriculture and industry) may be able to move into the watershed to continue to generate revenue for the tax base. This shift in economic base will change the watershed’s development mindset and reinforce the need for pro-development water policies. Continued change in landuse on the regional scale could make Lake Beulah being removed from the 303(d) list very difficult and thus strengthen the agro-industrial economic base.

A “Source of Resilience” dynamic was identified for the Lake Beulah Social-Ecological System at the individual and watershed scale (Figure 8D). The main concern of property owners is the state of the lake, which translates into a conservationist land ethic. Homeowners, both whose families have lived on Lake Beulah for generations and who have recently bought property, have a feeling of stewardship towards the lake informed by their environmental values. These individual environmental values scale up to generate a collective watershed identity around Lake Beulah. When issues like the high capacity well come up, the collective watershed identity sets Lake Beulah apart from Village of East Troy. When in the “Lake People” state, stewardship of the lake is the driving force to attain intended uses, namely recreation (Thornton et al. 2013a). As long as the people of Lake Beulah center their identity around the lake, a recreational economic base should persist that will result in “Clear” and “Resort” Surface Water and Housing Market states respectively.

System Dynamics and LSGW Governance

In both the adverse cascade and source of resilience dynamics the economic base factor plays a central role and results in alternative states of the Lake Beulah Social-Ecological System. This is a problem because there is currently no space for local governance and pro-development water policies are limiting the power of the WDNR in terms of high capacity well permitting and its effects on adjacent surface waters (Bergquist 2014, 2016b). Although the Lake Beulah Decision gives the WDNR authority to take high capacity well impacts on surface waters into consideration, the decision does not give the WDNR a specific process to evaluate these types of impacts (Author interview). Opponents to increased high capacity well regulations do not want a process to be developed because it would give the WDNR a standard method to exercise their authority, which does not currently exist. Agricultural and development interests would rather see the ruling over turned than adjust to more stringent environmental regulations (Richmond 2016). These interest groups then use their political capital to influence State Legislators and limit the WDNR's authority, a well-established practice in the realm of the Public Trust Doctrine (Scanlan 2000, 2012).

Since the Lake Beulah Decision, residents of Lake Beulah have moved on from trying to influence LSGW governance on the property and watershed scales. Instead, the LBMD has focused its efforts on obtaining the power to set lake levels, limit installation of piers in ecologically sensitive areas and preventing the spread of invasive species. Their environmental values pertain to the ecological integrity of Lake Beulah first and foremost. Communication and coordination between Lake Beulah and other organizations in the region has been described as "not that tight" (Author Interviews), and connections to other areas of the state is even less so. Lake Beulah residents will likely become involved in LSGW governance again, but only when the integrity of Lake Beulah is directly at risk. This hesitation to engage in overall LSGW governance is a barrier to both collective action and social learning. Reason for this is the process that communities utilize to protect their surface water resources: evolution of the Public Trust Doctrine.

Evolution of the Public Trust Doctrine occurs through the court system. The process occurs when beneficiaries, members of the public, believe the WDNR has either overreached or ignored their authority as trustee over waters of the state (Quick 1994). The judge's ruling either expands or constricts the definition of resources held in public trust. Case law shows that over time the definition of water resources held in public trust has consistently expanded

(Quick 1994, Scanlan 2000). On the other hand, Scanlan's 2000 and 2012 papers examining the implementation of the Public Trust Doctrine in Wisconsin show that enforcement is a political process. The Secretary of the WDNR, being an appointee of the governor, exposes the department's mission to political sovereignty. When resolving conflicts over LSGW resources, utilizing the courts to expand the Public Trust Doctrine does not address the underlying issue of political instability in the WDNR. Currently, the WDNR is the only agency with authority to make decisions under the Public Trust Doctrine (Scanlan 2012). Reliance on this centralized water policy is not enough to ensure the integrity of LSGW resources.

There are numerous frameworks available to implement decentralized and adaptive water governance (Pahl-Wostl et al. 2010, Knüppe and Pahl-Wostl 2011, Stein et al. 2011, Rockström et al. 2014). Pahl-Wostl et al. 2010 outlines the Management and Transition Framework, which is designed to analyze the current water governance system and aid in the transformation to more adaptive water governance. This requires a systemic perspective of water resources governance, a step that has not yet been taken in Wisconsin (Bergquist 2016b). The Lake Beulah case may link surface and groundwater resources under the Public Trust Doctrine, but it does not address underlying issues like the politicization of the WDNR (Scanlan 2000) and the amplifying feedback between development and water demand (Arnold et al. 2011). The incremental nature of evolution the Public Trust Doctrine cannot address these underlying issues because they do not fall under its jurisdiction.

Leverage Points and Adaptive Governance

In order to provide a systemic perspective of LSGW resources governance, one size fits all policies need to become more adaptable to case specific circumstances (Ostrom 1990, Dietz et al. 2003, Chapin et al. 2009). Garmestani and Benson 2013 discuss the prospect of resilience-based governance of social-ecological systems through applying reflexive law to address complex issues that result in environmental conflict. Reflexive law stresses the development of a procedural process to resolve environmental issues instead of a complex set of rules to govern a resource (Orts 1995). This would call for key actors at the appropriate scale to solve LSGW conflicts by adapting state law to fit the problem. The Lake Beulah decision accomplished the exact opposite, it created more rules at the state scale without developing a process to enforce them.

Proper governance of LSGW resources calls for the integration of social processes with environmental law and the use of multiple methods to resolve environmental conflicts (Arnold et al. 2011, Craig Arnold 2013). Integrationist and multimodal forms of governance are seen as the most appropriate way to address the complex problems occurring across the scales and domains of social-ecological systems (Arnold et al. 2011). In order to resolve LSGW conflicts within this new generation of environmental governance, many changes have to be made outside of the legal system. These changes include: a better understanding of the biophysical system under conflict (Ostrom 1990, 2009, Folke 2006) linking key actors across individual conflicts and scales to coordinate action and promote social learning (Pahl-Wostl et al. 2008, Bodin and Crona 2009, Ernstson et al. 2010, Newig et al. 2010, Stein et al. 2011) and addressing the perception gap (Slovic et al. 1982, Morehouse et al. 2010, Braman et al. 2011, Ropeik 2012) to generate consensus between parties in LSGW conflicts.

Understanding the boundaries and limits to resource use is necessary for the proper governance of social-ecological systems (Ostrom 2009). In order to make informed decisions regarding LSGW resources, knowledge to the effects to both surface water quantity and quality are necessary. This type of knowledge is highly context dependent, making simple statewide policies ill-fitting for effective governance of LSGW resources. For example Lake Beulah is a marl lake, a rare type of lake defined by high calcium concentrations due to regional geology and dependence on groundwater input (Wiik 2012). Marl lakes in southeastern Wisconsin have been shown to be able to withstand twice the amount of nutrient loading than non-marl lakes (Robertson et al. 2007) because calcium co-precipitates with phosphorus out of the water column (Otsuki and Wetzel 1972). What is not known is how reducing groundwater input through pumping might affect this relationship. In order to properly govern this resource, the threshold between pumping and lake water quality needs to be identified.

Furthermore, communication and collaboration across scales, domains and cases is necessary for collective action (Ostrom 1990, Anderies et al. 2004, Bodin et al. 2006, Brondizio et al. 2009, Ernstson et al. 2010, Stein et al. 2011) and social learning (Kilvington 2005, Pahl-Wostl et al. 2008, Newig et al. 2010). Sendzimir et al. 2008 highlight the importance of having a network of scientists, politicians and stakeholders to influence the policy process and promote a paradigm shift in water governance. Including a community or stakeholder platform (Halbe et al. 2013) in LSGW governance can provide an opportunity for participation and social learning through repeated interaction of parties involved. This will require the creation of networks that span the scales and domains of LSGW conflicts. Successful networks will utilize cross scale brokers (Ernstson et al. 2010) to coordinate efforts and share information across the state. In terms of Lake Beulah, the LBMD handled the high capacity well case with little to no help from the others in the Mukwonago River Basin (Interviewee 73). To transform water governance away from sole reliance on the Public Trust, lake managers and other water stewards need to act collectively to influence policy and protect their interests (Olsson et al. 2007, Ernstson et al. 2010).

Lastly, more research needs to be done on the role of risk perception in LSGW utilization. Risk perception research has started to pick up in studies that generate consensus about threats brought on by global climate change (Braman et al. 2011, Cardona et al. 2012, Ropeik 2012). Conflict over LSGW utilization, like global climate change, is not solely about the science of surface-groundwater interaction; it also involves what society deems as “dangerous” (Leiserowitz 2005, Lorenzoni et al. 2005). These differences in perception cause conflict between environmental and development interests time after time. Development of a risk perception index for LSGW resource use can frame the conversation to generate consensus between stakeholders on the issue.

Conclusions

The Lake Beulah Social Ecological System was analyzed to grasp the underlying cause of conflict over LSGW resources in Wisconsin. The threshold matrix identified multiple interacting dynamics that explain both the current situation and the theoretical trajectories of expected change. The result illustrates how actions at the state level can reinforce the paradigm of developing new areas to the detriment of groundwater dependent ecosystems. The perceived risk of environmental damage to a surface water triggers action from the community leading to LSGW conflict. This conflict was legally resolved in the courts, and the outcome set legal precedent and influenced water policy, but thereby creates another problem.

Once conflicts are legally resolved, communities shift their focus to different problems while development interests continue to lobby for pro-development water policies. This results in different communities engaging in conflict with the same development interests to further define the Public Trust Doctrine. Communities with groundwater dependent ecosystems lack communication and coordination to effectively influence the policy process. The current method of resolving disputes over water rights through evolving the Public Trust Doctrine does not fit with the current paradigm of water governance in the state. The process leaves communities vulnerable when their surface waters are threatened by LSGW utilization.

Sustainable governance of LSGW resources calls for the Public Trust Doctrine to be integrated with a governance process to resolve future conflicts. In order for this to be successful, communities must gather knowledge about the vulnerabilities that their water resources face in terms of shallow groundwater utilization. Watershed and community organizations need to engage with stakeholders across conflicts, scales and domains to proactively influence LSGW governance statewide. Generating consensus over the risks involved in LSGW utilization through the use of a risk perception index can provide a starting point for facilitation between environmental and development interests. The call for more participatory governance of LSGW resources in Wisconsin has become more pressing in recent months with the State's Attorney General limiting the authority of the WDNR concerning the cumulative impacts of high capacity wells on a surface water during the permitting process (Bergquist 2016a).

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Appendix A: Interview Protocol

Operationalizing Resilience in the Face of Water Conflict: Linking Social and Ecological Systems
Focus Group and Interview Protocol

Listening sessions and interviews will be open-ended. Because of this, we can only list initial prompts; follow-up questions will differ depending on responses.

Participants will each sign a waiver.

Background/Introduction

- We're getting to know the Lake Beulah / East Troy community and local organizations over the next several weeks to learn about how decisions concerning water resources are made in the area.
- (For interviews): I was referred to you by…because of your work with…

Questions/Prompts:

- What is your view of the situation between Lake Beulah and East Troy?
- Presently, what are your concerns over water resources in Lake Beulah or East Troy?
    - Have your concerns changed since the well was first proposed?
- How are decisions made concerning water resources in the Lake Beulah Watershed OR Village of East Troy?
- Who are the people/organizations involved?
    - Who do you think should be involved that is not currently?
- What information sources do you use when making decisions concerning water resources?
- What is the present state of information sharing between the Village and Lake Beulah?
    - Should the Village consult Lake Beulah when making water resource decisions and in what capacity?
    - Are any of these organizations outside of Lake Beulah and East Troy that have influence on decision making?
- Can you recommend anyone else we should talk to?

Overarching Research Questions:

- What is the structure of the Lake Beulah SES's institutional network and how does information flow through it?
- How are decisions made concerning water resources in both Lake Beulah and East Troy?
- Does the level of information sharing between Lake Beulah and East Troy allow for collaboration in times of abrupt change?
- What value systems are present in the Lake Beulah SES and how can they be implemented into (reflected in) the decision making process?

- What are the management paradigms present in the Lake Beulah SES and how do they compare to the dominant paradigm in the State of Wisconsin?

Appendix B: Example of Framework Analysis data extraction method

Interviewee 72	Description	Summary	Theme/Subsystem(s)	Category/System states
The DNR wanted the village to have sufficient capacity in reserve for things as fire. Which is funny because they had a huge building burn down. It was the DNR pushing them and I think they wanted to put in another well to so they didn't push back.	The **DNR wanted the village to have sufficient capacity** in reserve for things as fire. It was the DNR pushing them and **I think they wanted to put in another well to so they didn't push back.**	The DNR wanted to increase capacity for safety reasons because East Troy had been developing so quickly. This individual thinks the village wanted to put in another in order to continue to grow and used the capacity issue as a reason to do so.	1) Development Mindset	1) Smart Growth Suburban Sprawl
Almost every member of the management district is a member at the Lake Beulah Yacht Club. Its more than sailors it's social too and they're very good stewards of the Lake. There's probably 150 members of the lake and the money is there too so that probably helps.	...they're very **good stewards of the Lake**.. There's propbably **150 members** of the lake and the **money is there too so that probably helps**	The Lake Beulah Yacht Club provides a meeting place for many of the important political players on Lake Beulah and helps them coordinate their actions.	1) Watershed Identity 2) Land Ethic	1) Collective Individual 2) Conservation Utilization
It really counts on the people living on the lake. If they like the lake respect it take ownership that's what you really need	It really **counts on the people** If they **like the lake,respect it, take ownership** that's what you really **need**	The people living on/using the lake determines response to threats to the lake. Good stewards are necessary to keep the lake clean.	1) Watershed Identity 2) Identity 3) Land Ethic	1) Collective Individual 2) Lake People Townspeople 3) Conservation Utilization
When they first started thinking about putting it in no one thought much about it, but then a few people started talking saying "hey we have a similar situation down here in Illinois and it really wrecked the wells there and really wreaked havoc."	**then a few people started talking** we have a similar situation ... and it **really wrecked the wells** there and really **wreaked havoc**	Landowners drew from past experiences to get others involved with well issue. They also experienced the effects of down on other wells and on surface waters.	1) Watershed Identity 2) Aquifer 3) Water system	1) Collective Individual 2) Productive Depleted 3) Personal Municipal
The taxes of course are based on the value of the property and the properties along here probably go for about a million dollars and that's and the taxes around here are about 20 to 30 thousand dollars a year and you see you pump that kind of money in you got to be serious about it and that's the way it is. The village on the other hand a house might be 150 thousand and the taxes might be 3 thousand a year. So your interests are going to be different than if you live on the lake. One is not good or bad theyre just different.	the **properties** along here probably **go for about a million dollars** ... you pump that kind of money in **you got to be serious about it**.. The village on the other hand a house might be 150 thousand **your interests are going to be different than if you live on the lake**	Properties along Lake Beulah's shores are expensive where properties in the village and town are not. The economic investment in property justifies activist behavior to protect Lake Beulah's water quality and ,therefore, their investment. This, in the interviewee's opinion is the basis for the different interests between the lake and the town/village.	1) Housing Market 2) Watershed Identity 3) Identity	1) Resort Residential 2) Collective Individual 3) Lake People Townspeople
The lake is pretty stable and for a lot of folks it's a second home… we have a home in Arizona and a lot of people have other homes in Florida.	**The lake is pretty stable** and for a lot of folks **it's a second home**	Because the lake remains in a clear state, people invest in second homes on Lake Beulah to spend their summers	1) Surface Water 2)Housing Market 3) Economic Base	1) Clear Turbid 2) Resort Residential 3) Recreational Agri-Industrial

Chapter 3: Opportunities and barriers to collaborative adaptive governance: the case of linked surface-groundwater resources

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Abstract

Conflicts over linked surface-groundwater resources (LSGR) present considerable challenges to the governance frameworks surrounding water in the United States. The legal system's focus on stability and conservation of water based on previous conditions has reinforced the continued management of surface and groundwater as separate resources. This separation has created independent institutions that require a new scale of collaborative adaptive governance to manage LSGR. Identifying the opportunities and barriers to this collaborative adaptive governance is necessary to institutionalize practices that lead to sustainable resource use. To understand how this new scale of governance can emerge, Panarchy theory was applied to a conflict over LSGR between the Lake Beulah Management District and Village of East Troy in southeastern Wisconsin. Panarchy theory was applied as a lens to water governance questions due to its emphasis on historical context, management paradigms and cross-scale interactions. Analysis of local, regional and state development placed Lake Beulah and East Troy in their historical contexts and identified past management paradigms that influence current decision-

making. Cross-scale interactions outlined crises, opportunities and barriers to the emergence of adaptive governance in the new social-ecological system. We found that the current crisis was catalyzed by an attempt to revert to a previous management paradigm where power is conserved at the state scale. Perceived opportunities for collaborative adaptive governance in Lake Beulah and East Troy are centered on current conditions while operational barriers are rooted in social-ecological system development. The findings in this study emphasize the importance of historical analysis in framing options for resolving LSGR conflicts and that the barriers to collaborative adaptive governance need to be addressed before opportunities are seized.

Keywords: Social-Ecological Systems, Resilience, Cross-Scale Interactions, Conflict, Panarchy

Introduction

Laws and regulations neglecting the biophysical connection between surface and groundwater have led to conflict over water resource use (Hoffman and Zellmer, 2013; Lund, 2015; Megdal et al., 2015). Attempts to link these resources under a single legal framework have been difficult due to the different ecosystem goods and services historically provided to stakeholders. Matters become even more complex when conflicts involve governmental bodies that have overlapping political and ecological boundaries (Galaz et al., 2006; Garmestani et al., 2009; Thompson, 2011). In the State of Wisconsin, lake management districts have taxing and zoning authority within their watershed; allowing them to make decisions to protect the ecological integrity of their surface water resources (Lyden et al., 2006). Municipalities must remain in compliance with drinking water standards for water quality and quantity, forcing them to rely on their annexing power to gain access to new sources of water in times of rapid growth and development.

These circumstances call for collaboration and adaptive governance among governmental units to deliver the ecosystems goods and services provided by linked surface-groundwater resources (LSGR) in times of hydrologic uncertainty (Green et al., 2015). Applying a Panarchy lens places conflicting systems in their historical context and allows for the analysis of cross-scale interactions to identify opportunities and barriers to collaborative adaptive governance (Chaffin and Gunderson, 2016; F. S. I. Chapin et al., 2009; Gunderson and Holling, 2002). This method has been used to identify new water governance boundaries (Rockström et al., 2014), making it especially useful when new scales of governance emerge after the collision of two social-ecological systems.

This paper applies Panarchy theory to a conflict between the Lake Beulah Management District and Village of East Troy Wisconsin involving a high capacity well. Using document analysis and the recounting local, regional and state development, both governance systems were placed in their historical contexts. This allowed for the characterization of the management decision paradigms used leading to conflict. Analysis of legal proceedings and newspaper articles combined with stakeholder interviews outlined cross-scale interactions affecting the Lake Beulah / East Troy Social-Ecological System (LB/ET SES). These cross-scale interactions point to opportunities as well as barriers for the emergence of collaborative adaptive governance.

Collaborative Adaptive Governance

Collaborative adaptive governance draws from the literature of adaptive governance (Folke et al. 2005), adaptive co-management (Carlsson and Berkes 2005) and adaptive capacity (Armitage 2005). It is concerned with the social dimensions of ecosystem management including power dynamics (Lemos and Argawal 2005; Armitage 2005), social capital (Brondizio et al. 2009) and institutional fit (Galaz et al. 2008). A collaborative adaptive governance regime can be defined as a governance system involving state, market and community actors with: multiple centers of power (Lemos and Argawal 2005), open lines of communication (Folke et al 2005), shared decision-making authority (Carlsson and Berkes 2005), and legitimacy from a higher-level authority (Ostrom 1990). These governance attributes inform the identification of opportunities and barriers to collaborative adaptive governance in the LB/ET SES.

Adaptive Cycles and Panarchy

Panarchy theory grew out from the adaptive cycle framework (Figure 9) which has its roots in the field of ecology (F. S. I. Chapin et al., 2009; Gunderson and Holling, 2002; Walker and Salt, 2012). The adaptive cycle has become key to understanding the dynamics of complex social-ecological systems (Berkes et al., 2000; F. S. I. Chapin et al., 2009) as they transition through phases of growth, conservation, release and renewal. System identity is formed and reinforced in the growth and conservation phases (Gunderson and Holling, 2002). When management paradigms take hold, they function to maintain the attributes of a resource system that produce predictable patterns of use. This conservation of predictable patterns makes the social-ecological system vulnerable to disturbance, increasing the probability of initiating the phases of release and renewal (F. S. Chapin et al., 2009). During the release and renewal phases, the complexity of the system is greatly reduced and can either regenerate into a similar state or transform to a new one. The theme of systems changing over time highlights the importance of historical context when governing a social-ecological system (Chaffin and Gunderson, 2016).

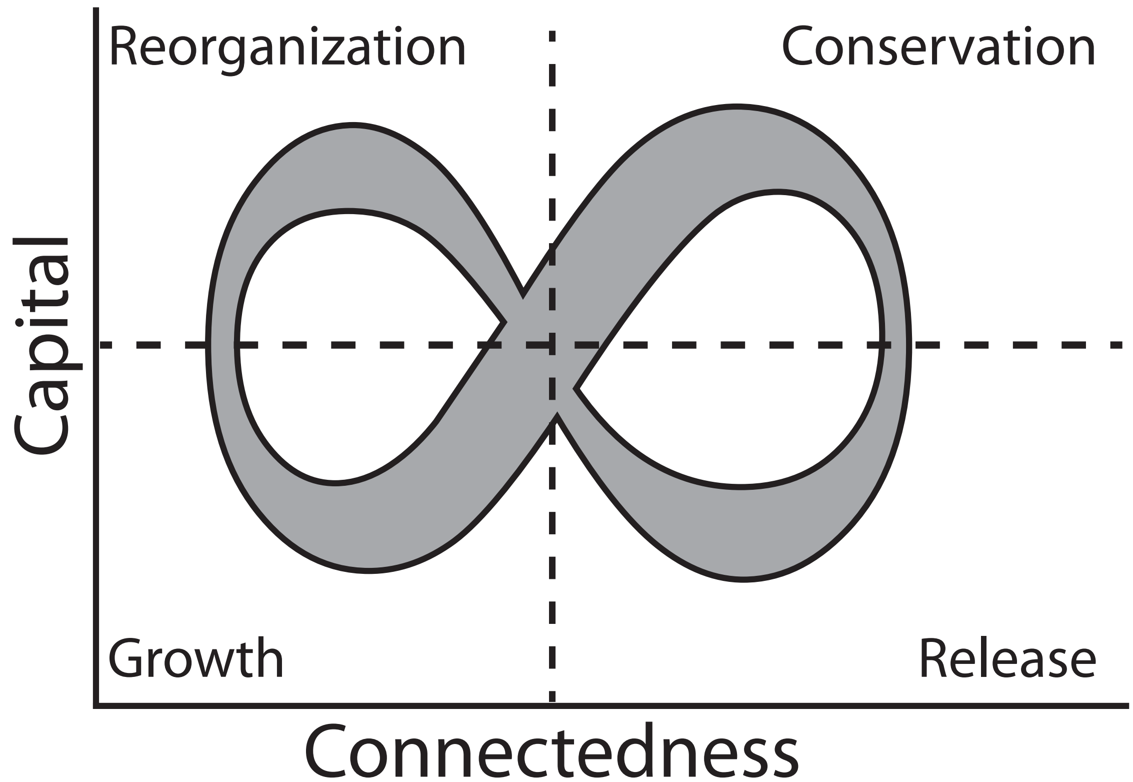

Figure 9: Adaptive cycle heuristic with phases of growth, conservation, release and reorganization.

Panarchy theory recognizes that the system of interest is not isolated but subject to influences from scales above and below it (Walker and Salt, 2012). Cross-scale interactions can initiate the release and direct the reorganization phases of an adaptive cycle, making interactions above and below the focal scale central to understanding the past and future development of social-ecological systems (Walker et al., 2004). Interactions up from the smaller scale tend to promote transformation of the system to a new state during the reorganization phase, while larger scale interactions from above promote reestablishment of the current state (Chaffin and Gunderson, 2016; Garmestani and Benson, 2013). As will be described in more detail in the next section, the LB/ET SES was produced from the collision of two separate social-ecological systems on different development paths resulting in the need for LSGR governance to transform to a novel scale.

Study context: The Lake Beulah – East Troy Social-Ecological System

Lake Beulah is a flow through marl lake in northeastern Walworth County, Wisconsin (Figure 10). The lake is part of the Mukwonago River Basin, one of the most biologically diverse and highest quality riverine ecosystems in the state (SEWRPC, 2010; Thornton et al., 2013). Located at the southern edge of the Wisconsin glaciation, subsurface soils in the region are predominantly well-sorted glacial outwash, allowing water to recharge the shallow aquifer and reduce surface runoff. As such, ample groundwater input from springs contributes to high aquatic ecological integrity of the lake and river system. In the mid 19th century, a dam was placed at the downstream discharge of Lake Beulah to raise water levels and increase developable shoreline property for building vacation homes for families traveling from regional urban centers. The majority of property owners on Lake Beulah today continue to have their primary residences out of state. Property values on the lake average around $1 million, and most property owners characterize themselves as “lake stewards” (McGuire and Ehlinger in review).

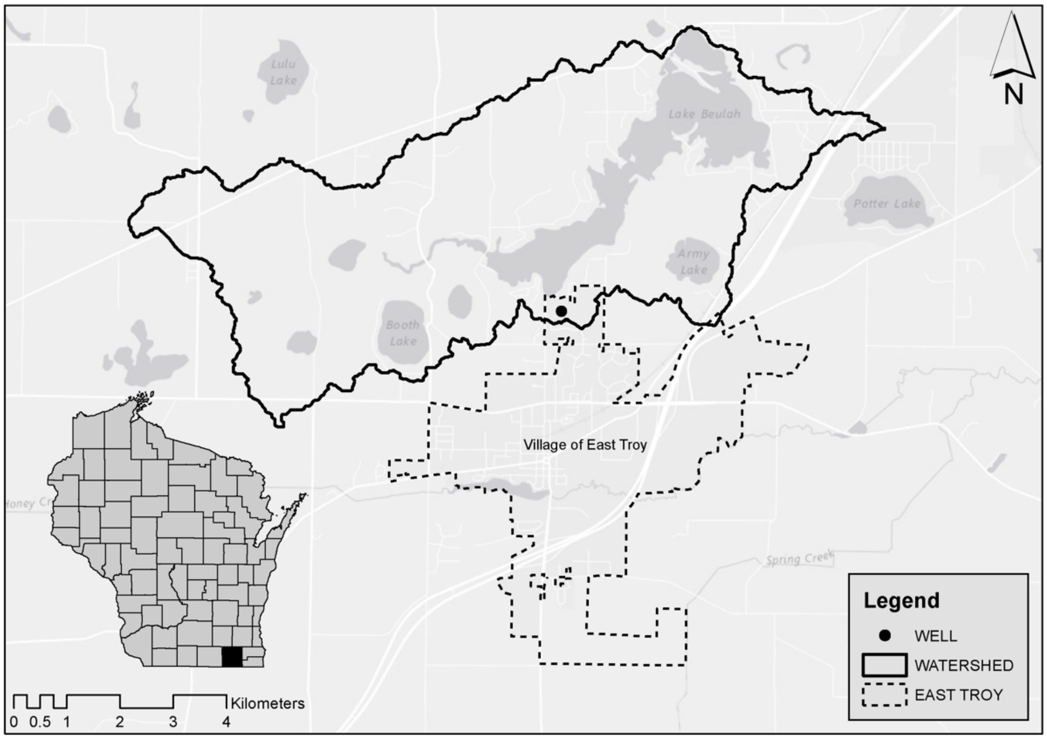

Figure 10: The Lake Beulah – East Troy Social Ecological System consists of the watershed boundary of Lake Beulah and the political boundary of the Village of East Troy.

In stark contrast, working and middle class families inhabit the Village of East Troy (Village of East Troy, 2008) just south of and adjacent to the Lake Beulah watershed; many of whom commute daily more than 30 miles to the City of Milwaukee for work. Recognized as a village in 1900 by the State Legislature, East Troy exhibited of slow or suspended growth for most of the 20th century due to its distance from urban centers. Although the period from the 1950s to the 1980s saw steady population migrations into the region (SEWRPC, 2002), it was not until the late 1980s when Interstate 43 was built through Walworth County that East Troy experienced a noticeable spike in growth (“I-43 changes face of Walworth County,” 1993) . The population trend resulted in increased pressure on public resources, which was manifested in 2002 when the Wisconsin Department of Natural Resources (WDNR) found East Troy out of compliance with state regulations for drinking water quantity (Author Interviews).

The compliance problem was addressed initially when a developer creating a residential subdivision in the area agreed to provide the necessary infrastructure to connect a new high capacity well to the village’s water system. In exchange, East Troy would annex the subdivision in accordance with their extraterritorial rights. However, when the residents on Lake Beulah learned of this, they organized a study to locate an alternate well site for the Village. Although satisfactory sites were found, East Troy proceeded with their original plan to drill at the primary site and submitted a high capacity well permit application, which was approved by the WDNR. A lawsuit ensued with the LBMD filing with the Wisconsin State Supreme Court in 2011 (Kobza, 2011). The LBMD argued the WDNR had authority under the Public Trust Doctrine to deny the high capacity well permit because of the well’s potential to cause adverse environmental impacts on the lake. East Troy argued that since groundwater and surface water are regulated under different statues, authority under the Public Trust Doctrine does not apply because groundwater resources are not “navigable waters”. The State Supreme Court Ruled that the WDNR did have the “right and general duty” under the Public Trust Doctrine to take into account the potential adverse environmental impacts a high capacity well poses on adjacent surface waters (Lake Beulah Management District v. DNR, 2011). This ruling, however, would not be retroactively imposed on the well installed by East Troy. The State Supreme Court also stated that in order for the WDNR’s Public Trust duties to be triggered, concrete scientific evidence of the potential adverse environmental impacts must be presented to them (Scanlan 2012).

The Lake Beulah Decision, as it is now known, set precedent in the State of Wisconsin by legally linking surface and groundwater resources under the Public Trust Doctrine. This decision has triggered significant ongoing debate about water governance in the state by exposing a gap between legal doctrine and scientific understanding (Bence, 2014; Bergquist, 2014; Hall, 2013). However, not much has changed with regards to LSGW governance at the scale of the conflict. The LBMD and East Troy share monitoring well and pumping data, but no rules of use or limits have been set. Meanwhile, development and agricultural interests continue to lobby the state legislature to pass regulations that will narrow the WDNR’s authority to regulate high capacity wells (Johnson, 2017). The State’s Attorney General also issued an opinion in May of 2016 that the WDNR does not have the authority to account for the cumulative impacts of high capacity wells on surface waters, rolling back a court decision from 2014 that was built on the Beulah Decision (Wis. Att'y Gen. 01 2016). The WDNR quickly responded by stating they will no longer be assessing cumulative impacts in accordance with the Attorney General's opinion (Verburg, 2016).

Factors influencing the emergence of collaborative adaptive governance in the LB/ET SES are complex and occur across multiple scales. Using the joined Lake Beulah watershed and Village of East Troy boundary as our focal scale, this study will utilize Panarchy theory to place the conflict in its historical context and identify cross scale interactions that appear as opportunities and barriers to the emergence of adaptive governance in the LB/ET SES.

Methods

Documents addressing local to statewide history and development were analyzed to understand the establishment, management paradigms and status of Lake Beulah, East Troy and LSGR governance in Wisconsin. These sources included documentation of local, regional and state history (Buenker, n.d.; ETAHS, n.d.; Gurda, 1999; LBPIA, n.d.; Wells, 1976) village smart growth plan (Village of East Troy, 2008), regional planning documents (SEWRPC, 2010, 2002), newspaper articles ("I-43 changes face of Walworth County," 1993), legal abstracts (Kobza, 2011) and court rulings (Lake Beulah Management District v. DNR, 2011). From these documents, dates of critical events were identified and management paradigms were defined. The effects of these events on the greater social-ecological system were used to inform their placement on the adaptive cycle. Information gathered from documents concerning the state of LSGR resources were analyzed using an adapted form of Framework Analysis.

Key stakeholder groups were identified from a list of parties who submitted amicus briefs in the Lake Beulah v. DNR case. Analysis of interview data was conducted using a modified version of the Framework Analysis Method (Smith and Firth, 2011; Srivastava and Thomson, 2009), which employs interviews of individuals directly involved with and affected by the given policy. Data gathered using the Framework Analysis identified state and local scale crises, opportunities and barriers for the emergence of adaptive LSGR governance in Lake Beulah and East Troy. Analysis of cross-scale interactions in the LB/ET SES required a priori identification of scales and categories or data organization., which was the only modification from the original method (Smith and Firth, 2011; Srivastava and Thomson, 2009). Interviewees consisted of consultants (3), state regulators (1), regional regulators (3), LBMD members (2), village officials (2), conservation groups (2), and residents on Lake Beulah (2). A more detailed presentation of the interview and analysis method are available in McGuire and Ehlinger (2017, Accepted and in revision).

Results and Discussion

Historical Analysis

Historical analysis of both Lake Beulah and East Troy identified a total of 18 major events and 6 management paradigms (Table 4, Figure 11). Both SESs had an initial management paradigm of “Settlement & Agriculture” marked by the signing of a treaty with multiple native nations for the area containing Walworth County in 1833 (ETAHS, n.d.; LBPIA, n.d.). Divergence into separate SESs of Lake Beulah and East Troy began in 1882 when the Hotel Beulah was constructed (LBPIA, n.d.). Intended for wealthy Chicagoans to vacation during the summer months, multiple hotels and summer homes began to appear and the “Recreational Development” paradigm arrived in 1894. In 1900 the State Legislature officially recognized the Village of East Troy initiating the “Slow Growth & Development” paradigm. These would remain the dominant management paradigms until the latter half of the 20th century

Table 4: Management paradigms and major historical events in Lake Beulah and East Troy. The event numbers used in figure 11 reference those found in this table.

East Troy					Lake Beulah				
Management Paradigm (Time Period)	Event No.	Event	Effect	Scale	Management Paradigm (Time Period)	Event No.	Event	Effect	Scale
Settlement and Development (1833 - 1950)	1	Treaty with Natives (1833)	Allowed for recognized settlement and governance of Euro-Americans	Region / State	Settlement and Agriculture (1833 - 1882)	1	Treaty with Natives (1833)	Allowed for recognized settlement and governance of Euro-Americans	State / Region
	2	Walworth Becomes County (1838)	Formalizes county and town boundaries in Walworth	Region / State		2	Dam installed at Outlet on Lake Beulah (1838-1845)	Saw mill installed at dam and threshing machine helped build an agrarian economy around Lake Beulah	Lake Beulah
	3	Towns of Troy and East Troy Split (1843)	Size of town proved to be an inconvenience for holding public meetings. Separation allowed East Troy to develop around its budding central village	East Troy		3	First Hotel Built on the shores of Lake Beulah (1882)	Hotels brought vacationers from Chicago to the area changing demographics during the growing season	Lake Beulah
Slow Growth and Development (1900 - 1988)	4	East Troy Becomes Village (1900)	Distinguished interests between village and town of East Troy	East Troy	Recreational Development (1894 - 1974)	4	Water level set by State Legislature and LBPIA founded(1894)	Conflict between farmers and vacationers forced the State Legislature to set the water level of Lake Beulah in favor of recreation. LBPIA was established to ensure recreational development and navigability on Lake Beulah	Lake Beulah
	5	East Troy Reoganized School District Established (1952)	Agreement between 21 individual schools; early sign of greater development to come	East Troy		5	Annual LBPIA meetings resume (1947)	After World Wars I and II the LBPIA resumed their annual meetings to address reccurant issues surrounding infrastrucutre maintanence and navigability	Lake Beulah
	6	Sprawling Development Outside Milwaukee (1970's)	Milwaukee had negative population growth while surrounding counties experience rapid growth rates	Region / State		6	Clean Water Act (1972)	National policy calling for the protection and restoration of phyiscial, chemical and biological integrity of surface water resources	National
Rapid Growth and Development (1988 - 2011)	7	Interstate Highway 43 goes through Walworth County (1988)	The interstate connected the Village to Milwaukee, now only a half hour drive away. This turned the Village of East Troy into an "exurb" sparking continued growth.	Region / State	Stewardship and Protection (1974 - 2011)	7	Establishment of Lake Management Districts (1974)	Provided state recognized self governance of watersheds for surface water protection and rehabilitation	State / Region
	8	East Troy Applies for High Capcity Well #7 (2002)	Being out of compliance for water supply, annexation of a subdivision within Lake Beulah's watershed gave the Village an opportunity to continue to growth. This sparked the conflict between the Village and Lake Beulah.	Lake Beulah / East Troy		8	Lake Beulah responds to East Troy well (2003)	The LBMD and LBPIA fund a study finding that the well would reverse the flow of water. This initiates the conflict between Lake Beulah and East Troy	Lake Beulah-East Troy
	9	Lake Beulah State Supreme Court Decision (2011)	Ruling gives the DNR authority to account for a high capacity well's affect on an adjacent surface water thus, linking surface and groundwater resources under the Public Trust Doctrine	Lake Beulah-East Troy State / Region		9	Lake Beulah State Supreme Court Decision (2011)	Ruling gives the DNR authority to account for a high capacity well's affect on an adjacent surface water thus, linking surface and groundwater resources under the Public Trust Doctrine	Lake Beulah-East Troy State / Region

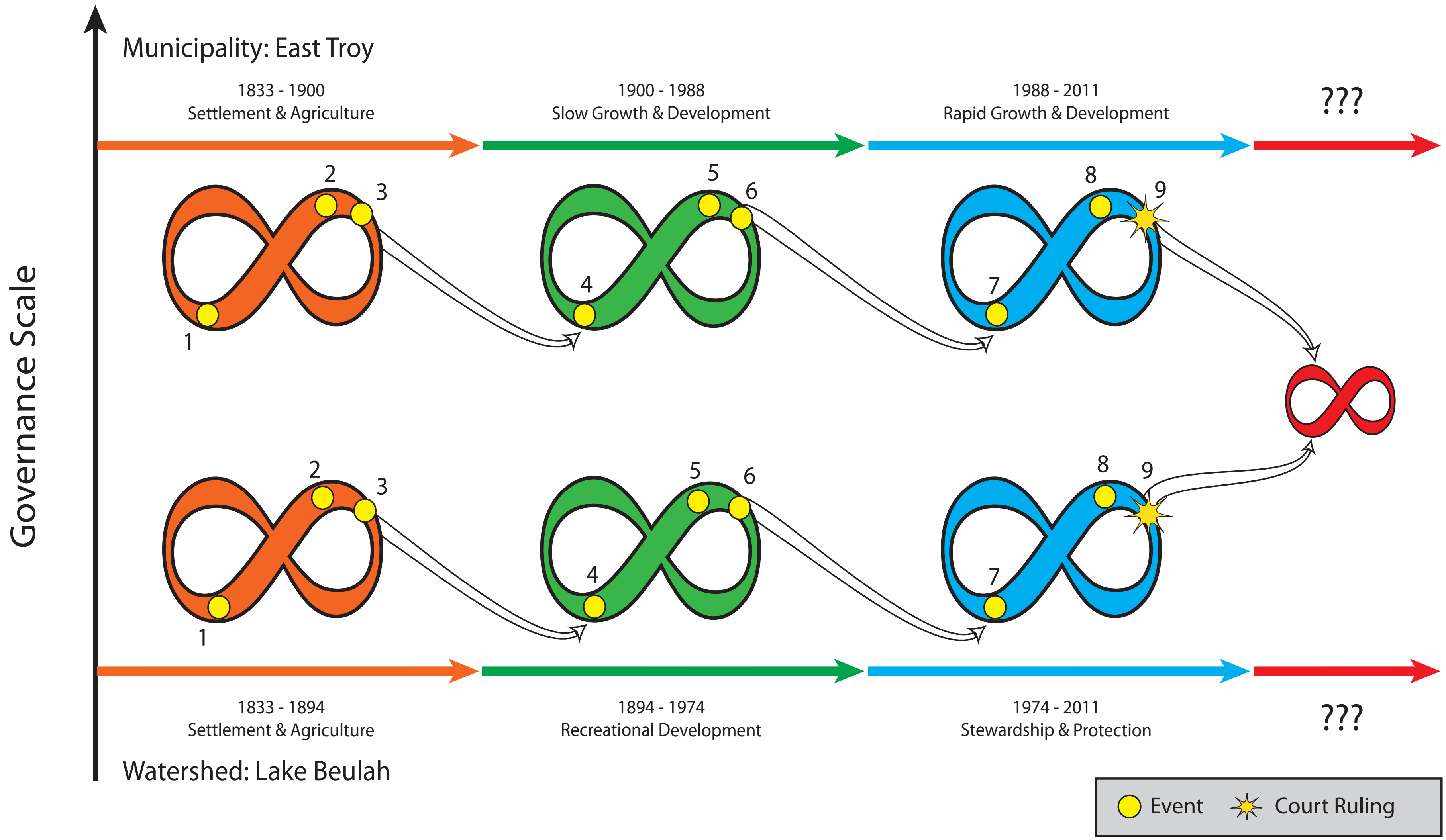

Figure 11: Historical analysis of Lake Beulah and East Troy. Significant events in each system's history cause phase shifts and transformations to new management paradigms. Event numbers correspond with Table 4.

Important events at the national, state and regional scales impacted the development trajectories of both Lake Beulah and East Troy. In 1972, the Clean Water Act was signed into law by the United States Government calling for the nation to protect the physical, chemical and biological integrity of surface water resources (Federal Water Pollution Control Act Amendments of 1972). In 1974, the Wisconsin State Legislature responded by creating Chapter 33 of the Wisconsin State Statues (Public Inland Waters, 1974). This allowed for watershed based governance to rehabilitate and protect inland water quality, and led to the establishment of the Lake Beulah Management District. Management districts are a recognized governmental body, and their establishment marked the start of the "Stewardship and Protection" management paradigm.

Development of surrounding areas including Waukesha and Mukwonago throughout the 1960s – 70s made the growth of East Troy inevitable. Expansion of Interstate Highway 43 through Walworth County in 1988 marked the beginning of the "Rapid Growth and Development" paradigm in East Troy. Connecting the village to the City of Milwaukee, East Troy quickly became a "bedroom community" contributing to further suburban sprawl in the region (Village of East Troy, 2008). From 1970 to 2000, the village population had increased 210% (Village of East Troy, 2008). Continued growth and development put the village out of compliance for drinking water supply in 2002 (Kobza, 2011). That same year, East Troy applied for a high capacity well to be placed in a recently annexed subdivision within Lake Beulah's watershed. This is the event where Lake Beulah and East Troy collided and further development by the village was seen to directly affect the lake. Coordination between the two parties initiated with members of the Lake Beulah Protection and Improvement Association funding a study to find an alternative site for the well. This quickly devolved into a legal battle and communication between the two parties ceased. The State Supreme Court settled the matter in 2011 (Lake Beulah Management District v. DNR, 2011).

The effect of the Lake Beulah Decision was twofold. The first was that the East Troy well could remain in place and continue to provide water to the village. This links the two SESs together and calls for collaborative governance between them to navigate an uncertain future devoid of legal conflict. However, little if any collaboration between the LBMD and East Troy has occurred. Currently, a monitoring program between the two parties includes data sharing from wells monitoring the effect of the East Troy well along with pumping data.

The second aspect of the decision was affirmation of the DNR's authority and general duty to consider the potential adverse environmental impacts of high capacity wells on adjacent surface waters when reviewing high capacity well permits. This radically changed the permitting process for high capacity wells in Wisconsin and linked surface and groundwater resources under the Public Trust Doctrine. This authority could be triggered in Lake Beulah but only if a demonstrable adverse impact could be linked to the well using scientific evidence.

Cross-Scale Interactions: Crises, Opportunities, and Barriers

Since the Lake Beulah decision, ambiguity regarding authority over LSGR resources has stalled institutionalization of governance from the state to the local scale. Using a modified version of Chaffin and Gunderson's heuristic (Chaffin and Gunderson, 2016), 12 cross-scale interactions were identified that influence the potentials for collaborative adaptive governance between Lake Beulah and East Troy. Cross-scale interactions were sorted by scale: state and local, and type: crisis, opportunity, and barrier (Table 5).

Table 5: Crises, opportunities and barriers affecting collaborative adaptive governance in the LB/ET SES.

Factor	Influence / Opportunity / Barrier	Scale
Attorney General Opinion	Influence	State
Pro-Development Water Policy	Influence	State
Uncertain Authority	Opportunity	State
State Control Over Water	Barrier	State
Pressure from Industry	Barrier	State
Lack of Bipartisanship	Barrier	State
Village Leadership	Opportunity	Local
Shared Monitoring	Opportunity	Local
Identified Threshold	Opportunity	Local
Social Ecological Condition	Opportunity	Local
Social-Ecological Memory	Barrier	Local
Conflicting Science	Barrier	Local

Crises at the state scale stem from an opinion issued by the Attorney General in May of 2016 (Wis. Att'y Gen 01 2016). The opinion stated that the DNR does not have the authority to assess cumulative impacts when permitting high capacity wells and the DNR stopped doing so the following month. However, the legal back and forth between the judicial and legislative branches of state government provides Lake Beulah and East Troy an opportunity to address the issue themselves and come up with a context specific solution. Political state scale barriers to the emergence of adaptive governance come from a lack of bipartisanship around water, a new phenomenon in the State of Wisconsin (Bergquist, 2016). Pressure from development, agriculture and industry interests have resulted in legislation aimed to undermine the authority of the DNR granted by the courts (Johnson, 2017). In addition, the courts have historically kept authority over navigable waters in the hands of the state (Lake Beulah Management District v. DNR, 2011). Repeatedly, the courts have stressed that surface water governance is of state concern and should not be delegated to local authorities.

Opportunities for the emergence of adaptive governance at the local scale revolve around untapped social capital between the LBMD and East Troy. Since the Lake Beulah decision, new village leadership is more willing to cooperate with the LBMD if necessary. These individuals have knowledge of the conflict and would be willing to negotiate should an issue with the well flare up. Other opportunities include a shared monitoring program where members of East Troy and LBMD meet to download data from monitoring wells around Lake Beulah. An eutrophication threshold was identified by McGuire et al. (in review) that provides a tool for the LBMD and East Troy to set water quality standards based on calcium and phosphorus levels in the lake. Finally, economic and environmental conditions of stagnant growth and high iron content in the groundwater have kept the well from being used consistently.

Conflicts between science and social ecological memory create barriers to adaptive governance at the local scale. Both the LBMD and East Troy believe that science is on their side. Since Lake Beulah's water quality has not degraded, East Troy sees that as proof that their well does not have an impact. The LBMD points to monitoring data indicating the well reverses groundwater flow making Lake Beulah a point of groundwater recharge instead of discharge. The barrier of social-ecological memory brings up multiple issues for collaborative adaptive governance. Historical decision-making creates inertia toward the adoption of new governance arrangements (Nykvist and von Heland, 2014). Memory of the monetary and temporal cost of the conflict left both parties preferring to let "sleeping dogs lie" now that the situation has calmed down.

Synthesis

Over time Lake Beulah and East Troy have developed different identities. The residents of Lake Beulah see themselves as a separate population and are solely concerned with matters involving the lake (McGuire and Ehlinger 2017, in revision). This insular approach to management was effective until conflict emerged over the well. In contrast, at the time of the well conflict East Troy was amid defining its identity. Rapid growth in the late 80s through the 1990s had East Troy trying to establish itself as a place where people live, work and play (Village of East Troy, 2008). Application for the well sparked conflict because communities on divergent development paths, one stable the other dynamic, collided. Now, interaction between East

Troy and the LBMD is necessary for both the lake to remain in a clear state and for East Troy to continue to develop.

The State Supreme Court ruling generated potential for collaborative adaptive governance of LSGR by not retroactively enforcing the decision (Figure 11) (Lake Beulah Management District v. DNR, 2011). This event triggers the release phase in the adaptive cycle and cross-scale interactions will either influence system transformation to LSGR governance or system reorganization to pre-conflict governance regimes (Chaffin and Gunderson, 2016; González et al., 2008). Currently, the LB/ET SES has neither transformed nor reorganized (Figure 12). Sharing of monitoring well and pumping data connects the parties, but the current social-ecological conditions (slowed growth in East Troy and high iron content in the well water) have resulted in little to no pumping (Author Interviews). Lack of pumping has also lowered the well issue on both Lake Beulah and East Troy's agendas, favoring system reorganization.

Key stakeholders from both Lake Beulah and East Troy believed that the well issue was not completely resolved and that its re-emergence would be the result of a decline in lake water quality (Author Interviews). Leadership in East Troy stated a preference for negotiation should this happen while Lake Beulah residents would not shy away from litigation. The attorney general's decision to limit DNR authority opens a window of opportunity by putting focus back on the well without directly reintroducing conflict, making transformation to collaborative adaptive LSGR governance possible (Figure 12). Lack of pumping provides the opportunity to create ground rules for resource use and the data sharing program provides a recurring date and venue for this to happen, allowing for the institutionalization of LSGR governance (Ostrom, 1990). However, barriers like social-ecological memory (Nykvist and von

Heland, 2014) keep Lake Beulah and East Troy from making informed decisions together. Whether LSGR governance materializes in the LB/ET SES is partially dependent on how the state defines the role of local scale actor.

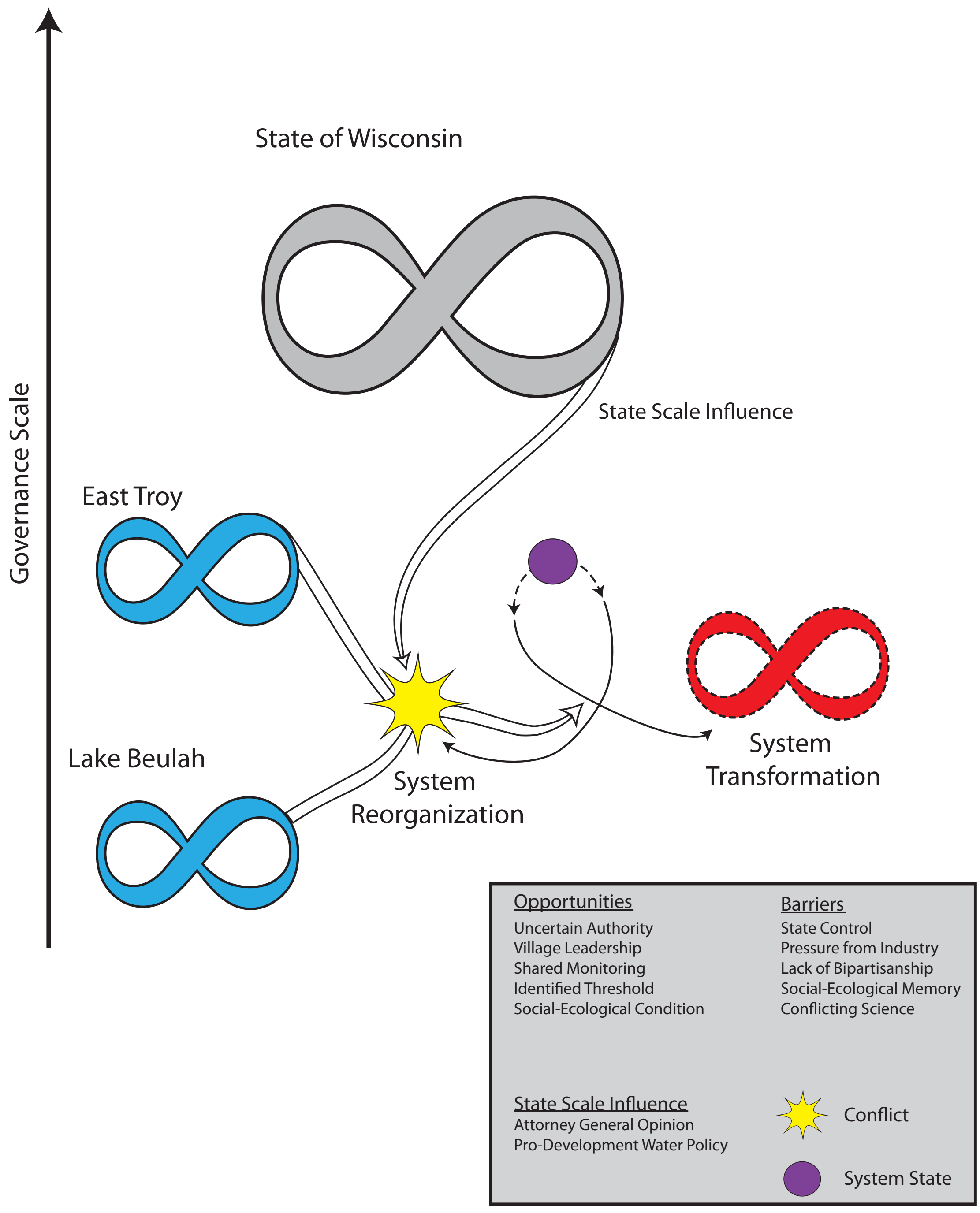

Figure 12: The state of the Lake Beulah – East Troy Social Ecological System can either transform into a new state centered on integrated surface-groundwater management or reorganize to separate systems that will periodically be in conflict over water.

Processes in Play

The attorney general's opinion to limit DNR authority is the result of dynamic process at the state scale favoring new development of land and calling for less regulation on high capacity wells. Similarly, lack of collaboration between the LBMD and East Troy has much to do with the social separation between the populations in terms of economics and culture. This highlights the resiliency of previous governance systems being reinforced by dynamic cascading thresholds (Kinzig et al., 2006), which can be used to identify areas of intervention and bring about systemic change. McGuire and Ehlinger (2017, in revision) identified cascading thresholds in the Lake Beulah Social Ecological System including the divergence between Lake and East Troy populations. In their trajectory of expected change, the Lake Beulah population sees the well as just the beginning of a larger process where East Troy overtakes the Lake population. This makes facilitation and collaboration difficult even though it is in both parties' best interest (Cuthill and Fein, 2005). However, through methods like agonistic pluralism (Horowitz, 2013), social perspective taking (Rios et al., 2003), and relational-cultural theory (Naibei, 2015), relationships between the two parties can advance and build social capital while maintaining personal identity.

Active Pursuit of Collaborative Adaptive Governance

Opportunities to pursue adaptive governance in the LB/ET SES are centered around current conditions while barriers stem from the historical context of the system. Currently, local governance of LSGR is risky because the authority of management agencies remains uncertain. Whether the state confirms the DNR's authority under the Public Trust Doctrine and provides a process to exercise it could have effects on the legitimacy of decisions made at the local level (Gunningham, 2009). However, the time political processes take to provide a decision leaves groundwater dependent ecosystems like Lake Beulah vulnerable to hazards brought on by the combination of continued development and climate change (Arnold and Gunderson, 2013; Cosens et al., 2014). New leadership in East Troy has proven to be more cooperative and this time of uncertain authority should be utilized by Lake Beulah and East Troy to develop their own rules of resource use (F. S. I. Chapin et al., 2009) and establish social capital (Brondizio et al., 2009).

Identification of an eutrophication threshold provides a boundary object for the LB/ET SES (McGuire et al. in review). For scientific information to be utilized successfully in natural resources management, it must be credible, salient and legitimate (Mollinga, 2010). The identified threshold provides credible and salient scientific knowledge of the lake's ecological condition that allows the community to set calcium levels for pumping. The legitimacy of this threshold relies on how the parties use this tool in the governance process (Clark et al., 2011; Cosens, 2013; Mollinga, 2010). If this tool is used to provide results based legitimacy (Cosens, 2013), where the model dictates the actions taken, the barrier of conflicting science will further devolve the situation into conflict. Conflicting scientific data and in interpretations were a major contributor to the initial conflict over the well (Author Interviews). Disagreements continue to persist regarding the validity and/or reliability of scientific studies and projections for adverse impacts on Lake Beulah. .On the other hand, a threshold model as a boundary concept (Clark et al., 2011; Mollinga, 2010) for visualizing adverse impact has the potential to establish a process based legitimacy, due in great part to its reliance on an open and transparent process for multiple perspectives to inform decision making and policy learning (Cosens, 2013; Kuzdas et al., 2015).

Current conditions in the LB/ET SES suggest that many of the attributes necessary for the sustainable governance of a shared resource may exist (Megdal et al., 2015). Monitoring data shared between East Troy and Lake Beulah provides a venue for deliberation and assessment of past and future conditions in the LB/ET SES (Author Interviews; Nauta, 2010). Low pumping rates due to stagnant growth in East Troy and high iron content in the groundwater provide the opportunity to establish meetings and set ground rules during a time of stability (Brondizio et al., 2009; Ulibarri and Scott, 2016). Finally, the parties could use the connected boundaries of the watershed and the town to exclude outsiders from installing more high capacity wells. It would be naïve to assume that the parties would do this willingly and without facilitation, but proper introduction to the collaborative process can build trust and social capital (Lebel et al., 2006; Ludwig, 2001; Sandstrom et al., 2014; Stern and Baird, 2015). These attributes can then be operationalized during times of crisis to allow for adaption to changing social-ecological conditions (Armitage, 2005; Plummer et al., 2013).

The barriers here are that social-ecological memory and path dependence can be sources of inertia against the adoption of new management practices (Ernstson et al., 2009; Nykvist and von Heland, 2014). Decisions concerning the states of Lake Beulah and East Troy have historically been made in isolation. In addition, the length and financial cost of the conflict has made both sides reluctant to initiate dialogue. Over all, reversion to historical decision making processes has taken place since the State Supreme Court Decision, signaling a lack of social capital and an unwillingness to work together to generate rules over resource use.

Conclusions: Implications for Collaborative Adaptive Governance

The collision of Lake Beulah and East Troy's development trajectories has created a new social-ecological reality that requires collaborative adaptive governance between two systems that were once mutually exclusive. Collaborative adaptive governance at this new scale requires input and integration of expert, political, community and stakeholder knowledge to inform the management of LSGR (Bodin and Norberg, 2005; Halbe et al., 2013; Lund, 2015; Sandström and Rova, 2009). Failure to do so will result in the degradation of the greater social-ecological system (Berkes et al., 2000). To accomplish the goal of implementing an adaptive governance regime will require time and effort to address the barriers that have established themselves historically in the LB/ET SES. The trajectory of the LB/ET SES is moving towards system reorganization, where Lake Beulah and East Troy will only be in communication when there is conflict over water use. However, there are opportunities to be taken advantage of, it just depends on if the attorney general's decision to limit DNR authority was the right catalyst to inspire system organization around adaptive governance.

Analysis of opportunities and barriers to the emergence of collaborative adaptive governance in the LB/ET SES provides stakeholders and managers with an informed point of entry into the collaborative adaptive governance processes (Chaffin and Gunderson, 2016). Opportunities in this study center around current conditions of the social-ecological system but the ability to foster collaborative adaptive governance are hindered by the conflict's historical context. This reaffirms that if collaborative adaptive governance is to emerge an understanding of the resource itself is not sufficient (Clark et al., 2011; Mollinga, 2010). Historical development and past management paradigms generate path dependency that influence current decision making (Chaffin et al., 2016; Hoffman and Zellmer, 2013; Nykvist and von Heland, 2014). In this sense, the opportunities present in the LB/ET SES are opportunities to address the barriers to the emergence of collaborative adaptive governance.

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Curriculum Vitae

Stephen Andrew McGuire

EDUCATION

2012 – 2017 *Doctoral Candidate,* University of Wisconsin-Milwaukee

Concentration: Biological Sciences (Current GPA: 4.0)

2012 *Bachelor's of Science,* University of Wisconsin-Milwaukee

Major: Conservation and Environmental Science (GPA: 3.64)

RESEARCH EXPERIENCE

University of Wisconsin-Milwaukee *Timothy Ehlinger,* PhD (Principal Investigator)

PhD Candidate (August 2012-2017 **Expected Graduation Date May 2017**)

Department of Biological Sciences

Operationalizing resilience in the face of water conflict: linking social and ecological systems

- Investigated the complexities of operationalizing community resilience for linked surface-groundwater governance through analyzing a conflict between the Lake Beulah Management District and the Village of East Troy in Walworth County Wisconsin.
- Interacting social-ecological dynamics occurring across scales and domains revealed a lack of governing ability at the watershed/community scale driving the conflict.
- Identified a groundwater reduction threshold for a marl lake using reservoir and geochemical modeling software and developed a decision support tool to assess the potential impacts of groundwater reduction on lake water quality
- Analyzed the historical, cultural and political contexts of the conflict to assess the possibility of collaborative governance between the two parties.

Lab Manager (May 2012-August 2012)

Department of Biological Sciences

- Responsibilities include:
  - Monitoring Stream Restoration Activities
  - Maintaining in field monitoring equipment
  - Deploying and retrieving field monitoring equipment
  - Assisting (under)graduate students with their field research

Undergraduate Research Assistant/Lab Assistant (July 2011-May2012)

Department of Biological Sciences

- Investigated the eco-toxicological effects of sediment contact on zebra fish (*Danio rerio*).
- Implemented a bioassay to study the effects of stream sediment on developing zebra fish.
- Creation of a land-use/cover database for Southeastern Wisconsin to be used in ArcGIS.

University of Wisconsin-Milwaukee *Gerlinde Höbel*, PhD (Advisor)

Undergraduate Research Assistant (May 2011-August 2011)

Department of Biological Sciences

- Investigated gray tree frog (*Hyla versicolor*) mating preferences and strategies.
- Responsibilities include:
  - Recording, capturing, and assessing physical characteristics of calling males.

- Test for female call preference
- Call analysis

Grants and Awards

2012 - 2017 Chancellor's Award for Academic Excellence
2012 Graduated Cum Laude in Class of 2012
2011-2012 Student Undergraduate Research Fellowship for research in the Höbel and Ehlinger Labs
2011 Spring Dean's Honor List

Teaching / Leadership Experience

- **Summer 2015 – Present:** Research Assistant for Dr. Timothy Ehlinger
- **Fall 2014 – Spring 2015:** Principles of Natural Resources Management (Teaching Assistant)
- **Spring 2013 – Spring 2014:** Conservation and Environmental Science (Teaching Assistant)
- **Fall 2012:** Zoology (Teaching Assistant)
- **Fall 2007 – Spring 2009:** Assistant Head Coach for Dominican High School Tennis

Presentations and Publications

McGuire, S.A. and Ehlinger, T.J. 2016. Analysis of social-ecological dynamics affecting governance in linked surface-groundwater systems. *Submitted to the publication Ecology and Society in December 2016.*

McGuire, S.A. and Ehlinger, T.J. Risk perception and the environmental impacts of high capacity wells: balancing the risk perception gap. *Presentation given to the Wisconsin Department of Natural Resources Southeast Region Drinking Water and Groundwater Division.*

Ehlinger, T.J., and **McGuire, S.A.** The State of Lake Beulah. *Presentation given to the Lake Beulah Protection and improvement Agency May 2016.*

O'Reilly, N., **McGuire, S.A.**, and Ghosh Roy, S. 2016. Development of Regional Regression Curves for Bankfull Stream Geometry in Eastern Wisconsin. *Presentation given at the Upper Midwest Stream Restoration Symposium January 2016.*

McGuire, S.A., and Ehlinger, T.J. 2015. Resilience Dynamics and Water Stewardship. *Poster presented at the Society of Freshwater Sciences Annual Conference May 2015.*

Ehlinger, T.J., Jensen, J., Dellinger, M., Ghosh Roy, S., **McGuire, S.A**., Ortenbald, A., and Schmitz, M. 2012. Monitoring of Stream Habitat & Aquatic Biotic Integrity. Interim Report Summary.

McGuire, S.A., and Ehlinger, T.J. 2012. Who's Driving?: An Analysis of Fish Biotic Integrity in a Restored Stream. *Poster presented at the UWM Undergraduate Research Symposium and UWM Biological Sciences Research Symposium April 2012.*