Assessing Michigan's 2008 Water Conservation Law: Scientific, Legal, and Policy Analyses

by

Shaw Nozaki Lacy

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Doctoral Committee:

Professor Michael J. Wiley, Chair
Adjunct Professor Dean Louis Bavington
Emeritus Professor Jason L. Finkle
Professor Maria Carmen de Mello Lemos
Adjunct Professor Paul W. Seelbach

For Rafaela

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Abstract

In 2008, the State of Michigan enacted a new water-conservation law as part of its responsibility as a signatory of the Great Lakes Compact. Public Act 185 of 2008 established a unique science-based water-withdrawal assessment-tool (WWAT) and water-withdrawal assessment-process (WWAP). This dissertation investigates the changes to Michigan's legal framework caused by the addition of significant water-withdrawal legislation in parallel with historic common-law. Both statute and science underpinning WWAP implicitly connect surface and groundwater, raising the possibility of challenging previous court decisions placing groundwater outside public trust. I explore the process by which the state-appointed Groundwater Conservation Advisory Council developed WWAT and WWAP and, as a boundary organization, facilitated iterative science-policy interactions over five years. During this time, scientist and policy-maker roles continually navigated both policy-construction and scientific-objectivism requirements. Concurrently, new regulatory and scientific terms were coined and defined, instituting lasting modifications to law and management-science. My dissertation also tests several legal-technical presumptions that arose during WWAP's development, including a rebuttal of an early presumption of no adverse impact occurring if large-scale water-withdrawals occurred at pumping distances greater than 1/4 mile from a designated trout-stream. A linked hydrologic and physical-habitat modeling-assessment indicated that pumping-induced temperature-increases caused significant losses of trout habitat in the headwaters of Augusta Creek at pumping-distances up to 1 mile from the creek and longitudinally upstream and downstream. These results, along with other studies, were incorporated into the scientific-development of WWAT and WWAP. I also tested the conservation presumption in WWAP by assessing the potential cumulative impacts of unregulated pumping on agricultural lands in the Muskegon River watershed. I modeled the impacts of different water-withdrawal regimes under present and future landscape and climate conditions and different levels of adaptive governance to future change. I found that, under the current regulatory-threshold of 100,000 gallons-per-day, much of the watershed experienced an adverse resource impact, without any withdrawals requiring registration with the State. Furthermore, future-scenario modeling indicated significant portions of the watershed could be variously and negatively impacted, and compounded misinterpretations of pumping impacts will occur if WWAT is not fully updated to reflect future hydrologic and thermal changes.

CHAPTER I:

Introduction

One way in which water policy issues have been explored is through the lens of water scarcity and water wars, quintessentially characterized in Marc Reisner's book, *Cadillac Desert* (Reisner, 1986). We are reminded, for example, of the major water projects that dammed up western rivers and moved water to the dry badlands in order to "reclaim" the land, and "improve" the land so that it could be "tamed" for farming. The American West is – in many ways – characterized by its lack of water, and the political relationship with this scarce resource continues to this day (Davis, 2001).

Moving eastward from the Rocky Mountains, past the High Plains of the Dakotas, one crosses the 100th meridian, and the climate becomes increasingly wet and the landscape evermore water-rich. The arid western Dakotas give way to corn fields, and these give way – eventually – to the great expanses of water that are the Great Lakes. Here, with over 80% of the fresh water of the entirety of North America – roughly 20% of the world's surface freshwater – the idea of water scarcity becomes laughable.

At the heart of the Great Lakes region lies the State of Michigan. Whereas the Great Lakes hold the vast majority of fresh water in North America, Michigan holds the vast majority of the water of the Great Lakes. Indeed, surrounded as its two peninsulas are by four of the five Great Lakes, the state has garnered the moniker "the Great Lakes State" (with an emphasis by some Michiganders on the definitive article, *the*). In Michigan, water is abundant, both on the surface and in the ground, and the idea of husbanding each drop is foreign. So, too, is the idea of owning such plentiful water; the ancient doctrine of "reasonable use" of water remained the dominant regulatory framework. Until just recently.

In 2003, the water-rich State of Michigan started to pass laws – along with the other Great Lakes states – to put into place the strongest possible water conservation measures. At the end of the process, in 2008, Michigan adopted a novel regulatory framework, basing water conservation on the functional integrity of aquatic ecosystems, and using a Michigan-developed, science-based assessment tool for streamlining decision-making and registration. In short, over the course of five years, Michigan went from being a relatively unregulated state to a state with major new water regulation that uses a completely new science-based tool. This rapid shift raises several interesting questions. Why did this all happen? How did this science-based decision-making policy tool develop? What impacts do the changes in the legal structure have on the state's water laws? Are the presumptions of the law likely to produce an end effect of conservation?

In this dissertation, I follow and analyze various aspects of Michigan's 2008 water law from conception through its current implementation, using the lenses of law, policy, and science. The 2008 law added a novel form of regulation into Michigan's pre-existing legal framework of riparianism. I explore important legal questions about the integration of the new approach with existing policy and existing court precedent. Through interviews with key actors and reviews of relevant documents, I examine factors shaping of the 2008 law: including the role of a boundary organization in facilitation of policy progress, and the ways in which science and policy worked together to create novel scientific and legal terminologies – “characteristic fish populations” and “adverse resource impacts” – that have now reshaped the water conservation framework of the state. From the perspective of more technical water science, I conducted model-based assessments of several legal presumptions that have played a role in shaping the new policy. Specifically the distance-to-stream assumption in an earlier version of the law and the conservation presumption in the current law itself with regard to the adequacy of the 100,000 gallons per day threshold for regulation. I have also used hydrologic modeling to explore some future implications of the new regulatory process, with an emphasis on the role of adaptive management in the context of future climate and land use change. To date, this dissertation is one of only a very few assessments of Michigan’s 2008 water withdrawal law (Mubako, Ruddell, & Mayer, 2013; Smith, 2009; Seedang, Norris, Batie, & Kaplowitz, 2013; Steinman, Nicholas, Seelbach, Allan, & Ruswick, 2011). However, I believe the research of this dissertation is unique in terms of the breadth and scope of perspectives. The dissertation is organized into seven chapters (including this one), each of which investigates a specific aspect and timeframe within the overall development of Michigan’s 2008 water law (Figure 1.1).

1.1 Dissertation Overview

Chapter 2 describes the policy development of the Great Lakes-St. Lawrence River Water Resources Compact of 2008 and describes how that larger, regional process brought about the creation and implementation of the state’s Water Withdrawal Assessment Tool (WWAT). WWAT is based heavily upon the findings from Zorn et al. (2002) and Wehrly et al. (2003): that the distribution of fishes in Michigan is strongly associated with stream size, hydrology, and temperature. All three parameters are heavily influenced by the surface-water-to-groundwater connectivity and the relatively unique abundance of groundwater-fed systems found in the state of Michigan. The modeling framework of Zorn et al. (2002) was generalized to the entire state (Zorn, Seelbach, & Rutherford, 2012) and integrated with state-wide groundwater and surface water hydrology models (Hamilton, Sorrell, & Holtschlag, 2008; Reeves, Hamilton, Seelbach, & Asher, 2009) . This coordinated set of models was the scientific basis of what would become WWAT, and was presented to the Technical Advisory Committee (TAC) of the Groundwater Conservation Advisory Council (GWCAC).

While Zorn et al. (2012) has explored the technical aspects of integrating the various models that formed WWAT and Steinman et al. (2011) have described the general process used by the GWCAC to produce WWAT.

Chapter 3 explores the changes in the legal landscape caused by the passage of the law by comparing the current regulated landscape with the previous largely unregulated one. It shows how water withdrawal law in Michigan now operates: with common law and WWAP decisions operating effectively in parallel, resting on the (still untested) assumption that there is an effective equivalence between analogous concepts within the two. Furthermore, due to the wording of the new law and the scientific basis upon which it rests, it discusses the implicit possibility that groundwater and surface water law might yet be harmonized..

Chapter 4 moves from an analysis of the legal landscape to the policy landscape, and it recapitulates the processes responsible for the creation of various key parts of WWAT and WWAP. In this analysis I use concepts of boundary work, boundary organizations, and boundary objects (Gieryn, 1983; Jasanoff, 1996). I conclude that

GWCAC acted as a boundary organization to create several new boundary objects, including the web-accessible WWAT and the coining of new regulatory terms, including for example: "characteristic fish populations" and "adverse resource impacts."

The chapter also assesses the level of understanding that various key actors had of the development of WWAT, and explores how these actors now understand the structural weaknesses of WWAT. Their perceptions were broadly consistent with other assessments of Great Lakes conservation in general (e.g., Dobornos 2010) or Michigan specifically (Annin, 2009).

Chapter 5 tests the rebuttable presumption of an interim water conservation law passed in 2006 about the impact of water withdrawals at different distances from a designated trout stream. This chapter rebutted the legal presumption that withdrawals more than ¼ mile away from a designated trout stream would have no impacts. It also showed that water temperature (and the effects of pumping on it) was the most significant factor affecting fish habitat in the study stream. While impacts were heaviest nearest the point of pumping, they also occurred several miles downstream.. These findings subsequently were incorporated into the policy discussion and helped support the decision to include explicit analysis of well distance as a part of WWAT.

Chapter 6 proceeds to test two of the recognized weaknesses of WWAT framework: unregulated pumping and hydrological change. This chapter uses the Muskegon River Ecologi cal Modeling System (MREMS) to test the impacts that large scale unregulated pumping on agricultural lands could have on water availability within the Muskegon River watershed. The regulatory threshold of 100,000 gpd is shown to create a system in which users who maximize their unregulated water withdrawal can collectively have a significant and unregulated impact on the hydrology and ecology of the system as a whole. Furthermore, even a diminution to a threshold of 10,000 gpd continues to show adverse resource impacts in certain areas.

Finally, **Chapter 7** concludes the dissertation, tying together some of the lessons from various chapters and suggesting additional work and new directions to take in future research.

1.2 Figures

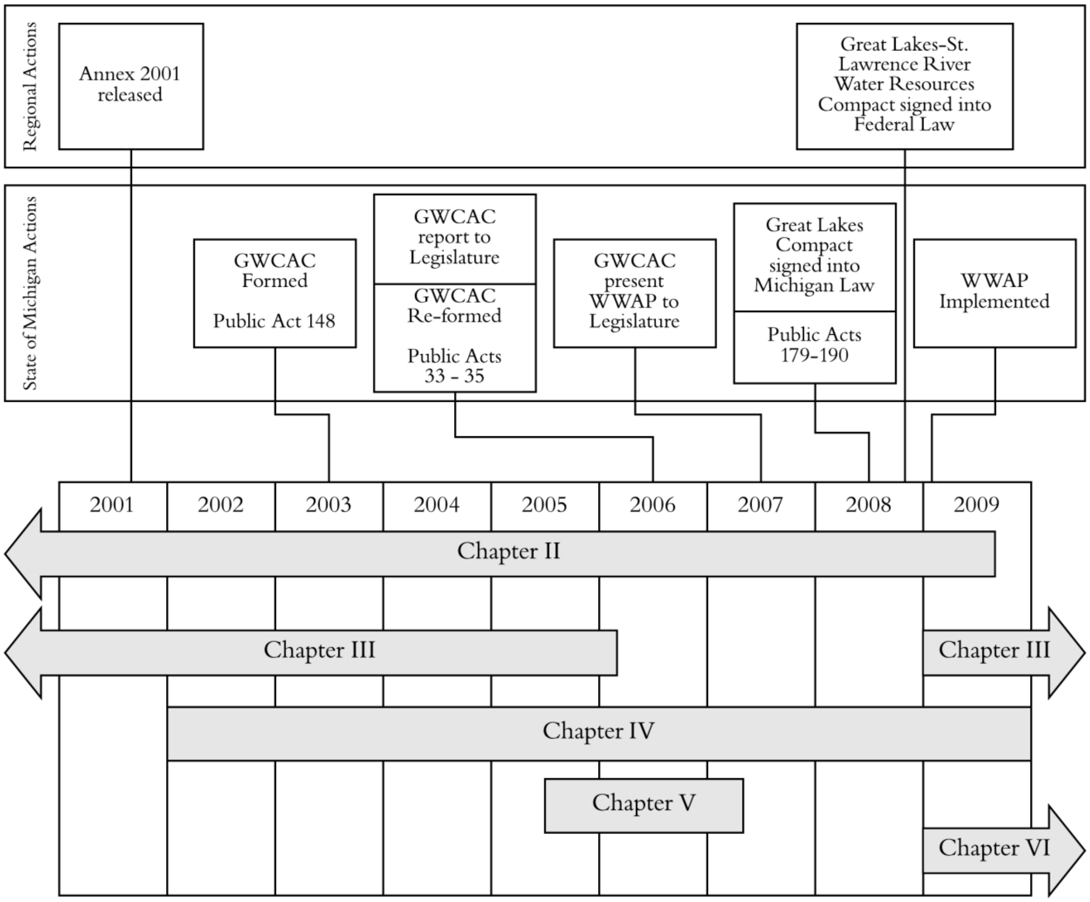


Figure 1.1. Map of the contents of the dissertation.

CHAPTER II:

The Regional Policy Context of Michigan's 2008 Water Conservation Law

It is often lamented that more science isn't used in making policy and in drafting legislation (Sarewitz & Pielke Jr., 2006). Often, this is done without describing how or when science should enter into the process (Pielke Jr., 2007). It is arguable that, while science may not play a direct role in the development of statutory law (i.e., legislation), it can have a more direct impact on those decision-makers who are developing regulatory laws. Specifically statutory law can be defined as "a written law passed by a legislature on the state or federal level. Statutes set forth general propositions of law that courts apply to specific situations. A statute may forbid a certain act, direct a certain act, make a declaration, or set forth governmental mechanisms to aid society."[1]

In contrast, regulatory laws are "the procedures created by administrative agencies (governmental bodies of the city, county, state or Federal government) involving rules, regulations, applications, licenses, permits, available information, hearings, appeals and decision-making."[2] Environmental law often requires quantification, measurement, and reporting of actions that alter the natural environment, either to determine, whether a permit is to be issued or whether a permitted standard has been exceeded. In the case of environmental laws, where the goal is often conservation or restoration, there are typically

[1] http://legal-dictionary.thefreedictionary.com/statute+law
[2] http://legal-dictionary.thefreedictionary.com/Regulatory+law

explicit regulatory standards identified (e.g. maxima or minima) that cannot be crossed without violating the goal of the law. For example, under the total maximum daily load (TMDL) requirement of the Clean Water Act (CWA), specific regulated parameters are set for each point-source discharger's permit, which ostensibly attempt to meet the aspirational goals of fishable and swimmable waters throughout the United States.

Another example of the distinction between statutory and regulatory law is Michigan's groundwater pumping permits. Under current statutory law – the context of this dissertation anyone proposing to make a withdrawal of greater than 100,000 gallons per day (gpd) must determine whether their pumping is likely to cause an adverse resource impact (ARI) on characteristic fish populations before continuing and registering the withdrawal with the state. Neither the amount of water removal that constitutes an ARI, nor the definition of "characteristic fish populations," were a part of the initial legislation (PA33-2006) laying out making this requirement. Definitions of these terms and methodologies to measure and predict them were only later determined by the state-appointed Groundwater Conservation Advisory Council (GWCAC) and their recommendations for regulation were presented to the legislature in 2007 (Groundwater Conservation Advisory Council, 2007) and eventually adopted as a package of both statutory and regulatory law.

This adoption changed the relatively *laissez faire* form of riparianism that historically characterized Michigan (Stapilus, 2010) to a more regulated form of riparianism. Today registration and reporting of groundwater withdrawals is required through the use of the state's water withdrawal assessment process (WWAP) and online water withdrawal assessment tool (WWAT)[3]. The development and assessment of WWAP will be discussed in Chapter 4, but it is worth noting here that these changes were made as a result of the passage of the Great Lakes-St. Lawrence River Water Resources Compact (the Great Lakes Compact, the Compact), which required a significant change in the process of water governance in Michigan, as well as all other Great Lakes states. Both the introduction of pumping regulations and the linkage made implicit in the new law between groundwater and surface water make Michigan's WWAP a significant policy innovation.

The linkage between groundwater withdrawal and characteristic fish populations is not intuitively obvious, and this connection bears some attention since the relatively unique physical and ecological contexts of Michigan physiography allow for this rather interesting regulatory metric (Wehrly, Wiley, & Seelbach, 2003). However, before discussing this eco-physical relationship, it is important to understand how a Supreme Court decision – namely *Sporhase v. Nebraska* – initiated the process through which a region of the country that holds the vast majority of surface and groundwater of the nation engaged in a multi-state, multi-decade effort to create binding legislation conserving the waters of the Great Lakes.

2.1 The Great Lakes-St. Lawrence River Basin Water Resources Compact

Prior to the passage of any Great Lakes-wide water governance legislation, the governors of the Great Lakes states (i.e., the governors of Minnesota, Wisconsin, Illinois, Indiana, Michigan, Ohio, Pennsylvania, and New York) had been given certain levels of power in reviewing new water diversions from the Great Lakes, under the Water Resources

[3] http://www.miwwat.org/

Development Act of 1986 (WRDA). This was in reaction to a series of large-scale water diversion projects that had been proposed in the previous decade. In 1976, a U.S. Army Corps of Engineers (ACE) plan to divert Great Lakes water to help recharge the Ogallala Aquifer in the Great Plains started inciting significant political concern. This concern was deepened by a more serious plan in 1981 to construct a 1,900-mile water pipeline to support a coal-slurry operation in Wyoming's Powder River. The protections under WRDA were assumed to provide sufficient protection against water withdrawals, but through a 1999 legal assessment, the implications of the 1982 Supreme Court of the United States decision on *Sporhase* eventually forced Great Lakes governors along the path toward a new law that could protect Great Lakes water from diversions in a manner that was constitutional (Annin, 2006).

Although the *Sporhase* case began several thousands of miles away from the Great Lakes, the eventual Supreme Court decision had an important implication for the WRDA-based governance of Great Lakes water, in which individual state governors could ban water exports proposed in other states. What was significant about *Sporhase* was that the Supreme Court decided that a state (and therefore a state's governor) cannot ban the movement of water between states, since pumped water was considered to be an article of commerce, and was thus not within a state's right to regulate under the Commerce Clause of the U.S. Constitution. Since the strength of water protections in the Great Lakes rested on the direct action of governors, the *Sporhase* seriously undercut the ability of the states to protect the water through a mechanism like WRDA. (Annin, 2006)

In 1997, the specter of water withdrawals from the Great Lakes arose once more with a plan to export Great Lakes water as drinking water. (Annin, 2006) This eventually led to a renewed realization that the Great Lakes states still lacked adequate means to control Great Lakes water. In 1999, work began on a basic legal and management framework for a future water governance structure. The result was the Annex 2001 document, which suggested the legal structure of a multi-state legislative agreement, otherwise known as an interstate compact.

As an amendment to the Great Lakes Charter (Anonymous, 1985), Annex 2001 directed the Great Lakes governors and the premiers of Ontario and Quebec to immediately begin working on a legally binding, basin-wide agreement to be completed within the following three years. It also required the establishment of a decision-making standard based on the following principles:

- Preventing or minimizing basin water loss through implementation of environmentally sound and economically feasible water conservation measures; and
- Preventing adverse individual or cumulative impacts to the quantity or quality of the Waters and Water-Dependent Natural Resources of the Great Lakes Basin; and
- Improving the Waters and Water-Dependent Natural Resources of the Great Lakes Basin; and
- Compliance with all the applicable state, provincial, federal, and international laws and treaties. (Annex 2001, Directive #3)

In order for the Compact to become regional law, each of the eight Great Lakes states had to enact the same law using in the same language through their respective legislatures, and then have the same law with the same language pass the U.S. Congress and be signed into law by the President. A failure at any juncture would mean a failure for the Compact. All the state governments, as well as the US Congress, passed the final version of the Compact in 2008, with President George W. Bush signing the Compact into law in December of that year. While the language of the Compact is identical across all states, it does not set up any governance structures to conserve each state's waters, instead requiring each state to create and follow their own water-conservation plan, based on their own methods and using their own metrics.

On July 9, 2008, Michigan passed Public Act 190 of 2008 (referred to as "PA190" in the rest of this chapter), which constituted its passage of the Compact[4]. The portion of PA190 (and, therefore, the Compact) that is relevant in this dissertation is found in Article 4 – "Water Management & Regulation" – that requires (among other things), within five years of the passage of the Compact (i.e., in 2013), the following be completed in Michigan:

1. Development and maintenance of a inventory "for the collection, interpretation, storage, retrieval exchange, and dissemination of information concerning the water resources of [Michigan]" (PA190, Article 4, Section 4.1, Part 1)
2. Development and maintenance of a database of water use information of "any Person who Withdraws Water in an amount of 100,000 gallons per day or greater average in any 30-day period (including Consumptive Uses) from all sources, or Diverts of Water of any amount" (PA190, Article 4, Section 4.1, Part 3)
3. Creation of "a program for the management and regulation of New or Increased Withdrawals and Consumptive Uses by adopting and implementing Measures consistent with the Decision-Making Standard. Each Party, through a considered process, shall set and may modify threshold levels for the regulation of New or Increased Withdrawals in order to assure an effective and efficient Water management program that will ensure that uses overall are reasonable, that Withdrawals overall will not result in significant impacts to the Waters and Water Dependent Natural Resources of the Basin, determined on the basis of significant impacts to the physical, chemical, and biological integrity of Source Watersheds, and that all other objectives of the Compact are achieved. Each Party may determine the scope and thresholds of its program, including which New or Increased Withdrawals and Consumptive Uses will be subject to the program." (PA190, Article 4, Section 4.10, Part 1)

Much of this work of preparing and developing a water conservation framework had been begun in 2003, during the negotiations that formed the Compact after signing of Annex 2001. As mentioned above (and in more detail in Chapter 4), a state-appointed

[4] http://www.legislature.mi.gov/documents/2007-2008/publicact/pdf/2008-PA-0190.pdf

Groundwater Conservation Advisory Council developed the water withdrawal assessment process and the online screening tool (WWAT) that became Michigan's means of pursuing its obligations under the Great Lakes Compact. The finalized science-based models used in the WWAP are based on historically robust relationships and good empirical scientific understandings of the state's ecohydrology.

However, as the saying goes, "All models are wrong, but some are useful." In the process of developing the science-based models of the WWAP, scientific assumptions were made about the relationships between various physical and ecological parameters, due to constraints of time and money, for the sake of simplicity (and political expediency), and with the expectation that they would eventually be included in future models. These scientific assumptions were either explicitly or implicitly included as legal presumptions, which provide an opportunity to test the extent of their reasonableness through science-based methodologies. Such tests are presented in Chapters 5 and 6.

The ability to scientifically test the legal presumptions of a law provides an additional avenue of determining the adequacy of that law. With operationalized parameters feeding a series of regulatory models, it is possible to generate analogues in order to ask various types of questions about the validity of the legal standards, the likelihood of the success of the law (given a series of modeled pressures), etc. In this way, scientific assessments of regulatory law can help refine and improve not only the science underlying a series of regulatory models, but also provide decision-makers with highly relevant scientific results that automatically hang on the legal and policy framework being used. In other words, it builds upon the existing series of boundary-objects already in use by both regulators and decision-makers.

CHAPTER III:

How Michigan Stopped Worrying and Learned to Love Regulated Riparianism: Changes in Michigan's Water Withdrawal Laws Caused by the Great Lakes Compact

United States water law is split along two major divisions: east and west and surface water and groundwater. The United States primarily operates under two different surface water law regimes: prior appropriation (found primarily in Western states) and riparianism (found primarily in Eastern states).[5] In addition to the geographic division in surface water law, groundwater law is separated into a distinct category of law due to historical reasons (Freeman, 1998; Getches, 1997).

In addition to these geographic and physical splits in US water law, there is also the separation between federal and state law. Prior to the enactment of the Clean Water Act in 1972 (as well as the larger set of federal environmental protection legislation of that era), the ability to govern water resources were held by the states. Ever since the passage of the major pieces of environmental legislation in the 1970s, federal involvement in environmental and natural resource management, but it is neither fully centralized nor absolute. Outside the relatively narrow constitutional limits of federal legislation regarding

[5] A minority of states operate under a hybrid of these two systems, and two states – Louisiana and Hawai'i – operate under completely different water law regimes than the rest of the country (Getches, 1997). These hybrid and unique systems will not be discussed in this dissertation, but a brief discussion of these can be found in the various editions of *Water Law* by Getches, among other sources.

water quality and navigation (and outside the borders of federal and tribal lands) states remain the primary governors of natural resource use. This governance, however, is constrained by the fundamental legal framework of law-making found in much of the United States.

The law-making in the United States is derived from three different sources: statute law (also called legislation), in which the bases of laws are written; regulatory law (also called regulation), in which the bases for standards and monitoring that relate to various statues – if not already enumerated in the statute – are defined; and judge-made law (also called common law), in which interpretations of statute laws are made by sitting judges that may result in new understandings of the extent of a law, obligations of an agency, validity of a previous court decision, etc.

What this means is that the passage of the Compact created a regional, interstate governance structure – recognized by the federal government – and a set of legal obligations for each of the Great Lakes states through the passage of identical legislation that required each state to develop its own fact-based regulatory system to ensure the conservation of all waters of the Great Lakes, which (a) tacitly combines surface and groundwater of the Great Lakes basin into one regulated object and (b) redefines the state and federal relationship of water governance within the Great Lakes basin, through the creation of a shared interstate statute (i.e., the Compact) and state-by-state regulatory methods, each enacted by its own set of statutes. To understand the broader implications of this shift, it is useful to explore the legal underpinnings of Michigan water governance prior to the passage of the Compact.

3.1 Eastern versus Western Water Law

In examining water law in the United States, it is common to first define the differences between Eastern and Western systems. The rough dividing line between Eastern and Western water law is the Mississippi River; a geographic shorthand that is used to describe the origins of the legal divide caused by prevailing regional climates. The area east of the Mississippi River is relatively wetter than much of the area west of the Mississippi River. A major part of the history of occupation, territoriality, and statehood of the western United States has been around water projects and water use (Reisner, 1986). As westward expansion started to threaten the access to surface waters through the systems of canals that had already been built by previous settlers, major pressure was placed upon state law makers to assure that historical water use was given precedence over new uses. In this way, the system termed "prior appropriation" emerged (Getches, 1997). Further discussion of prior appropriation can be found in Getches and others.

In contrast, eastern water law, referred generally as "riparianism", remained a form of law that was inherited from British practices, and which was – in turn –a hybridized from English, French, and Roman law (Getches, 1997; Narasimhan, 2008). Within the structure of riparianism, the discussion of "riparian rights" focuses around questions of access to and use of surface water, with the major rights often including:

- To have access to the water.
- To build a wharf or pier into the water.
- To use the water without transforming it.
- To consume the water.
- To acquire accretions (alluvium).
- To own the subsoil of nonnavigable streams and other "private" waters. (Christman, 1998, p. 24)

Furthermore, riparian owners (i.e., those whose properties contain a shoreline or river bank) are allowed to make "reasonable use" of the water adjoining or within their property. The idea of "reasonable use" (outside of any specific regulation that would curtail or otherwise define uses explicitly) is determined (by a judge, regulators, or some other authoritative body) using a variety of considerations, including:

- The purpose of the use of water.
- Its suitability to the water body.
- Its economic value.
- Its social value.
- The harm it causes.
- Its potential for coordination with competing uses.
- Its temporal priority relative to competing uses.
- The justice of imposing a loss on the use. (Christman, 1998, p. 24)

3.1.1 Regulated Riparianism and Michigan

Adjudication of questions concerning whether one or another use was "reasonable" was done primarily in court, as were questions of access and right to build a wharf or pier. In some states, the presence of a variety of legal decisions led to the decision to enact various statutes that defined the conditions under which actions were "reasonable," access to water was permitted, and/or construction was allowed. States in which these additional statues were passed are generally referred to as, "regulated riparian" states, and comprise, to one degree or another, almost all states east of the Mississippi River. Michigan was one of only a handful of states that remained an effectively truly "riparian" state.

Up to the passage of the legislation that started to set up the legal structure necessary for the Compact, Michigan followed riparianism (Stapilus, 2010). With regard to rivers, the basic premise of water rights in Michigan prior to 2003 followed the spirit of the Roman statement of, "*aqua profluens res communis omnium est*," or that "flowing water (and their banks) belongs to everyone." This, and the more formalized concept of the "public trust doctrine" stemmed from the Northwest Ordinance (which included the territory that would become the state of Michigan), passed by the Confederate Congress of 1787, which stated:

> The navigable waters leading into the Mississippi and Saint Lawrence, and the carrying places between the same, shall be common highways, and for ever free…

3.2 Groundwater Law

Due to the limited scientific understandings of groundwater during the majority of time when groundwater laws were employed, the institution of groundwater law developed quite differently from surface water law. Indeed, in much of US groundwater law, there is no recognition that groundwater and surface water were connected in a predictable way, that it was "secret, occult and concealed, that any attempt to administer any set of legal rules in respect to [it] would be involved in hopeless uncertainty, and would be, therefore, practically impossible,"[6] except in cases of springs and natural seeps (Bartholic, et al., 2007). The system that was inherited by the United States was under the Absolute Ownership Rule, which allowed the land owner the ability to pump as much groundwater as they wanted, even if neighboring properties were harmed.[7]

Under this system, groundwater was not considered under the public trust, but was regulated more like minerals, while springs and seeps (i.e., groundwater that emerged onto the surface) were regulated more like surface waters. However, beginning in the early 20th century, especially following the widespread use of the Manning's equation to determine the hydrological character of groundwater flow, changes started to emerge as greater understanding of the relationship of groundwater and surface water became uncovered (Narasimhan, 2008), and this was also the case in Michigan.

[6] Frazier v. Brown, 12 Ohio St. 294, 311 (Ohio 1861).
[7] (1843) 152 Eng. Rep. 1235 (Ex. Ch.)

While the legal code governing the public trust of water is based on a civil code – first articulated in the Northwest Ordinance and later in successive state constitutions – the means through which much of American court cases are decided is through the common law practice of legal precedent (Getches, 1997). It is important to recognize this point, since it is upon legal precedent – minus any change to the relevant statutory law – that regulatory and governance decisions are based. Furthermore, the implications of this distinction is that – minus any change of statutory law (or constitutional law) that explicitly places groundwater into the same legally recognized category as the surface waters that they sustain (i.e., make groundwater part of the public trust) – decisions about groundwater management and surface water management were required to be made independently from each other, even as an increasing amount of science showed that the surface waters of the state were – for almost the entire state – were fed and sustained through their connection with groundwater.

3.3 Interstate Compacts

The Compact, signed on December 8, 2008 by President George W. Bush, was the final legislative product of a long process through which Great Lakes water diversions would be managed by the Great Lakes states and provinces. A major impetus for pursuing the interstate compact option was that, although the 1985 Great Lakes Charter provided each governor with veto power to halt water diversions from the Great Lakes (Anonymous, 1985), the fact that governors could veto water diversion projects in other states was felt to go against the *Sporhase* decision (Annin, 2009) as well as Article 1, Section 10, Clause 3 of the Constitution; otherwise known as the "Compact Clause" (<u>emphasis</u> added for clarity):

> No State shall, without the Consent of Congress, lay any Duty of Tonnage, keep Troops, or Ships of War in time of Peace, enter into any Agreement or Compact with another State, or with a foreign Power, or engage in War, unless actually invaded, or in such imminent Danger as will not admit of delay.

States may engage in interstate *agreements* without the need for consent of Congress so long as these agreements do not affect federal powers or rights (Dellapenna, 1998). The formal interstate *compact* process is required for states to govern in such a way that is "directed to the formation of any combination tending to the increase of political power in the States, which may encroach upon or interfere with the just supremacy of the United States" (Tribe, 2000, pp. 649-651). Once a compact is in place, however, it becomes a binding federal statute, affecting both the compact states and their citizens (Dellapenna, 1998). Since the decision of *Sporhase* defined interstate water diversions as subject to the federal commerce clause, the Great Lakes Charter was considered to be vulnerable to a constitutional challenge. Therefore, in order to effectively manage interstate water diversions, a formal compact was needed to overcome any constitutional challenge (Annin, 2009).

3.3.1 Eastern Interstate Water Compacts

While the Western interstate water compacts are primarily about the allocation of volumes of water between states due to the relative lack of water in the West, such in the case of the Colorado River Compact (Reisner, 1986), Eastern interstate water compacts are rarely about volumetric water allocation. Many Eastern interstate water compacts date before 1972 and the passage of federal environmental legislation, and focus on pollution and ecological issues through information sharing, which resulted in very limited success in dealing with interstate pollution problems. Together with social pressures triggered by environmental disasters (such as the burning Cuyahoga River, the assessment that Lake Erie was “dead”, and many others), the inability of pre-existing interstate compacts to realize environmental protections led to the passage of many pieces of federal legislation, including the Clean Water Act in 1972 (which – perhaps tellingly – contained little language about the role of interstate water compacts) (Dellapenna, 1998).

Prior to the passage of the Great Lakes Compact, only two Eastern interstate water compacts created major systems of interstate management of and governance structures over their shared waters: the Delaware River Basin Compact and the Susquehanna River Basin Compact (which was based on the structure of the already extant Delaware River Basin Compact). Briefly, both compacts created an interstate agency with regulatory powers and built upon the existing system of water law in the member states (instead of replacing them) except in the case of Pennsylvania, where the interstate agency acts as a permitting agency only within the basins that are in the Delaware and Susquehanna watersheds (Dellapenna, 1998). The passage of the Great Lakes Compact has effectively created another example of an Eastern Water Compact that goes beyond monitoring and sharing information.

3.3.2 The Great Lakes-St. Lawrence River Basin Water Resources Compact

Due to the nature of the Compact and the various legal and political systems between the eight Great Lakes states and the two Great Lakes provinces, each state and province was given the opportunity to provide the mechanism by which they would meet their obligations under the Compact. This requirement would have likely devolved to the individual states anyway, due to the lack of authority held by the federal government to regulate intra-state water resource quantity, even under the Clean Water Act. Federal regulation over interstate transfers of water resources also did not exist, nor did a national water policy. To that end, the state of Michigan chose to pursue legislation that regulated water conservation by the means of predicted impacts of withdrawals to surface water "characteristic fish populations" (see Sections 4.4 and 4.5.1.1 for more detailed information about the process). However, if this was the end-point of the process, from where did Michigan begin their quest toward such a form of water regulation?

3.4 Michigan Water Conservation prior to the Compact

The vast majority of Michigan natural resource and environmental law is contained in the state's Natural Resources and Environmental Protection Act of 1994 (NREPA), and the majority of water law is found in Section III.1.301-317 of that act. Prior to the passage of the Compact, Michigan had very little regulatory capacity over groundwater or surface water withdrawals, other than regulations for very large water withdrawals (primarily for municipal and industrial uses) and the broad language written in the NREPA. As previously mentioned, Michigan was effectively a truly riparian state with a *laissez faire* approach to codified water regulation. Furthermore, this broadly defined oversight of water was written into various state constitutions, including the current one:

> The conservation and development of the natural resources of the state are hereby declared to be of paramount public concern in the interest of the health, safety and general welfare of the people. The legislature shall provide for the protection of the air, water and other natural resources of the state from pollution, impairment and destruction.[8]

[8] Constitution of the State of Michigan of 1963, revised 12/2010. URL: http://www.legislature.mi.gov/documents/publications/constitution.pdf (Accessed December 1, 2012)

Under this doctrine of public trust, the state holds the resource in question so that the public at large has reasonable use of that resource. Michigan water law stated that no one could own the water in the river, nor could impairments to flowing streams could be made – although reasonable use of water by adjacent landowners is permitted (Getches, 1997; Stapilus, 2010).

Following the riparian framework groundwater was governed separately from surface water. In the case of groundwater regulation, the major case that set the groundwork for much of Michigan's groundwater regulation was decided in the case of *Schenk v. City of Ann Arbor*,[9] in which the court found that the city does not have the right to pump water out of its lands if it would materially injure the neighboring properties. More broadly, the court ruling set groundwater use to fit into the Reasonable Use doctrine. Under this ruling, if the water was *not* to be used on the property from which it was withdrawn, then it could not be of such a volume as to affect neighboring property users' access to the groundwater. However, if the water *was* to be used on the property, then there was effectively no limit to the amount of water that could be withdrawn. This decision was later amended so that competing on-property uses of water were balanced against each other, instead of allowing each to have unlimited ability to withdraw water (Bartholic, et al., 2007). The last major case concerning groundwater regulation prior to the Great Lakes Compact was *Michigan Citizens for Water Conservation v. Nestlé Waters North America, Inc.* in 2005, which – with respect to the discussion of limits to groundwater withdrawals – provided that a "reasonable use balancing test" between the various land owners and uses be weighed.

[9] 163 N.W. 109 (Mich. 1917)

In reviewing *Michigan Citizens for Water Conservation vs. Nestlé Waters North America Inc.*, Michigan Court of Appeals upheld the trial court's reasoning of groundwater being outside the public trust and rejecting any argument that groundwater was held by the state in trust by writing:

> The Constitution and statutes cited [that groundwater is part of the public trust] do not attempt to claim ownership of water [in general] by the state itself. Indeed, this state has long recognized that private persons obtain property rights in water on the basis of their ownership of land. Therefore, the trial court properly determined that water, while a resource common to all Michigan citizens, is neither owned by the state nor subject to the public trust absent a determination that the body of water in question is navigable.[10]

The interesting – and somewhat academic – point made by the appeals court was that the problem was not that major water withdrawals did not affect a surface water body, but that the surface water body that was affected was not deemed to be navigable; both the trial court and the appeals court didn't disagree with the scientific point that the (non-navigable) surface water was hydrologically connected to the groundwater.

When the case was taken to the Michigan Supreme Court, however, the idea that the "interconnectedness" of surface- and groundwaters was the means through which the legal standing of Michigan Citizens for Water Conservation to even bring the case was challenged:

> The trial court found as fact that many of the streams, lakes and wetlands in the Tri-Lakes area are joined by an inextricable, hydrological link … [with] the springs, the aquifer, and defendant Nestlé's pumping activities, whereby impact on one particular resource caused by Nestlé's pumping necessarily affects other resources in the surrounding area [beyond the waters adjacent to the plaintiffs' properties]. … [T]he relevant inquiry in standing analysis is not whether the environment suffered injury, but whether the plaintiff suffered injury. ... [P]laintiffs must still establish how they have suffered a concrete and particularized injury in fact within this interrelated ecosystem. … No matter how pervasive the environmental damage

[10] Michigan Citizens for Water Conservation vs. Nestlé Waters North America Inc., 709 N.W. 2d at 221.

in an ecosystem, plaintiffs must still successfully and succinctly establish their injury in fact.[11]

In short, the Michigan Supreme Court restated the basis of riparian rights within the common-law framework of arbitration: that Michigan Citizens for Water Conservation did not have the right to bring the law suit for damages that were not associated with waters that were not adjacent to their property or connected via surface water connections (i.e., since they were not riparian owners of the affected water body, they had no legal standing). Furthermore, even though the environment might have suffered a harm due to the pumping caused by Nestlé Waters North America Inc., unless the plaintiffs could show a harm done to their property or their use of the surface waters adjacent to their properties, they could not bring a law suit against Nestlé.

The standard of groundwater regulation that Michigan adopted following the various court decisions through the *Nestlé* decision is that individuals do not have an absolute right to groundwater, but they do have an exclusive right to it. In other words, they do not automatically have rights to all the water they can pump from their ground, but they do have unlimited rights to it, *subject to certain limitations* set by government; an exclusive right to groundwater that follows a "reasonable use balancing test."

In contrast, up through the *Nestlé* decision, surface water law stated that riparian users were subject to the long-held rules of "reasonable use" (which is not to be confused with "reasonable use balancing test" for groundwater).

In summary, it is important to recognize that, prior to the passage of the Compact, the state of Michigan preferred to have very few regulations on the form of riparianism

[11] Michigan Citizens for Water Conservation vs. Nestlé Waters North America Inc. Bollman, (Mich. July 25, 2007), URL: http://caselaw.findlaw.com/mi-supreme-court/1363710.html (Accessed December 1, 2012)

practiced in the state (Stapilus, 2010). The adoption of statutes that would – without any doubt – lead to greater regulation of both surface water and groundwater use was a major turning point for water governance in the state. That turning point of moving toward a region-wide Compact and concomitant regulations over water pumping began with one statutory change made to the issue of groundwater removal as the GWCAC was reconvened in 2006: as an interim measure to comply with the water conservation requirements of the Compact until a water withdrawal assessment tool could be created, a law was passed that forbade shallow groundwater pumping within a quarter mile of a designated trout stream (PA33, 2006):

> Until a water withdrawal assessment tool becomes effective upon legislative enactment pursuant to the recommendations of the groundwater conservation advisory council …, there is a rebuttable presumption that a new or increased large quantity withdrawal will not cause an adverse resource impact … under either of the following circumstances: (a) The location of the withdrawal is more than 1,320 feet from the banks of a designated trout stream[, and] (b) The withdrawal depth of the well is at least 150 feet.

In this act, "trout stream" was defined as those stretches of the state's navigable waters that were designated in a Michigan Department of Natural Resources report (MDNR, 2003). These presumptions would be overturned in the final assessment conducted by the 2006 GWCAC (see Section 4.4 for more details). It shows, however, that there was a growing recognition outside the scientific realm that trout streams were characteristic of those places that had a high connectivity with groundwater, and if groundwater conservation was to be pursued, it initially made sense to use trout streams as a proxy for areas with significant amounts of shallow groundwater (i.e., groundwater less shallow than 150 feet depth).

CHAPTER IV:

Constructing Michigan's Waters: The Development of the Policy, Law, and Science of Michigan's Water Withdrawal Assessment Process

4.1 Introduction

The legitimacy of science – both to scientists and non-scientists – is based partially on a demarcation between processes (and the results of those processes) recognized to be "scientific" and those that are "nonscientific." The creation of a "boundary" between activities and methodologies deemed to be scientific and nonscientific – and acting on the appropriate side of that boundary – helps scientists foster and maintain a sense of legitimacy (Gieryn, 1983). The highly influential report – *Science, The Endless Frontier* – advocated for a separation between science and society for the purpose of maintaining scientific legitimacy through objectivity and credibility (Bush, 1945). Working across such boundaries, though, has proven to lead to productive policy-making (Jasanoff, 1990), irrespective of the rhetorical statements about the necessity to maintain intentional separation (Lackey, 2007). Indeed, reassessments of the nature of knowledge indicate that scientific knowledge and methodologies are rarely – if ever – truly objective and value-free, but is actually influenced by a host of social factors (Gibbons, et al., 1994; Sarewitz, 1996).

Recognizing that the practice of science – and the assessment of such scientific practice – is a social endeavor that carries with it real effects on scientists who are perceived to “stray” too far (Gieryn, 1983), the question of the politicization of science (as well as the converse question of the scientization of politics) is an important one to address (Sarewitz, 1996). The notions of “boundary objects” and “boundary organizations” help in producing a relatively safe solution for scientists (and politicians) to become involved in action without being accused of straying too far across their respective boundaries.

Boundary objects – such as patents on scientific discoveries (Guston, 1999) or even professional science organizations (Moore, 1996) – straddle the science-nonscience boundary, and allow actors on each side of that boundary to use the object for their specific purposes without losing credibility (Star & Griesemer, 1989). The use of these objects by scientists and non-scientists, though, may be for completely independent purposes, and – as such – the mere production of boundary objects may not help in effective decision-making. For example, a politician using the number of patents derived from a project as a metric of productivity is only a useful metric of productivity if the scientist is involved in filing patents (or if the project’s results are amenable to being patented). While such a metric of productivity may be useful in some fields (i.e., fields that produce many patents and in which filing patents is a norm), it cannot adequately be used to compare productivity across disparate fields (especially if comparing a high-patent field against a low-patent field).

Boundary organizations attempt to facilitate integrative decision-making by providing opening a space within the science-nonscience boundary where there are incentives to create specific boundary objects through the participation of actors from both sides of the boundary, and furthermore, all actors are held accountable by the norms and functions of their respective disciplines (Guston, 1999). Indeed, the structure of a boundary organization can often lead to recurrent questions about their integrity and to defensive strategies to monitor and respond to them (Guston, 2000). In so doing, boundary organizations actually create a legitimizing space for actors within the organization that come from both sides of the boundary, and can shield the production of the boundary objects from external politics. This, in turn, can help create positive incentives to produce boundary objects (Guston, 1999).

Success or failure of a boundary organization depends on external actors on both sides of the boundary that require the creation of boundary objects by the organization. It also depends on the actions of the members of the boundary organization itself in navigating conflicting external forces while shaping the required boundary objects. Successful navigation between external forces and internal actors is described as a process of "co-production" (Jasanoff, 1996), which is the iterative and simultaneous production of knowledge and order through facilitated interactions of scientists and nonscientists (O'Mahony & Bechky, 2008) to create a space where members' perspectives, understandings, and knowledge systems can converse (Carr & Wilkinson, 2005).

In this chapter, I propose that the Groundwater Conservation Advisory Council acted as a boundary organization in the creation of several boundary objects, including a water inventory of the state, reports to the legislature, the Water Withdrawal Assessment Process (WWAP), its primary components – the Water Withdrawal Assessment Tool (WWAT) and process of Site-Specific Review (SSR) – and terminologies and concepts that played a key scientific and legal role of WWAP – "characteristic fish populations" and "adverse resource impact" (Figure 4.1). I further propose that these boundary objects were created through a process of co-production of knowledge, in which the Council – together with iterative work with state scientists, initial input from the legislature, and continued input from their constituent groups – helped shape a novel science-based assessment tool for the impacts of proposed water withdrawals. In the process of creating the tool, the Council was required to work collaboratively with scientists to create a science-based and legally defensible definition for key legal, policy, and scientific terms. The outcome of the Council's process also led to a re-imagination of the conceptualization of water conservation metrics from physical/legal constructs to an ecological construct.

4.1.1 Policy Context

In the Laurentian Great Lakes, the possibility of water diversions to other portions of the United States has long been present in people's minds. Although technically feasible (Bulkley, Wright, & Wright, 1984), and seen by many in arid regions of United States as desirable, the idea of large-scale diversions has been a non-starter for the majority of people local to the Great Lakes (Annin, 2009; Hall, Personal Communication). One rather clear example of this dichotomous popular view toward water can be seen in the comment made to the *Las Vegas Sun Times* by New Mexico's former Governor, Bill Richardson, when he was a presidential candidate in 2007 (emphasis added):

> I believe that Western states and Eastern states have not been talking to each other when it comes to proper use of our water resources … I want a national water policy. We need a dialogue between states to deal with issues like water conservation, water reuse technology, water delivery and water production. States like Wisconsin are awash in water. (Mishak, 2007)

The comment of water-as-fungible-commodity – so innocuous in the arid American West – was met with hostility in most of the Great Lakes region, encapsulating to many in the Great Lakes region yet another in a long list of examples of what would happen in a future in which Great Lakes states couldn't control the fate of the water with which many hold personal identification (Hall, Personal Communication). While Richardson's statement cannot be said to have impacted the eventual votes for passing state and regional Great Lakes water conservation legislation, it was remarked upon at the time as one more example of why the water conservation became a driving force in Michigan politics.

The necessity of creating a constitutionally defensible structure to conserve the waters of the Great Lakes through a Great-Lakes-wide compact, the Michigan Legislature created the Groundwater Conservation Advisory Council (GWCAC, the Council) in 2003 to assess the condition of available groundwater within the state. In 2006, the GWCAC's mandate was expanded to develop a process and science-based governance tool to screen prospective groundwater withdrawals in the state in order to meet the goal of water conservation. Advisory councils are generally given the responsibility to determine and assess existing legal framework, but have sometimes been criticized for being bureaucratically opaque and providing few directly useful outcomes (Pielke Jr., 2007). These criticisms do not appear to be fully applicable to Michigan's Groundwater Conservation Advisory Council, which was able to produce a novel framework – known as the Water Withdrawal Assessment Process (WWAP) – to govern the state's groundwater as well as an integrated and automated, online registration system: the Water Withdrawal Assessment Tool (WWAT). In 2008, after legislative negotiations following the GWCAC presentation of their findings to the Michigan legislature, Michigan became the final US state to pass the Great Lakes-St. Lawrence River Basin Water Resources Compact (a.k.a., the Great Lakes Compact, the Compact). Michigan's then-novel form of a regional water conservation compact with state/province-determined science-based governance structures as part of the Compact and was then forwarded to the US Congress for approval. The Compact was approved by Congress and signed into law on December 8, 2008.

4.2 Various Views of Science

In many polls of society's view of scientists – and (presumably) of the practice of science – there is a consistently high level of trust (Trumble, 2013). However, this trust is belied by a simultaneous general lack of agreement about what the practice of science entails between scientists and various members of the public. There is, though, a general agreement that "science" is a potent force for potentially defining and forming policy goals as well as objectively determining outcomes that would be free of political intent (Jasanoff, 1997; Linton, 2008; Liptak, 2008; Lynch & Cole, 2005; Narasimhan, 2008; Pielke Jr., 2007; Reisner, 1986; Sarewitz, 1996).

4.2.1 Political View of Science

Within a policy context, science tends also to be viewed in a variety of manners, but always tend to be utilitarian, with (Pielke Jr., 2007; Sarewitz, 1996) rhetorical support and display of scientific evidence restricted to those pieces that support a predefined policy stance. Conversely, scientific evidence seen to run counter to a political stance rhetorically downplayed, discredited or ignored.

Sarewitz (1995) points out that the use of science in policy is predicated upon "a social consensus that treats the validity of the scientific method as proven" and is not based on the pursuit of science as a cultural activity of discovery by itself (Sarewitz, 1996, p. 5). Furthermore, the use of science within the rhetoric of policy tends to be based on "myths" of science, including the myths of infinite benefit, unfettered research, accountability, authoritativeness, and the endless frontier, based heavily on the proved efficacy of the products of science, the social benefits ascribed to science, and the political interests of scientists and scientific organizations themselves (Pielke Jr., 2007; Sarewitz, 1996).

4.2.2 Legal View of Science

One of the fundamental points about the law is that it is predicated on proof and facts in an attempt to determine (or at least persuade a jury about) the truth of an event: the prosecution and defense seek to prove their cases, witnesses swear to tell the truth, penalties exist for not telling the truth, and juries weigh the veracity of the stated truth as proof for prosecution or defense. In this vein, science is used as a truth-telling medium, much like any other witness, with the findings used as proof to support one side or the other, and the veracity of the evidence based on proxies of trust. Indeed, even Supreme Court decisions have cited the findings of scientific papers that have sided with the opinions of the justices, but even the choice of whether to include or dismiss a particular scientific article was based on the perceived veracity of the scientists, and not on a scientific assessment of the material contained in the article itself (Liptak, 2008).

In the United States, scientific evidence in a court room must meet several requirements based on the 1993 Supreme Court decision in *Daubert v. Merrell Dow Pharmaceuticals, Inc.* (shortened to *Daubert*), which amended, and formalized in Federal Rules in 2000, the requirements of including the testimony of experts (Faigman, Kaye, Saks, & Sanders, 2002). Often, trials that include scientific testimony undergo preliminary hearings in "*Daubert* courts" that assess validity of the scientific evidence to be presented to the jury and the expertise of the witness (Faigman, Kaye, Saks, & Sanders, 2002).

The *Daubert* courts are set up to determine the veracity of the scientific expert in helping determine the truth of a claim, and varying experts' testimonies are weighed based on the perceived veracity of their claims (Lynch & Cole, 2005). Here, the law encounters a problem between the asymmetrical principles of verifiability in law (i.e., the accumulation of facts and proof) and falsifiability in science (i.e., the ability of a question to be proven false). Although the United States Supreme Court chose the criterion of falsifiability through testable hypothesis as the means of determining whether evidence is scientific, it gave no methodology for actually conducting such determination, leaving it up to the determination of judges and lawyers to distinguish between science and non-science. This gap leads to trusting in proxies of scientific merit, including peer review, status of a scientific expert, or the consensus views of scientific bodies, and the novelty of a methodology (Faigman, Kaye, Saks, & Sanders, 2002; Lynch & Cole, 2005; Taslitz, 1995).

There are only two general situations in which the law perceives scientific evidence to be limited: when the determination of a fact is too complex for scientists to ascertain or when it is so commonly known as to render expertise redundant (Faigman, Kaye, Saks, & Sanders, 2002). Presumably, as scientific understanding of complex problems improves, their utility to the law will also improve (Narasimhan, 2008).

4.2.3 The Co-Production of Science

The scientific framework that eventually would come to characterize the WWAP was imported from a pre-existing science-based regulatory screening technology, but was actually formed as a process of co-production within the GWCAC. In this context, "co-production" is the synthesis of knowledge (in this case science) both by and within the social framework that will eventually house it, utilize it, and derive new meanings from it. It is the processes of dialogue between those who "create" the science and those who guide scientific understanding to meet social ends (Jasanoff, 2004).

The idea of "co-production" describes the development of science for directed social purposes and outside of the contexts of pure science, often within boundary organizations. To the pure scientist, such boundary work runs counter to their perception of the role of the scientist within the social contract, and to these pure scientists, the objectivity of science is at risk when an objective science is bent toward political ends. For example, Lackey (2007) cautions against scientists deviating too far from that path of being committed to impartial observation and the truth, and to maintain the distinction between objective science and policy advocacy, both in the implementation of science as well as in the interpretation and reporting of science. Furthermore, Lackey cautions that it is when the line between science and policy is dim that a scientist must be the most vigilant in not deviating from impartial objectivity.

However, Lackey's call for "objectivity" is based on the assumption that objectivity is actually impartial, but it is fails to recognize that scientists are the products of societies, and carry with them their own embedded social biases that shape their approach to the development and investigation of science. One iconic example is that of the independent discovery of the arguably objective field of calculus by Isaac Newton and Gottfried Liebniz as well as the subsequent socialized formalization of calculus notation along the lines of Liebniz over that of Newton. The historic social dominance of an ideographic mathematic that was practiced in continental Europe – and which took over mathematical practice – was what ended up allowing Liebniz's formulation of calculus to become the standard, and not because it happened to be "more objective" or that it was inherently more impartial. Furthermore, in areas where science and established social morals interact closely, such as in medical science, the embedded morality of scientists' decision-making goes unquestioned unless and until the decisions start to move toward the boundaries of established social morals, for example with cloning. While it appears that it is to this end that Lackey cautions, the idea that science is somehow independent of the social forces that new scientific discoveries create remains strong within the scientific community. At its most liberal, the admonition implies that scientists should not speak beyond what their data and methodologies can illuminate.

In contrast to Lackey's strict non-interventionist position, other scientists perceive a need for active scientific input into decision-making, due to a perceived civic responsibility (e.g., the "citizen scientist" and the "science advocate"), being part of a mission-driven organization (e.g., a scientist for a regulatory agency), or because they find themselves within a field that advocates a socially predetermined axiomatic basis for scientific inquiry (e.g., research in medicine is based on a particular axiomatic rationale of ethics that prescribe acceptable methodologies and research frameworks within which to conduct research; research into the impacts of climate change presume a need to assist those who are negatively impacted and/or to minimize negative impacts). In areas in which science and public life have become intertwined, the concerns and contentions of the pure scientists are seen by those involved at the boundary to be ineffectual, since the processes of pure science tend to be insulated from the policy process and the greater needs that the policy process seeks to address (Sarewitz & Pielke Jr., 2006).

There are several lenses through which co-production can be viewed, including the emergence and stabilization of novel objects and phenomena, the framing and resolution of controversy, understanding of the products of science and technology over time, and the legitimizing cultural practices surrounding science and technology (Jasanoff, 2004). Indeed, many of these activities were undertaken during the process of the GWCAC through the definition of novel terminologies and management practices (i.e., simultaneously determining legal and scientific definitions of "characteristic fish populations" and "adverse resource impact"), the re-framing of water conservation (i.e., from a water-only framework to a more ecologically based framework), and recognizing the necessary socially understood legitimating steps for the science to progress (i.e., peer review).

4.3 Study Methodology

In order to understand how the science used by the GWCAC came to be tied together in the WWAP, I interviewed a number of people key to the entire process, from the development of the GWCAC through to the eventual utilization of the WWAP in the regulation of Michigan's waters. During the course of developing the interview prompts, a number of questions motivated the selection of topics for interview. Specifically, though, four goals were central to the interviews. The first was to outline the timeline and actions that led to the development and passage of the water withdrawal assessment tool (WWAP), something that was not elucidated in the two major journal articles written about it (Steinman, Nicholas, Seelbach, Allan, & Ruswick, 2011; Zorn, Seelbach, & Rutherford, 2012). The next was to determine how specific terminology that would form the basis of regulatory law were decided, operationalized, and finally interpreted on the ground for the purpose of enacting regulation. The third was a retrospective evaluation of WWAP as it now stands, having been in regulatory service for three years. Last of all, was to examine the status of water governance within the state of Michigan and what role the WWAP plays in the state's governance.

4.3.1 Interview Protocol

I conducted targeted interviews with 13 key actors that have intimate knowledge of the development of the WWAP, including individuals from the state legislature ($n = 2$), the Groundwater Conservation Advisory Council and the Water Resources Conservation Advisory Council ($n = 6$), the science committee to the GWCAC ($n = 4$), and the Michigan Department of Environmental Quality, the state regulatory agency now enforcing WWAP, ($n = 3$) (Table 4.2; note: some individuals served in more than one capacity). An initial group of three interviewees were selected on the basis of their interaction with and knowledge of the development and use of the WWAP. From this small group, a modified snowball methodology was used in order to expand the pool of interviewees. Interviews were conducted after receiving an exception for a need for approval by the Institutional Review Board at the University of Michigan, Ann Arbor. This exemption meant that subjects could be contacted and interviewed, so long as informed consent was given to the interview and identities were only to be used publicly with the consent of the interviewee. For this reason, unless otherwise noted, individuals will be identified by their organizational relationship to WWAP. Furthermore, where a subject's name is given, the person's title will be based on the relationship that the subject had during the time of the WWAP process, not the current title held by the subject (see Appendix 3 for the basic interview protocol).

After transcribing the interview notes, I conducted a qualitative comparison of the responses that the interviewees provided in addition to government documents and other materials associated with the overall process of the development and use and assessment of the WWAP.

4.4 The Development of WWAP: The Realization of Science-Based Policy

It is important to recognize that the development of the WWAP began shortly after the publication of the Annex 2001 document to the 1984 Great Lakes Charter. With this document, it was clear that Michigan would have to change its style of water governance from one of effectively *laissez faire* governance within a riparian framework to one in which a greater level of monitoring and regulation would become the norm. In the meetings and negotiations with the other states and provinces, it quickly became clear that both surface water and groundwater needed to have the same level of conservation protection if the law were to meet the requirements of conserving Great Lakes water (Annin, 2009). To that end, the Compact makes no distinction between groundwater and surface water, but treats them all as a single entity: “the waters of the Great Lakes,” and – due to the legal necessity of ensuring that the language of the eventual Compact would be conserved across all the states – this language of “waters of the Great Lakes” (and “waters” more generally) was promulgated throughout subsequent state legislation. This specific non-distinction between surface water and groundwater has not yet been tested legally, but it marks an interesting potential transition in assessing the connection between surface and ground within water law, at least in the context of the Great Lakes basin, which – in the case of Michigan – is nearly the entirety of the state.

Through the process leading from the publication of the Annex 2001 document until the passage of the Compact, the Michigan Legislature passed eighteen public acts related to the Compact (Table 4.1), with most of them being directly related to the creation of the WWAP and/or changing portions of the extant Michigan Environmental Protection Act (MEPA) to allow for a future WWAP to function appropriately as a regulatory tool within the state.

4.4.1 Formation of the Groundwater Conservation Advisory Council

The Annex 2001 document marked a turning point in how Michigan would proceed with meeting its obligations to a future Great Lakes Compact. With a win in the 2002 senate election, Senator Patricia ("Patti") Birkholz was placed in the senate Natural Resources committee by then-senate-leader, Senator Ken Sikkema. This placement would prove providential, as Sen. Birkholz would come to act as a major proponent for producing a robust groundwater conservation law through the use of a science-informed advisory council; would act as both a protector and advocate for that council within the state senate; would find ways to create strong collaborations with the governor, Jennifer Granholm, and the House chair of the Great Lakes and Environment committee, Rebekah Warren; and – after being placed as the chair of the Natural Resources committee for a second term, something that is a rare occurrence – a major actor in pressing for both the WWAP and the recommendations of the GWCAC to be accepted. According to one of her staffers (I7), in hindsight, "the timing was perfect."

Recalling that time, Sen. Birkholz (I8) described seeing the implications of what the yet-to-be-written Compact, in addition to the potential political behavior of state actors, would entail:

> Michigan needed a strong groundwater control law. If [there wasn't a strong groundwater control law], there would be a strong attack from agriculture and certain businesses to remove or weaken whatever was put in place under the Compact. [Furthermore,] it was important to tie the passage of the groundwater withdrawal law to the Great Lakes Compact.

Sen. Birkholz recalled that even early in the process of shifting toward a more regulated form of water governance, there were vested interests that acted to oppose any regulatory actions, describing their water use figures as "proprietary". However, other businesses were starting to recognize that the rising price of electricity was causing many businesses a lot of money, due to electricity use in water pumps. This meant that, despite the social desire to protect Great Lakes water from large-scale out-of-basin withdrawals, in order to have robust water conservation legislation that could meet the goals of the Great Lakes Compact, a coalition of various interest groups would have to be brought together in order to create wide-spread support and buy-in.

During 2002, Sen. Birkholz and her office consulted with "trusted people" among interest groups on how to form a groundwater advisory council to explore the available groundwater in the state, since – according to a USGS scientist who had a long history of working in Michigan (I6) – there was no groundwater inventory or monitoring program: "MDEQ had no water scientists; [Michigan] has always utilized USGS." However, if the waters of the Great Lakes were to be conserved, then an accounting of the state's groundwater had to first be done, and it now had to be done with the recognition that the inventory would likely become a very political topic. To that end, Sen. Birkholz and her office met with a variety of interest groups to try and organize a roster of council members. Said one former senate staffer (I7) of the Council and the people chosen:

> From the outset, the people who were to be on the Council were known. The position descriptions [in PA148 of 2003] were written with these specific people in mind. Members of the Council already had a long working relationship in Lansing.

This point was also confirmed by Sen. Birkholz, who indicated that she, "consulted various trusted people among interest groups," and that, "in the Michigan legislature, the interest groups were specifically included in the make-up of the Council."

4.4.2 The Groundwater Conservation Advisory Council of 2003-2006

On August 7, 2003, the Michigan legislature initially created the Michigan Groundwater Conservation Advisory Council (GWCAC, the Council) through the State of Michigan Public Act 148 of 2003. This GWCAC comprised thirteen members, representing a broad mixture of interest groups. Three individuals appointed by the senate majority leader ("representing business and manufacturing interests, utilities, and conservation organizations"), three individuals appointed by the house speaker ("representing well drilling contractors, local units of government, and agricultural interests"), four individuals appointed by the director of the Michigan Department of Environmental Quality ("representing nonagriculture irrigators, the aggregate industry, environmental organizations, and the general public"), and three non-voting individuals "representing the department [of environmental quality], the department of agriculture, and the department of natural resources". The mandate given to the Council was to produce a groundwater inventory and map; study the sustainability of the state's groundwater use; monitor Michigan's compliance with the Annex 2001 implementation; study the implementation of the then-new groundwater dispute resolution program and to present these to the legislature in two years. (Michigan State Legislature, 2003)

Jon Allan, one of the Council co-chairs, recounted that the Council was, "given a lot of leeway in its actions," and that this was significantly helped by Sen. Birkholz "running interference for upcoming legislation so that the Council could get on with its duties." This was confirmed by Sen. Birkholz and senate staffers.

Early in the process, the co-chairs of the 2003 GWCAC, Jon Allan and Kurt Heise, recognized the importance of focusing the policy discussion toward issues of shared interests and values. Therefore, they decided that decisions within the Council would be determined through consensus: "The Council did agree, however, to report on a consensus basis. That is, the information in this report, including all findings and recommendations, are agreed upon by all voting members" (Groundwater Conservation Advisory Council, 2006, p. 3). Furthermore, they would meet regularly – once per month for weekend-long meetings – and throughout the state – in various settings that were "home" to each council member in order to create an environment in which people were willing and free to speak things they might not have done before; breaking away from advocacy. "You got to try on a new pair of pants once in a while," Allan quipped.

What this meant was that the Council members spent a lot of time, not only with each other, but also with state and federal scientists as well as numerous academics. In many of these sessions, the councilors spent time learning how to understand each other's language as well as to grapple with the science underlying their mission. "It was like taking a grad-level class on the topic," said Kurt Heise, indicating the amount of effort that many councilors had to make to bridge a gap of knowledge and understanding between their policy and legal backgrounds and the science and modeling methods, data, and implications that they were receiving. Too, bridging this gap was a commonality for many councilors, since – of the thirteen – only a handful held a university degree in a science discipline.

However, before the Council could proceed with their statute-defined mission, the Council co-chairs felt that it was important to define their guiding principles that "form the foundation for perspectives and viewpoints represented [by the Council]" (Groundwater Conservation Advisory Council, 2006) (see appendix). Jon Allen felt that the principles "created a different expectation about the solution set," and they meant that discussions would "start with large-scale themes that everyone agrees with." In addition to these guiding principles, the GWCAC even went to the effort of defining what they meant by the term *conservation*:

> Conservation means that to meet the needs of existing and future users and to ensure that habitats and ecosystems are protected, the use of the State's water must be done in a sustainable and renewable manner. Sound water-resource management emphasizes careful and informed use of water, which is essential to meet these objectives. (Groundwater Conservation Advisory Council, 2006, p. 4)

Taken together, the guiding principles (Appendix 1) and the definition of conservation would prove to form the philosophical basis and provide the normative justification for how the science was defined, how the process of the Council was described in the media, and – in some meetings – how discussions that had broken into wrangling could be brought back toward consensus.

Through the process of 17 full-Council meetings and over 120 hours of work, the GWCAC made various findings and provided recommendations for each statutory requirement. With regard to the points of water withdrawal regulation, the Council made several findings, the most pertinent to this chapter being: Finding 7, that Michigan water laws were not in line with Annex 2001; Finding 8, that Michigan lacked a coordinated state-wide groundwater management system; Finding 11, that although the links between local groundwater withdrawal and localized impacts to fishes appear difficult to draw, it is possible to build a water withdrawal assessment tool capable of incorporating it; and Finding 12, that little research has been done looking at localized impacts to non-fish aquatic biota. In addition to these findings, the GWCAC produced the GWIM (Groundwater Inventory and Mapping) database of well pumping registrations, which would form a foundational support of the eventual construction of the state-wide WWAP (Groundwater Conservation Advisory Council, 2006).

4.4.3 The Groundwater Conservation Advisory Council of 2006-2008

On February 22, 2006, the Michigan legislature reconstituted the GWCAC through 2006 PA 34 (Michigan State Legislature, 2006). Senator Birkholz noted that it was clear that the Council would be retained to continue with the process of developing the WWAP, and, in that way, the next iteration of the GWCAC comprised the same thirteen people of the original 2003 Council. It was also expanded to include four more members, one to be appointed by the senate majority leader ("representing a statewide agricultural organization"), one by the house speaker ("a registered well driller with knowledge and expertise in hydrogeology"), and two by the governor ("representing municipal water suppliers and a statewide conservation organization"). Among the responsibilities of this advisory council was one to, "Design and make recommendations regarding a water withdrawal assessment tool [under the auspices of its technical advisory committee (TAC)]," that:

> ... can be utilized to protect and conserve the waters of the state and the water-dependent natural resources of the state. The water withdrawal assessment tool

> shall be designed to be used by a person proposing a new or increased large quantity withdrawal to assist in determining whether the proposed withdrawal may cause an adverse impact to the waters of the state or to the water-dependent natural resources of the state.

The requirement of constructing the WWAP had the further stipulation that the TAC must "make factually based recommendations for the policy-based parameters and variables of the [WWAP]". Unlike the mission of the 2003 GWCAC, this incarnation of the Council would be required to use scientific information to set recommendations for regulatory policy regarding permissible levels of groundwater pumping; something that had not – prior to 2003 – been a necessary part of Michigan's groundwater management, outside of massive water withdrawals made primarily by public utilities and municipalities.

In Public Act 33 of 2006 (Michigan State Legislature, 2006), the GWCAC and TAC were furnished with the terms "adverse resource impacts" (ARIs) and "characteristic fish populations" (CFPs). The definition for ARI was determined in terms of independent and dependent variables that would constitute the metrics of the management decision. However, these were not well defined, either:

> "Decreasing the flow of a stream by part of the index flow such that the stream's ability to support characteristic fish populations is functionally impaired," or, "Decreasing the level of a body of surface water such that the body of surface water's ability to support characteristic fish populations is functionally impaired."

A definition for CFPs, however, was never supplied by the legislature. Together with a determination of what it meant to "support characteristic fish populations," significant portions of the statutory law appeared to be left to further development under the discretion of the GWCAC and the TAC. A description and analysis of how these terms were defined through the process of the development of the WWAP will be provided in a subsequent section. However, what is interesting is to note how much leeway the GWCAC had with definitions, both legal and scientific, for both of the metrics cited as being the ones used for regulation: ARI and CFPs.

Unlike the original Council, the 2006 GWCAC had no funds for remuneration, but the fact that no one of the 2003 GWCAC dropped out of the Council spoke, to Sen. Birkholz, of the members' commitment and investment in the process. This opinion was seconded by the GWCAC members that were interviewed. Despite the lack of remuneration for meetings, the Council continued with their process of holding monthly meetings that would meet over the course of one or two whole days. At these meetings, the technical advisory committee (TAC) would report the progress made by the technical working group – the agency and academic scientists working on addressing and solving the smaller issues of science development and scientific integration. One USGS scientist (I4) said, "We had weekly meetings among the technical working group. From this we would update the technical advisory committee, who then reported to the groundwater council at their monthly meetings." This was corroborated by a MDEQ scientist (I5), who said, "During weekly meetings, other scientists could learn about the other models and understand how they worked."

At the full Council meetings, scientists from state agencies or academia would give presentations about the progress made in their groups and in the TAC, and then questions and discussions about the implications of the newly developed scientific models were made by the Council, with suggestions about what direction they felt was necessary to be taken. These suggestions were then disseminated back to the various scientists within the technical working group, who would try to integrate the new suggestions before continuing the development of the WWAP. "Toward the end of the process, we were presented with many different types of fish curves," GWCAC co-chair Kurt Heise recounted of the process of developing the fish curves.

In July of 2007, the Council presented their report to the Michigan legislature (Groundwater Conservation Advisory Council, 2007). The presentation laid out the findings and product of the work of the Council, which proved to be vast majority of the pieces that would eventually become the WWAP.

4.4.3.1 Science Used in the WWAP

It should be noted that neither the 2006 GWCAC nor the various scientists from state agencies or academia constructed the science of the WWAP from scratch during the time of the 2006 GWCAC. Indeed the 2006 GWCAC was greatly helped by the fact that they were able to leverage much existing scientific knowledge and studies of Michigan ecology that were built over the previous twenty years (e.g., Brendan, Wang, & Seelbach, 2008; Wehrly, Wiley, & Seelbach, 2003; Zorn, Seelbach, & Wiley, 2002), robust, extant regression models for computing index flows (Hamilton, Sorrell, & Holtschlag, 2008), and the application of MODFLOW to the groundwater hydrology conditions of the state (Reeves, Hamilton, Seelbach, & Asher, 2009), much of which was assisted through the Groundwater Inventory and Mapping (GWIM) database that was created as a major product of the 2003 GWCAC.

In developing the surface hydrology model, a standard and proven technique was used, precisely because they were proven techniques. "The hydrology model was relatively simple. [Even after some controversy], even the industry [skeptics] were convinced of the science [behind the simple model], and everyone bought into the hydrology model." (I5) For the groundwater module, an analytic method that was relatively simple, had relatively few data needs, and made simplistic assumptions about water cycling was used, because its use "implies that you're doing a generalized estimate." (I4) The fish model was a statistical model of fish abundance based on state-wide historical data, and was based on the assumption that "summer flows were what was biologically limiting, not the flows of other seasons." (I2) However, in early discussions with the both the technical working groups and the technical advisory committee, this was "thought to be a suitable way to go." (I2)

Furthermore, the WWAT is actually an integration of three different spatial models – an ecological model, a surface hydrology model, and a groundwater hydrology model – all set upon a web-accessible platform that integrates a Geographic Information Science (GIS) interface to query any geographic location in the state (Zorn, Seelbach, & Rutherford, 2012).

As part of the process of assessing the scientific merit of the proposed pieces that would make up the WWAT, a review process was undertaken by an external science review panel that found the process was on "sound footing" (Beecher, DePinto, Poff, & Woessner, 2006).

4.4.4 The Implementation of the WWAT

December 8, 2008 was the deadline for reporting existing water withdrawals, which were needed in order to establish a baseline level of withdrawals, pursuant to the Great Lakes Compact (2008). At that time, Michigan had 10,751 registered water withdrawals, with 3,501 registered withdrawals being 1 MGD or greater, the great majority of these (2,703 registered withdrawals) coming from irrigation permits (Great Lakes Compact Council, 2009). Since the implementation of the WWAT, Michigan added 593 permits in the first two years (July 9, 2009 – July 8, 2010 and July 9, 2010 – July 8, 2011) (MDEQ, 2011). Of these, 480 permits were granted via the screening tool, with the additional 113 permits being granted after undergoing site-specific review (SSR). In addition, over the first two years, 4 permits were denied, due to creating a possible ARI (i.e., they were classified under "Zone D" and didn't pass SSR). Looking at the spatial distribution of the granted permits, most appear to have been from southwestern Michigan.

In the regulatory process of water conservation in Michigan, the WWAT is meant to serve as an initial screening tool to ensure that a proposed water withdrawal of more than 100,000 gpd would not cause an adverse resource impact to nearby rivers or lakes. However, the WWAT is "supposed to be conservative … and – for the requests that didn't go through – the MDEQ would look at site-specific information, like what are other users doing, determine if there is a problem in the model, determine if the groundwater model is adequate for the user, etc." (I5)

In current cases of site-specific review, the MDEQ scientists recognize that, "flow and temperature are the basis for monitoring but it could include fish. … [and] SSRs are primarily a confirmation of flows." (I9) However, while the WWAT may currently provide information and insight to the impacts of pumping on river systems, several interviewees pointed out that it does not currently look at the impacts to lakes, well, wetlands, or other users. This raises problems of monitoring and enforcement.

Furthermore, there is currently a concern about enforcement and how to handle any major updates or changes to the models underpinning the WWAT. The drought during the summer of 2012 proved to be the first year in which enforcement of Michigan's water conservation law came into effect. However, there were few enforcement mechanisms that existed at the time. Luckily, the cases that were mentioned in interviews were addressed through existing regulatory requirements (either predating any Compact-related legislation or related to the requirement for registering all pre-2009 withdrawals by the deadline of December 8, 2008).

In the short term, an MDEQ scientist pointed out that he expected "more SSRs over time and [ARIs] over time as the available water is diminished," (I9) and a failure to have an enforcement mechanism in place could prove problematic. Another MDEQ scientist pointed to a conundrum with the potential of updating the model, stating, "if the changing the model causes an ARI notification for existing registered users, there is no clear statutory language about SSR registrations." (I10).

4.4.5 The WWAT: A Boundary Object Produced by Co-Production

The GWCAC was an organization that was created for the express purpose of providing an opportunity for stakeholder organizations to produce a science-based decision-making tool for the purpose of water conservation. To that end, various state and federal agency scientists were recruited, in addition to scientific investigation being done by universities.

It is clear that the scientists recognized the existence of a science-politics boundary and worked to ensure that they did not stray across (let alone too close) to that boundary. Although state-agency scientists did sit as members of the GWCAC (with one agency scientist sitting as co-chair), the fact that they did not take any votes in the council indicate their recognition of a need for independence from the politics of the GWCAC – and water conservation in general – in order to maintain legitimacy as scientists in the production of the various components of the WWAT. In addition, the creation of the Technical Advisory

Committee allowed a greater "distance" from the science-politics boundary, within which the science of the WWAT could be developed, even as it was shaped through communications with the GWCAC.

The process that the GWCAC decided to pursue (Steinman, Nicholas, Seelbach, Allan, & Ruswick, 2011) was one that actually provided a lot of opportunities for non-scientist members of the council to both learn about the science and also shape – to an extent – the direction and form of the science that eventually became part of the WWAT while also maintaining the scientific integrity through the process of peer-review. The necessity of ensuring that each component of WWAT underwent successful peer-review indicated an understanding by members of the GWCAC as well as those outside the boundary organization – the Michigan Legislature, stakeholder groups, and the scientists involved in producing the science – of the importance that the resultant WWAT (the boundary object) be deemed scientifically legitimate. Without that stamp of approval, one of the major policy goals – an objective tool – would be undermined. In these ways, it is clear that the GWCAC operated as a boundary organization to produce the WWAT. However, this does not – in itself – make the WWAT a boundary object.

It is clear that there was a fair amount of pre-existing science that was used in developing the WWAT, and it is also clear that none of the pieces of the pre-existing science was the WWAT. The creation of the WWAT as Michigan's answer to fulfilling its water conservation obligations under the Great Lakes Compact also instituted a new framework of thinking about water conservation: though the lens of ecology. Furthermore, the creation of this tool created a focal point for legislators, regulators, water managers, and the public when thinking and talking about water conservation. In this way, it is possible to describe the WWAT as a boundary object, fulfilling scientific and nonscientific purposes. In addition, in the process of redefining the framework of state water conservation, the GWCAC also had to develop definitions for scientifically and legally novel concepts – while also ensuring that those legal definitions would be scientifically defensible.

4.5 The Importance of Definition: Conforming the Scientific with the Legal

It can be said that, in law – statutory, regulatory, and common law – definitions and interpretations of language matter (Bix, 1993; Sinclair, 1984-1985). In the case of water law, due to the legal foundation of the public trust doctrine (see Section 3.1), government only has control over water resources such as they refer to navigability as a definitions of commerce (over which the government has regulatory authority). Any deviation from those legal precedents and judicial interpretations may well be overruled or dismissed over a lack of standing (similar to the Michigan Supreme Court decision in *Nestlé*, described previously). In short, under the public trust doctrine, the definition of *navigable waters* has become a central concern as to whether a piece of statutory law is constitutional, how a regulatory water law can be enforced, and upon what bases of legal precedent a common law decision about surface water is made. However, if the *interpretation* of statutory language in executing the law is important, then the *writing* of statutory law – including the definitions of terms – is an even more important point to examine, since the writing will form the basis of regulation, argumentation, and future adjudication (i.e., interpretation). As Bix writes:

> It is a matter of considering what percentage of choices regarding the (legal) co-ordination or regulation of action are attributable primarily or entirely to the

> legislature or executive [in drafting and passing statutes] against those attributable primarily or entirely to the judiciary [in interpreting statutes and upholding common law]. (Bix, 1993, p. 2)

In science, definitions of key terms also matter. Whether it is determining the exact definition of a physical constant, defining a variable in a model, asserting the boundaries of a scientific theory, or stating an hypothesis, definitions play a crucial role in the process, understanding, and data management of the scientific enterprise. Disagreement does not tend to be focused on the truthfulness of data, but rather on the methodology used to attain the data or on the interpretation of the data, and thus, the need for definition in science (Boring, 1945). Sometimes, differences in definition (sometimes over the terminology of metrics but often over the inherent assumptions held within a disciplinary paradigm) between disciplines may result in confusions. Therefore, to use an example taken from the multi-disciplinary work done on the Augusta Creek project (Chapter 5), almost a whole day's worth of meeting time was taken to explore the different inherent assumptions, measurement methods, and applications of the seemingly simple concept of *base flow* across the different disciplines present at an early group meeting.

The purpose of this definition-making and definition-seeking is different between law and science, though. As Jasanoff points out, " 'science' emerges as unswervingly committed to the truth, while the [legal process] is shown as intent on winning adversarial games at any cost," and, "fact-finding in the [legal process] is always contingent on a particular vision (and mechanism for) delivering social justice … [whereas] science is ordinarily seen as set apart from all other social activities by virtue of its institutionalized procedures for overcoming particularity and context dependence and its capacity for generating claims of universal validity" (Jasanoff, 1997, p. 7).

4.5.1 Defining Terms within the Conservation Law

In the case of Michigan, as the state moved from its form of relatively *laissez faire* riprianism toward a form of regulated riparianism that was in line with the Compact, the 2003 GWCAC outlined the manner in which the state's statutory definitions did not "include numerous definitions in the Compact" (Groundwater Conservation Advisory Council, 2006, p. 38). Similarly, an analysis of the twenty or so individual public acts relating to the passage of the Compact will show that almost all of them contained a section specifically for definitions that were to be used throughout the act and – in some cases – adding to or amending the Michigan Environmental Protection Act (which most of these public acts were also amending).

Maybe it is not a big surprise that the Council, whose membership was mostly drawn from law and policy fields, spent time qualifying the definitions of so much terminology that they found within their bailiwick. For example, they spent additional time to define *sustainability*, having recognized that the term was not well defined, and then provided their statutorily required recommendations based on their definition (Groundwater Conservation Advisory Council, 2006).

4.5.1.1 Defining "Characteristic Fish Populations"

The term "characteristic fish populations" first appears in Public Act 33 of 2006, in the portion that modifies Section 32701 of MEPA, and it is provided only as a part of the definition of what constitutes an adverse resource impact:

> Decreasing the flow of a stream by part of the index flow such that the stream's ability to support characteristic fish populations is functionally impaired (Michigan State Legislature, 2006).

According to Senator Birkholz, who wrote, introduced, and co-sponsored the bill that would become PA33 of 2006, the phrase was originally came out of the work being done by the 2003 GWCAC. In the final report of the 2003 GWCAC to the legislature, although the specific phrase "characteristic fish population" was not used, the very similar phrase "characteristic fauna" is used twice to describe the relationship between groundwater availability and aquatic ecology (emphasis added for clarity):

> Moderate groundwater inflow occurs in streams that drain soils of mixed or intermediate textures, and these coolwater streams support a characteristic fauna, as well as species at the edge of their cold or warmwater limits. … Streams that drain bedrock or fine-textured soil typically have small groundwater inflow. These streams are termed warmwater streams, and, though groundwater inflow is small, they have baseflow habitats that support a productive and characteristic fauna. (Groundwater Conservation Advisory Council, 2006, p. 18)

Senator Birkholz recounted that the concept was raised during talks with Council members as well as during their testimony to her committee, stating, "The health of a waterway is indicated by its fish population. It became very clear that if fish are dying or dead, there is a problem, therefore fish should be the determination of the ARI."

Furthermore, when she found herself trying to explain the concept to editorial boards, those editors didn't understand the concepts of either characteristic fish populations or adverse resource impacts. To help with visualizing these concepts, Sen. Birkholz recalled that "[one Council member] came up with a cartoon describing adverse resource impacts and characteristic fish, and everybody suddenly understood. However, when the fish were described as 'dead fish', [the Council member] asked them not to use the term 'dead fish' but to use 'adverse resource impact' and 'characteristic fish'."

GWCAC co-chair, Jon Allan, also described his reasons for why he pushed for the language of "characteristic fish populations" as being motivated by shifting the concept of conservation A) away from existing – and therefore pre-defined – legal language and B) toward the concept of the "functional integrity" of the ecosystem:

> Based on the words of the Great Lakes Compact, which are basically, "Thou shalt not create an adverse impact to the water or water-dependent natural resources," how do you do this? I knew that there was forty years of fish data available, and that it was important to change the focus from individual fish to the populations of fish. The lynchpin was around the idea of functional integrity. People kept coming up with "significance", but I wanted to focus on the biology and not the legal language. If we used terms already existing in the legal lexicon, discussion in the Council would devolve into arguing about limits and standards based on existing legal frameworks. Also, the concept of functional integrity was important and fit the mission of the Compact, because you don't want to affect the system, and any effect of the system could be measured by populations. Therefore I pushed for functional integrity as an idea, because "characteristic fish populations" was a conscious choice to make a novel word to be defined in biological terms and not to be based on previous legal terms. It also gave the Council a mechanism through which to define "adverse" in a way that wouldn't be linked to existing standards of "adverse."

The potential of using a biological standard of a macro-fauna for the regulatory metric of an environmental standard – as opposed to a bacterial or chemical metric – was huge. According to an MDEQ scientist, "at that time, the legislature was willing to use a biological standard, but not until the Council defined it scientifically. The legislature probably didn't recognize the import of that choice." (I5)

From an early stage in the 2006 GWCAC, another co-chair, Paul Seelbach[12], was a supporter of the concept of characteristic fish populations, since it would focus the attention away from the traditional single-species approach to conservation, and refocus the attention on using the functional impairment of a fish community as a whole to describe the condition of water quality – and therefore of water quantity – in a particular river. According to one MDNR fisheries scientist (I1), "No one really knew how this would look

[12] Since Paul Seelbach is also a member of my PhD committee, he was not included as an interviewee.

like in the end, but it would include all the fish, and he [Paul] said that it [regulation] cannot be only about game species, but about fish communities. This meant that you could consider streams other than just cold water." This was confirmed by a USGS scientist who recounted, "The characteristic fish language was put in at the influence of Jon Allan and Paul Seelbach to steer away from only protecting trout." (I6)

4.5.1.2 Producing the Scientific Definition of "Characteristic Fish Populations"

Even after the potentiality of the science was presented to the external review committee (Beecher, DePinto, Poff, & Woessner, 2006), it was clear that work would need to be done in order to connect the existing ecological data and science with the statutory requirements. In other words, "We needed something that was measurable and tied to the amount of water withdrawn." (I5) There is a very detailed account of the methods that linked fish abundances to water withdrawals (Zorn, Seelbach, & Rutherford, 2012), but even in that report, some explanations for why certain choices were made are described as being contingent upon statutory requirements or guidance from the Council. Many of these decisions were made due to the shaping process that emerged through the iterative conversations and educational activities between the technical working group (which was basically made up of the agency and academic scientists working on the individual issues of the WWAP), the technical advisory committee (which included members of the GWCAC as well as a handful of agency scientists), and the Council at large. The result of this iterative process of conversations helped shape what many of the interviewees now call the "fish curves," which is effectively a scientific definition of what is a "characteristic fish population."

These fish curves do, however, have many assumptions built into them that, due to issues of time, lack of adequate data, model-integration concerns, and political compromise, are now also a part of the working definition of what is a CFP. One TAC scientist stated, "realistically, the characteristic fish curves should include error" (I1), while another stated, "it's regionally applicable… however, there wasn't good data on very small streams" (I2). Bryan Burroughs (I12) also lamented the inability to make modifications to the model at the later stage in which he was involved in the process ("I tried to raise several points that I know are important in fish modeling, but I could never change the model during the process [of the WRCAC].") One potential danger of presenting fish curves without error is that people could draw the assumption that there is a one-to-one predictable association between water quantity and fish community. One USGS scientist (I6) pointed out several differences between the allowed level of correlation between ecology and engineering, in which ecology is allowed to have a far lower level of correlation than engineering, indicating a recognition of the inherent variability of ecological systems. However, one MDEQ scientist stated that "flow and temperature can predict very well the expected fish that one would find," (I9) implying that the WWAT predictions were directly predictive of the expected fish community.

4.5.1.3 Adding the Definition of "Thriving Fish Populations"

The terminology of "thriving fish" suddenly emerges as part of the development of the fish curves and is restricted to only the most abundant species found in that river type (Zorn, Seelbach, & Rutherford, 2012). However, the statute (PA33 of 2006) makes no reference to any form of metric other than "characteristic fish." Since the concept of "characteristic fish" included all examples of "thriving fish," then what was the justification of distinguishing this group from the rest?

Bryan Burroughs (I12), a member of the Water Resources Conservation Advisory Council (WRCAC) explained that he pushed for inclusion of the "thriving fish" language to go into the final recommendations for implementation, because the concept of "characteristic fish" didn't necessarily incorporate the social associations that draw people to fish.

> It isn't a question of existence, but the cultural and social benefits of a river are based on thriving and abundant fish. In other words, cold water fisheries are about thriving fishes, not merely characteristic fishes. People could grasp this argument, and the policy line in the cold water classification moved from characteristic fish populations to thriving fish populations.

This sort of social assessment is not an uncommon reason that people use to describe the motivation behind a particular regulation or statute. Indeed, social reasons are often the reason for why laws are proposed and passed.

4.5.1.4 Defining "Adverse Resource Impact"

Although there was statute language that gave a broad definition of what an adverse resource impact (ARI) constituted, "no one had defined ARI in a real manner prior to the tool." (I13) This placed the responsibility of creating an operational and measurable definition of ARI with the Council. Unlike the definitions of characteristic fish populations, however, the particular level of an ARI was deemed to be a socially determined concept, and members of the TAC shifted from the role of scientific advisor to that of scientific assessor. Now, scientists would run scenarios of what would happen when an ARI was set at particular levels. “Stakeholder groups [represented by Council members] were asked to help determine the [threshold] levels of the ARIs using the scientists’ expertise.” (I13)

4.5.1.5 Definitions Affecting the Relationship of Groundwater and the Public Trust

Although the wording of the language tacitly shifted away, with the recognition the traditional legal distinction of groundwater and surface water, one of Senator Patti Birkholz’s senate staffers (I7) recalled that there was a conscious decision not to make an explicit and definite shift away from the traditional legal distinctions between groundwater and surface water laws, even though it would implicitly happen under the Compact:

> It was a political move NOT to explicitly state connections between surface water and groundwater in the bills. We focused, instead, on the constructive portions of water conservation and anti-withdrawals.

One GWCAC member wondered whether “a use under the tool would be considered *de facto* ‘reasonable’… because permit approval for large scale withdrawals are a decision of reasonable use”(I13). Put into this context, it is possible that withdrawals under the Compact, and withdrawals registered due to the Compact could move all waters – groundwater and surface water – toward the public trust.

However, this is not the only view. Jon Allan perceived the WWAP as consistent with maintaining the existing spirit of water dispute resolutions, stating, “The tool is not a permitting model, but an informing model, and there is an expectation of reasonable use of users. There is a social obligation to not cause harm. … The tool was built around the concept that there is no priority of use … and [decisions should be made] outside the DEQ to give choices over the use of a common resource to the community.” This evokes an image of increasing the avenues of community involvement and individual responsibility over government involvement, which is more similar to the position of groundwater governance as one of private ownership rather than of public trust.

4.5.2 Reflecting of the Defining Terms in the WWAP

While spending time discussing the development of definitions of specific terms may seem not to be terribly relevant to larger issues of water conservation, when these definitions "hit the road" of regulatory management, they become critically important. In the interviews with members of the MDEQ – the agency that is in charge of most environmental regulation enforcement – the implications for regulation (and therefore potentially for governance) of the resource of groundwater was made more clear.

The process of scientifically defining the term "characteristic fish population" built upon existing scientific research and resulted in a codification of relationships between water withdrawals and changes to characteristic fish populations across 11 classes of rivers: the characteristic fish curves. These curves, though, were a product of negotiation, compromise, and simplification. Furthermore, the concept of characteristic fish populations was expanded to include the concept of *thriving* fish populations, in order to account for social motivations that lay behind why people may wish to conserve or protect a river's fishes.

The question of whether the impact of Compact's folding together of the spheres of groundwater and surface water into the unified "waters of the Great Lakes" will have a future impact on the determination of the state's groundwater to be a resource in the public trust is yet to be determined. Neither the Compact nor Michigan's conservation law make any mention of altering the relationship between groundwater and surface water within the

Michigan's legal framework. It is at best a "toehold" – as I7 stated – for those who wish to extend the public trust doctrine to groundwater.

4.5.3 Co-producing a Language Common to Science, Law, and Policy

Throughout the process of developing the WWAP, the Council continually returned to reiterating their consensus statements of the mission of the Council, the definition of "conservation" under which they were mandated to act, and – later – the definitions of the regulatory terms of "characteristic fish populations" and "adverse resource impact" as well as the implications of those terms. Similarly, the Technical Advisory Group was tasked with working iteratively with members of the Council in developing the science to meet the policy ends while simultaneously (a) being true to standards of scientific objectivism and keeping conscientiously distant from making social policy recommendations and (b) returning to provide instruction and advice to the Council members in how to interpret the conceptual bases of the science itself. Finally, the legal group was fastidious in ensuring that they link legal precedence in existing common law and statutory law with the scientific peer-review process and the objective physical bases upon which the various definitions and principles of the WWAP were based.

In the context of the Great Lakes, the Compact had the impact of creating a water quantity conservation process that allowed each member state and province to derive their own objective legal bases by which to determine the required conservation outcomes. The case of Michigan was unique in that the three "realms" of knowledge production and use – policy, science, and law – worked collaboratively, integratively, and iteratively to converse over a period of years about all the salient points necessary in producing an effective regulatory process that was – at least on paper – an objective, adaptive, and multi-stakeholder-based water conservation framework.

The term "characteristic fish population" displaced the concept and associated management goals of the previously established "designated trout stream" framework. As such, it was a conscious decision on the part of the GWCAC and state scientists to move away from a single-species-based approach of conservation to one of functional integrity. Arguably, ecological science had already shown the deficiencies of a single-species-based approach on conservation and the relative benefits of a community-based approach, and this recognition appears to have dovetailed with the shift in focus away from the designated-trout-stream approach among the policy-makers. That the final, technical, definition of "characteristic fish populations" was guided and shaped through interactions between the TAC and GWCAC members further indicates that this term is a product of co-production.

Similarly, the term "adverse resource impact" displaced all previous concepts of "adverse" and "impact" that were produced within the long course of common law. It is clear that various definitions of ARI – a unique definition for each of the eleven defined river types – was also a product of co-production, since the GWCAC members negotiated levels of conservation that would be amenable to their constituent groups; scientists associated with the GWCAC circumscribed their advice to scientific determinations; and the council as a whole continued to operate in consensus in order to provide the Michigan Legislature with their recommended levels of conservation.

Finally, given the centrality of the terms within the WWAT, and the necessity of understanding and using these terms to discuss water conservation within the state, the terms can also be considered to be new boundary objects that will be used by nonscientists to discuss water conservation within the state. They will also – undoubtedly – be used by scientists to assess the efficacy of water conservation, determine the various qualities of the scientific models underlying the WWAT, and carry out science-based site-specific reviews.

4.6 A Retrospective Assessment of WWAP

Although the WWAP was produced by the GWCAC, was voted into existence by the Michigan Legislature as the means of regulating groundwater withdrawals, implemented by the MDEQ, and has been in use for three years, the perceived quality of the WWAP has not received much formal scrutiny. This is surprising for a regulatory product that has the statutory requirement of periodic review under terms of the state's enforcement of the Compact (which was added, because it was a requirement of the Annex 2001 document as well as the Great Lakes Compact). Furthermore, the WWAP is supposed to be an adaptive management model, implying regular feedback. Finally, periodic review was a central suggestion of every major internal and external report from the various councils (Beecher, DePinto, Poff, & Woessner, 2006; Groundwater Conservation Advisory Council, 2006; Groundwater Conservation Advisory Council, 2007). Despite all this, the WWAP has apparently disappeared from view in the legislature and even in much of the MDEQ. Several interviewees who were involved in the construction of the WWAP indicated no certain knowledge about any review of the tool ("I hadn't heard anything bad about the tool… but I'm not certain about the use of the tool in practice," said former Council co-chair, Kurt Heise), even while they recognized that the quality and reliability of the tool was contingent upon continued funding (Sen. Birkholz said, "The tool works well [as a regulatory tool] so long as it is funded," and former GWCAC co-chair, Jon Allan, said, "The Council built a tool based on the empirical relationships and based on the expectation of changing and updating the model."). Some were aware of recent budget cuts to the agencies that would certainly curtail updates and reviews of the tool ("Funds were earmarked, but money was pulled for actual evaluation," and "there is no fiscal support to do this [evaluation] at this time, so it's unlikely to get done," and, "there is presently no money to review the models or suggest changes," among other similar comments). The first five-year review period required by the Compact is at the end of 2013, and – at the time of these interviews – many doubts were expressed about the feasibility of conducting a substantial review of WWAP, in compliance with the Compact. However, I believe that it will be illustrative to see how the people involved in the development, implementation, and use of the WWAP perceive the strengths, weaknesses, and challenges of the process as it currently is being used.

4.6.1 Perceived Strengths of the Current WWAP

There was a strong consensus among the interviewees that the current WWAP was a good regulatory process. The comments about the strengths of the process were generally based on the factors that were most familiar to the interviewee, and so all the agency scientists tended to comment on the strengths of the underlying science of the process ("All the empirical data came only from Michigan. We didn't have to use outside data," and, "A multi-watershed interpretation in the Kalamazoo River was pretty close to the tool's predictions."), while all the members of the GWCAC and WRCAC described the strengths of the tool in regard to governance issues ("Michigan needed a way to define ARIs, because of the Compact, but it could have been done in a very arbitrary way. Instead Michigan looked at all streams and all impacts, which means that it can look at cumulative withdrawals," said one USGS scientist, and Council co-chair, Jon Allan endorsed the WWAP as a means of enshrining the principle of fair use, saying, "the process surrounding the WWAP provides a town hall style of governance that maximizes the concept of reasonable use, which returns management questions about a common resource to the community."). Many of the interviewees also commented that these strengths of the WWAP were due in major part to the long-term collaborative process of the GWCAC ("The process works incredibly well, because of the people that put it together," said one MDEQ scientist, "Instead of focusing on contentious language, the Council focused instead on the constructive portions of water conservation and anti-withdrawals," said a senate staffer), with a number of interviewees attributing the success of the process to the relatively long periods of time that the Council members worked together ("[I5] had been talking about the fish curves for two years before I joined the technical committee" (I1), "It took us a couple of years to learn all the science" (I2), "I designed the basic framework of the tool in 2005" (I5)) as well as the mechanism of consensus ("The recommendations from the Council was a consensus document. You can't get an outcome without buy-in on this point [of consensus]," opined a senior DNR scientist) and continued, iterative communication with scientists ("There was an iterative process with the scientists and the Council" (I1), "The science of the fish curves led to the political process of determining the ARIs" (I6)) as the key points of how the process was able to move forward so strongly. Furthermore, the strength of this consensus was, according to Council co-chair, Kurt Heise, one of the major reasons that helped persuade somewhat skeptical senators to support the recommendations of the Council.

4.6.2 Reflections of the Perception of Strengths

While there was strong consensus on the opinion that the current WWAP was a good regulatory process, this is not a surprising outcome, since almost all of the interviewees worked directly in the development of the WWAP in one capacity or another. However, I believe that it is useful to recognize that this understanding of success was based on something more than a sense of ownership or stewardship toward the WWAP; the commentary was conditioned on perceptions of the successes related to the individual's work done in the creation of the WWAP as well as the perception of how that work fit into the greater part of the operation and deployment of the WWAP and not general pronouncements of praise that went beyond each interviewee's area of understanding. When pressed with follow up questions into areas in which an interviewee didn't have much expertise, the appraisal of the WWAP strayed toward technical or policy connections, depending on the expertise of the interviewee. Whenever interviewees described what they felt was a strength of the WWAP, they invariably started by framing their answers to begin with the topics of which they were most familiar, before – if they proceeded beyond it – they tried to tie those strengths to a greater sense of success. Furthermore, among those who were not involved with the creation of the WWAP but with its implementation and use, there was less outright praise and a greater level of criticality (see Perceived Weaknesses and Perceived Challenges, below).

What may be interesting to note is none of the interviewees said that the current version of the WWAP would remain satisfactory. This recognition was held by the agency scientists and the council members, even though many of these individuals are aware of the difficulties that adaptive management faces in politics.

4.6.3 Perceived Weaknesses of the Current WWAP and Underlying Tensions between Science and Law

Unlike their perceptions of the strengths of the WWAP, there was no consensus among the group as to the weaknesses of the current WWAP. However, interviewees were either reticent in voicing their thoughts of what weaknesses the WWAP has or they couldn't think of any at the time of the interview. In either case, the number of weaknesses that the interviewee volunteered was far fewer than the number of strengths that were mentioned. However, the most common weakness that was pointed out was related to the lack of current funding to assess, maintain and update the WWAP. (e.g., Sen. Birkholz noted, "the tool works well so long as it is funded, but it is receiving less funding now," a MDEQ scientist (I10) stated, "budget-cutting has led to no state action on maintaining the model", and Bryan Burroughs stated, "over the past three years, there were no monies for maintaining the tool, and … the MDEQ doesn't have enough people.") However, scientists were more critical of the assumptions of the models underpinning the WWAP:

> The characteristic fish curves should include error bars, because the science as error. (I1)

> There is a lack of data from Upper Peninsula streams. We are trying to do 100 or more samples to fill the gaps. (I2)

> Downstream warming effects were limited in the model primarily because of the lengths of the stream arcs [in the GIS model] and the modelers wanted to tie the conditions to existing survey points. (I2)

> The water accounting tool [within the WWAP] just takes water out. It doesn't put any back in. It assumes that the registered rate will be constantly used. (I4)

> The WWAP is likely to have problems in Southwest Michigan, which shows the limitation of a state-wide model in a specific watershed. (I5)

> The stream flow used a regression method of historical data, therefore the regression method might not be the best option for future models. In addition, stream flow information was not available in very small streams, and it is in very small streams where ecological impacts are likely to be the highest. (I6)

> It would be nice to see ground truthing of the model to test the efficacy of the models. (I9)

> The tool is based on a probabilistic model, not a mechanistic one. … The tool relies on the assumption that the most important bottleneck is summer temperatures. … There is little data from small streams. (I12)

In contrast, interviewees without a strong science background discussed a variety if perceived weaknesses:

> The MDEQ needs more staffing to understand aquifers in Michigan, since they are different than in other states. (I8)

> New water users have to approach existing users, and existing users have to work to let new users in through the use of water councils. (I11)

> The USGS is cutting back on the number of flow gauges, and they place them mostly for flood control, like large rivers. (I13)

4.6.4 Perceived Challenges of the Current WWAP

Although there is some overlap between the concept of "challenges" and "weaknesses", I have chosen to separate out those items that were, at the time of the development of the WWAP, left to future compromise (e.g., climate change) from to those items that were not foreseen during that process (e.g., socioeconomic incentives to convert significant portions of land to a water-intensive use).

Similar to the perceptions of strengths and weaknesses, most of the interviewees spoke primarily of those challenges that related to their roles within the process of developing the WWAP. Many of the agency scientists noted – as already discussed – that updated versions of the WWAP would have to be made, accompanied by increased data collection to fill in holes in the model.

> We need significant investment to maintain flow gages and get more data. The government needs to make environmental monitoring and modeling more of a priority. (I2)

> We need to be able to update the tool. It currently uses historical flow data to create regressions. As we move away from the calibration period, we will need to update the models. (I4)

> The tool in its current form was not meant to be a long-term management tool. (I6)

Furthermore, most of the agency scientists noted that near-future climatic changes would need to be incorporated into the underlying models in some way.

> Temperature changes as well as precipitation and groundwater recharge connections will need to be investigated. There is an expected increase in water in the fall and winter and a decrease during the summers. But the impact to fish is unknown. (I1)

> I don’t know how climate change will affect groundwater variability and temperatures and how these will affect the model, because BFY is too coarse and doesn’t include parameters that may be critical to fish, like dissolved oxygen. Climate change leads to changes in the physical relationships in rivers, and this just isn’t covered in this version of the tool. (I2)

> The regulation needs to be able to determine change over time and make them attributable to things we can control. If the changes are caused by climate, we can’t [do enforcement]. (I4)

> Demand for irrigation will increase due to longer growing seasons, and the tool needs to consider both [increased numbers of irrigators and the changed length of the growing season]. (I10).

Among the members of both the GWCAC and the WRCAC, the issue of climate change as a future challenge was far more muted, with only one council member raising it as an issue without any prompting. Even with prompting (using language like, “climate variability”), the interviewees didn’t seem to include the idea of near and distant future climate as one of the major challenges for the WWAP.

In contrast to the agency scientists, most Council members cited regional conditions and the question of whether updates to the scientific models underlying the tool would take place. The issue of Southwestern Michigan, while not raised by any of the agency scientists, was an often-cited challenge brought up by the Council members:

> In the near term, the Southwest Michigan process is the biggest challenge for the WWAP. (I5)

> There are political challenges from irrigators, especially if the tool or process is not changed. Southwest Michigan is trying to develop a model to show that the state model is wrong. Some way to manage water for the state versus the region is necessary. What the state needs is a region where there is a difference in using the tool in order to make a groundwater flow model, especially in Southwest Michigan. (I6)

> Other, newer, studies will out-trump the state model, which will lead to a re-entry into a lawsuit-dominated regime. Southwest Michigan is producing a model for their region that will out-trump the current state tool’s models. (I12)

4.7 Conclusions

The Great Lakes Compact required the State of Michigan produce a regulatory system through which to conduct registration and oversight, which resulted in the creation of the Groundwater Conservation Advisory Council, an advisory council that acted as a boundary organization, working together with scientists to synthesize the science necessary to scientifically define the statutory terms “characteristic fish population” and “adverse resource impact”. The Council also managed to propose legal definitions – based on the science – for these terms, and these were codified into law. These terms act as boundary objects between science and policy, now serving as a scientific and policy definition of water conservation as well as potentially setting the basis within the law for describing unreasonable use with regards to large-scale water withdrawals. In a similar way, the resultant Water Withdrawal Assessment Tool (WWAT) now acts as a boundary object, offering the public a science-based and objective method of assessing the legality of potential water withdrawals; providing the government and regulatory agencies an automated and effectively socially equitable mechanism to streamline the assessments of proposed water withdrawals; and opening new areas for applied scientific research, data collection, and model-building for improving and updating the underlying models that form the WWAT.

In general, those who participated in creating the WWAP held strong consensus about the strengths of the tool, but they were less unified as to its weaknesses. There was recognition in all quarters as to the future challenges that would face the WWAP as a regulatory tool, although these challenges varied across the different groups. There was general recognition, however, that the WWAP – if it wasn't updated or maintained – would eventually become either superseded or effectively useless.

This level of success and high degree of consensus would have been difficult to achieve if there hadn't been any recognition by the GWCAC and the TAC that, without working across familiar boundaries, the process would likely have led nowhere. Furthermore, understanding early on that the entire framework of thinking about conservation needed to be changed, linking it to novel concepts like "characteristic fish populations" allowed the members of the GWCAC the freedom to think in new ways. Finally, the importance of consensus-based work over a long period of time allowed the

GWCAC to engender trust between members that would – outside the context of the GWCAC – often be seen as being rivals.

4.8 Tables

Table 4.1. Michigan Public Acts Relevant to Passage of the Great Lakes Compact

Year	Public Act #	Major pieces of legislative action
2003	148	• Set limits to allowable groundwater pumping with no registration • Set registration requirements for pumping above 100,000 gpd • Creation of the GWCAC • Mission to create a groundwater inventory
2003	177	• Creation of the Groundwater Dispute Resolution process
2006	33	• Introduces ARIs to be tied to CFPs • Protects trout streams (no pumping w/in ¼ mile from trout streams and <150 ft depth. • Findings by the legislature about the nature of water
2006	34	• Reconstitutes the GWCAC ○ Adds 4 new members • Mission to create the WWAP
2006	35	• Creation of a pumping registry
2006	36	• Creation of "Water Users Committees"
2008	179	• Definition of ARI • Definition of regulatory zones for purposes of regulation
2008	180	• Prohibition of out-of-basin diversions • Provision for registration and permitting of certain large-quantity water withdrawals.
2008	181	• Provisions for SSRs • Definition of stream flow measurement protocol.
2008	182	• Provision for water conservation measures
2008	183	• Prohibition of water withdrawals that will result in an ARI. • Provision of specific presumptions and exceptions.
2008	184	• Provision of duties for water resources assessments and education committees and water users committees.
2008	185	• Implementation of the WWAT.
2008	186	• Definition of water withdrawal violations. • Provision of penalties and remedies
2008	187	• Requirement of certain water providers to conduct evaluations.
2008	188	• Requirement of bottle water producers to conduct evaluations.
2008	189	• Creation of the Water Resources Conservation Advisory Council
2008	190	• Passage of the Great Lakes Compact

Table 4.2. List of interviewees

Interviewee #	Identity	Interview Date
I1	MDNR fisheries scientist	July 13, 2012
I2	MDNR fisheries scientist	July 20, 2012
I3	Kurt Heise, GWCAC co-chair	August 1, 2012
I4	USGS scientist	August 1, 2012
I5	MDEQ scientist	August 7, 2012
I6	USGS scientist	September 14, 2012
I7	Senate staffer	September 14, 2012
I8	Senator Patricia Birkholz	September 26, 2012
I9	MDEQ scientist	October 5, 2012
I10	MDEQ scientist	October 5, 2012
I11	Jon Allan, GWCAC co-chair, WRCAC member	October 9, 2012
I12	Bryan Burroughs, WRCAC co-chair	October 10, 2012
I13	GWCAC member, WRCAC member	October 10, 2012

4.9 Figures

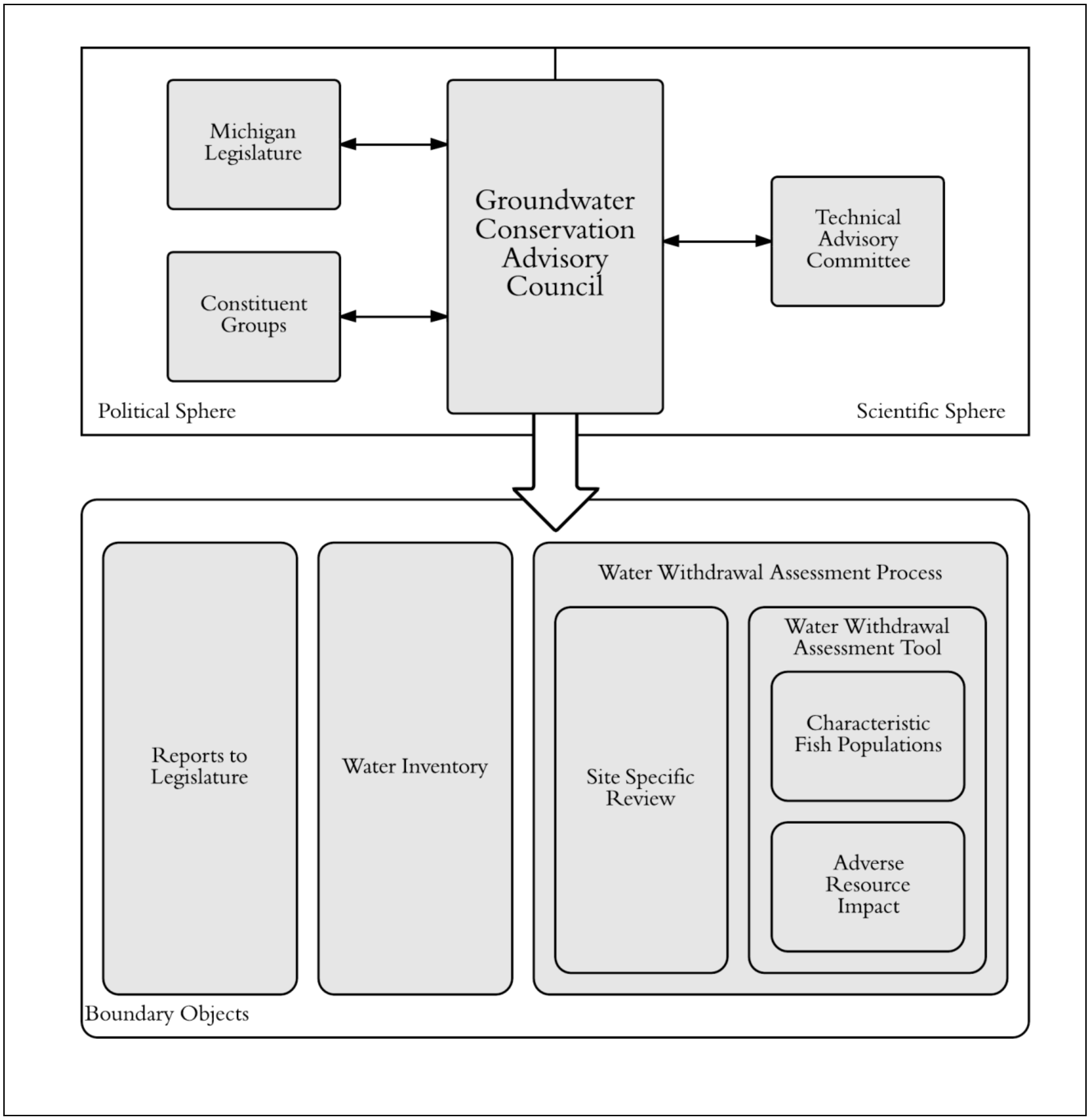


Figure 4.1. The Groundwater Conservation Advisory Council as a boundary organization along with the various boundary objects it created.

4.10 Appendices

4.10.1 Appendix 1

<u>Thirteen Principles of the GWCAC</u>

The 13 Principles that the GWCAC agreed upon that formed a basis for continuing collaboration were:

1. Michigan has an abundance of water resources, both groundwater and surface water. Certain groundwater sources can support a large amount of withdrawal without harm to other users or to the ecosystem. Other groundwater sources are more vulnerable to large withdrawals.
2. There is no overall shortage of water in the State. Currently, groundwater withdrawals in Michigan do not present a crisis.
3. Groundwater sustainability involves balancing the demands placed on the resource by the economic, social, and environmental sectors, ensuring that the needs of current and future generations are not compromised by current usage. The resource should be managed for current and future use based on well-founded scientific analysis.
4. The Council recognizes that conservation of our groundwater and our surface water includes both the efficient use of water and also the protection of quality.
5. Groundwater is a valuable asset, and if used efficiently, can provide the basis of a strong economy and high quality of life in Michigan. Nearly half of Michigan's population relies on groundwater for drinking water. Many others rely on groundwater for a variety of other purposes.
6. The Council has studied groundwater and withdrawals of water from groundwater sources, not surface water. However, the Council recognizes that groundwater and surface water are strongly interrelated and cannot be viewed as separate and distinct.
7. Michigan does not have a coordinated statewide process to manage groundwater use; such a process could minimize water-use conflicts and adverse environmental impacts. Recently a groundwater dispute resolution statute was enacted to supplement Michigan common law for evaluating reasonable use.
8. Some areas of the state have been identified as sensitive to groundwater withdrawal. Current and future withdrawals in these areas require a higher degree of monitoring, scientific research, and understanding.
9. Not all groundwater withdrawals are alike, and have differing levels and types of impacts; how much water that would be withdrawn, from where (location and depth), at what frequency and time of year, and ecological conditions are all major factors that determine whether and where an impact may occur.

10. Additional monitoring of stream flows, groundwater levels, aquatic ecosystems, and related mapping and analysis is essential to protecting groundwater resources.
11. Consistency and predictability of regulation between state and local units of government are essential to managing the resource. The state should encourage regional and multijurisdictional approaches to groundwater management and wellhead protection.
12. Local, voluntary, problem-solving approaches for resolving groundwater disputes and withdrawal impacts are the desirable starting point for conflict resolution.
13. The Council has not prioritized water use by type of user or by purpose of use. We recognize that the amount of groundwater withdrawn from an aquifer must be sustainable. (GWCAC, 2006, pp 3-4).

4.10.2 Appendix 2

Current Legal Definitions of Fish

Currently, the Michigan Compiled Laws (MCL) defines “characteristic fish population” as:

> the fish species, including thriving fish, typically found at relatively high densities in stream reaches having specific drainage area, index flow, and summer temperature characteristics. (Michigan Compiled Laws, 2012)

“characteristic fish curves” as:

> a fish functional response curve that describes the abundance of characteristic fish populations in response to reductions in index flow as published in the document entitled "Report to the Michigan Legislature in response to 2006 Public Act 34" by the former groundwater conservation advisory council dated July 2007, which is incorporated by reference. (Michigan Compiled Laws, 2012)

“thriving fish population” as:

> the fish species that are expected to flourish at very high densities in stream reaches having specific drainage area, index flow, and summer temperature characteristics. (Michigan Compiled Laws, 2012)

and “thriving fish curve” as:

> a fish functional response curve that describes the initial decline in density of thriving fish populations in response to reductions in index flow as published in the document entitled "Report to the Michigan Legislature in response to 2006 Public Act 34" by the former groundwater conservation advisory council dated July 2007, which is incorporated by reference. (Michigan Compiled Laws, 2012)

4.10.3 Appendix 3

Interview Protocol

The interview is semi-structured and questions are open-ended to allow flexibility in responses. All responses will be kept strictly confidential and will only be used for the purpose of research and no specific attribution will be made to the source. There are five (5) question areas: (A) issues you see as having been important in working with the GWCAC in developing the science behind the tool; (B) how statute law was translated into science; (C) the perceived strengths, weaknesses, and challenges inherent in the current permitting model; (D) future challenges to water conservation in the state; and (E) increasing water resource resilience.

A. Critical Issues in Developing the Science

During the development of Michigan's groundwater pumping permitting model from 2006 through 2007, DNR scientists were involved in formulating mechanisms for determining the science behind the management tool. To the best of your recollection, could you elaborate on the role that DNR scientists played in the process of determining the what science was used and how it was used in the tool?

- (If not already addressed): In what way did the agency work with the GWCAC and other agencies in developing the scientific basis of the permitting tool?
- What role did the agency play in presenting the findings to the legislature? In the debates within the legislature prior to final passage?

B. Translating statutory law

Michigan's groundwater conservation law presented very specific language of management metrics ("characteristic fish populations" and "adverse resource impacts") that had neither a scientific nor legal meaning. Could you describe the process in how these phrases were given scientific meaning? To what extent were other state agencies involved in this process of definition?

- (If not already addressed): What do you perceive to be the major assumptions and compromises that were made when translating statutory legal requirements into a science framework?
- (If not already addressed): How effective do you feel this collaboration was in producing a science-based tool to address the policy goals while also being scientifically and legally defensible?
- (If not already addressed): How often will a state agency determine the accuracy of model assumptions on the ground?

C. Perceived Strengths, Weaknesses, and Challenges of the Model

Currently and in moving forward, what are the major strengths, weaknesses, and challenges that you perceive of the permitting tool? What changes do you think ought to be made to the model? To the overall management process? Why?

D. Future Challenges

What do you perceive to be the major physical challenges facing Michigan water management in the next 15 years; 50 years? How capable do you feel about the current management process and structure in successfully addressing these problems?

- (If not already addressed): What role do you think that the permitting model will play in these management questions?
- (If not already addressed): What changes do you think will need to be made to either the permitting model or to the overall strategy of Michigan water management to deal with these perceived physical changes?

E. Increasing Resilience

Climate variability and change pose a challenge to water resources management. In your view, what are the critical limitations to improving water resources management to be more resilient to climate variability and change at the state level? (What about at the local level?)

- (If time permits): What limits the agency's regional ability to adapt to climate variability (or climate change) and how might (or how has) the state help address those limitations?

CHAPTER V:

A Modeling Assessment of Groundwater Pumping in Augusta Creek: Distance and Ecological Impact.

5.1 Abstract

Historically, the ecological impact of groundwater pumping on nearby surface water systems has received no formal attention, but as a result of a 2006 Michigan groundwater conservation law, the determination of well impacts on fish habitat become a key consideration in withdrawal decisions for all large-scale groundwater pumping operations. A modeling investigation of high-capacity groundwater pumping was undertaken and found that significant impacts to fish habitats in a transitional Michigan stream were affected primarily by well-induced changes in stream temperature. Adverse resource impacts occurred even at a pumping distance of 1 mi from the stream, suggesting that these thermally transitional systems were particularly vulnerable. Downstream impacts to fish community habitat were also demonstrated.

5.2 Introduction

The state of Michigan is blessed with an abundance of both surface and groundwater, being surrounded by the Great Lakes, which contains roughly 84% accessible of the United States' freshwater (Groombridge & Jenkins, 1998), and vast amounts of groundwater also provide the water source for many of the rivers in the state. Furthermore, it is well documented that the relative amount of groundwater influx has a strong influence on the taxonomic composition and diversity of fish communities in Michigan (Abbas, Liao, Li, & Richard, 2010; Brendan, Wang, & Seelbach, 2008; Seelbach, Wiley, Kotanchik, & Baker, 1997; Wehrly, Wiley, & Seelbach, 2003; Zorn, Seelbach, & Wiley, 2002). Recent concerns over groundwater withdrawal led Michigan to pass legislation whose language explicitly connected permitting of groundwater withdrawals to the conservation of specific fish assemblages (Annin, 2009; Steinman, Nicholas, Seelbach, Allan, & Ruswick, 2011). See Chapters 3 and 4 for further details on the history and process of developing this law.

By examining characteristics of the sites in which they occur, it is possible to group Michigan fishes into different "guilds" of species reflecting their association with hydrologic habitat conditions including rates of groundwater influenced baseflow (Zorn, Seelbach, & Wiley, 2002). Further, state-wide statistical analyses have shown that the relationship between groundwater input – indexed as "baseflow yield" – and a fish species' abundance is relatively consistent (Zorn, Seelbach, & Rutherford, 2012). This relationship provides an ability to predict the expected range of abundance of fish species in a particular stretch of river, based primarily on water yield and stream size, discounting pollution or other direct stressors.

In 2006, the State of Michigan passed Public Act 33 (Legislature, 2006) a groundwater conservation law that – among other things – provided the following standard of water conservation to serve in the interim period prior to the development of the now-established Water Withdrawal Assessment Tool:

> … there is a rebuttable presumption that a new or increased large quantity [water] withdrawal will not cause an adverse resource impact in [a designated trout stream] under either of the following circumstances:

(a) The location of the withdrawal is more than 1,320 feet from the banks of a designated trout stream.

(b) The withdrawal depth of the well is at least 150 feet. (Legislature, 2006, pp. 5-6)

Furthermore, the only definition of “adverse resource impact” for a stream or river to found in the law was:

> Decreasing the flow of a stream by part of the index flow such that the stream’s ability to support characteristic fish populations is functionally impaired. (Legislature, 2006, p. 12)

The legal presumption in Public Act 33 of 2006 (PA33-2006) is amenable to scientific assessment, since each circumstance provides a testable inherent hypothesis. This chapter tested the first circumstance of the rebuttable presumption (named here as the “quarter-mile-buffer conservation presumption”) by assessing the impacts to fish habitat – as a proxy for “the stream’s ability to support characteristic fish populations” – on a designated trout stream caused under different pumping scenarios that placed a large quantity water withdrawal at varying distances from the banks of Augusta Creek – a designated trout stream. This setup could assess whether the quarter-mile-buffer conservation presumption is sufficient to provide conservation, measured as no significant losses to fish habitat due to large-quantity water withdrawals.

5.3 Methods

Augusta Creek is one of the major tributaries of the Kalamazoo River, located in Michigan’s Lower Peninsula. It is located in the middle segment of the Kalamazoo River, and at its confluence with the Kalamazoo River (42.3330, -85.3504) it is characterized by a stable flow regime and cooler waters due to high groundwater inputs. The groundwater-dominated nature of Augusta Creek, together with low sediment embeddedness and lack of impoundments within the creek-shed, with an abundance of high quality coldwater and cool-water fishery habitats (Wesley, 2005). The majority of the watershed has little urban development, and no existing large groundwater abstractions.

Augusta Creek itself has two minor tributary systems; the main branch of the creek is roughly 19 miles long; its watershed covers an area of 37.9 sq. mi. The upper portions of the watershed stand at roughly 915 feet elevation, while the mouth of the watershed – where Augusta Creek empties into the Kalamazoo River – is at roughly 785 feet elevation. The creek flows roughly southward, passing through the town of Augusta, MI before entering the Kalamazoo River as a third-order stream (Figure 5.1).

Augusta Creek was a well-stocked trout stream, having over 1,000 trout stocked during any one particular stocking period, based on stocking data held in the Institute for Fisheries Research (unpublished data). Previous stock-recruitment assessments of brown trout have shown the creek to be a marginal trout stream (Wesley, 2005). Indeed, historical fish surveys of Augusta Creek have shown it to be home to principally coolwater and coldwater fish. Species include (by proportion of catch number) *Semotilus atromaculatus* (creek chub) (25%), *Catostomus commersonii* (white sucker) (18%), and *Rhinichthys atratulus* (blacknose dace) (12%), with *Salmo trutta* (brown trout) present at a rate of 32 trout per acre (MDNR, unpublished data). This sort of fish assemblage is characteristic of marginal/transitional trout streams (Wehrly, Wiley, & Seelbach, 2003).

With an understanding of the low level of water abstraction in the watershed as well as it being classified as a designated trout stream, Augusta Creek was chosen as a candidate for analyzing the potential physical impacts arising from groundwater pumping at different distances from the creek, and how these physical impacts translate to changes in trout habitat availability.

Due to the lack detailed site data about the Augusta Creek system, preliminary fieldwork was undertaken throughout the summer of 2005 (June through August) to investigate water temperature regime, flow rates, and fish diversity at nine sites throughout the creek system (Figure 5.1). During the course of the preliminary investigation, it was determined that a sub-watershed region in the headwaters of Augusta Creek would be more optimal for investigation (Abbas, et al., 2006), due to the dominance of regional groundwater hydrodynamics downstream (Figure 5.2).

5.3.1 Study Area Description

The study area had a total upstream catchment area of 19.1 square miles, a channel length of roughly 6.5 miles, and its groundwater table was not significantly affected by the greater, regional groundwater flow (Figure 5.3). Furthermore, the area of the chosen sub-watershed was large enough to investigate adjacent upstream and downstream impacts from pumping

Three sites were selected within this sub-watershed – one upstream site, one downstream site, and one mid-basin site (Figure 5.3). Channel morphology surveys were conducted at each of these three sites. The upstream site was situated just below of a constructed wetland. The majority of the river's substrate was characterized by sand, with vegetation lining the banks. The site was characterized by having a relatively wide flood zone covered in emergent plants. The surveying was conducted over a 393-foot (120m) length of the creek. Cross-sectional data was collected along pool-riffle systems as well as straight “runs”. A total of five cross-sections were taken. The modeled mean July stream discharge was 12.57 cfs, and its estimated long-term baseflow inputs from groundwater was 1.70 cfs.

The mid-basin pumping site was located close to the middle of the watershed, and was the site most likely to be influenced by its proximity to the proposed model wells in our scenario analysis. The site was just downstream of a series of cedar swamp wetlands. Here, substrate size ranged from fine particulate organic matter (FPOM) to small boulders over 40 cm in diameter. The surveying was conducted over a 328-foot (100m) length of the creek. A total of seven cross-sections were taken. The modeled mean July stream discharge was 12.78 cfs, and its estimated long-term baseflow inputs from groundwater was 4.31 cfs.

The downstream site was located at the downstream extent of the sub-watershed. The site was set within a relatively wide floodplain, with the remains of what appeared to be the retaining walls of an old dam. The stream substrate was mostly characterized by sand and gravel, with some FPOM along the banks in some cross sections, as well as boulders (>40 cm diameter) in other cross sections. The surveying was conducted over a 393-foot (120m) length of the creek, with a total of six cross-sections taken. The modeled mean July stream discharge was 20.66 cfs, and its estimated long-term baseflow inputs from groundwater was 8.79 cfs.

5.3.2 Modeling Adverse Resource Impacts to a Designated Trout Stream

State law in 2006 required that an adverse resource impact occur due to water withdrawal, but that such impacts were presumed not to happen to designated trout streams if pumping were to occur beyond ¼ mile from the banks of the stream. However, regulatory definitions of “characteristic fish populations” (CFPs) and “adverse resource impact” (ARI) had not yet been finalized at the time the research on this chapter was carried out in 2005. (See Chapter 4 for more information about how these terms were developed.) Indeed, the research reported in this chapter was carried out at the request of MDNR as an attempt to model the impacts of groundwater pumping on the changes in those metrics related to the index flow of a groundwater-fed stream and to the fish populations found in designated trout streams. In lieu of an official list of fish species associated with designated trout streams, the assessment in this chapter investigated the changes in habitat to those fish species found in biological sampling conducted in Augusta Creek (

Table 5.2).

Changes in groundwater and surface hydrology were modeled by project collaborators at Michigan State University (Abbas, et al., 2006; Abbas, Liao, Li, & Richard, 2010). I modeled the ecological impacts using a modified version (Figure 5.4) of the Physical Habitat Simulation model (PHABSIM) from the US Geological Survey (Bovee, 1982). The PHABSIM software program has a long history of use to quantify the impact of instream flow variation on fish habitats (Johnson, Elliott, & Gustard, 1995), and in the UK (Petts & Bickerton, 1994), although there is no standard methodology for using PHABSIM in assessing the effects of groundwater withdrawals on fish habitat. PHABSIM uses hydraulic and substrate parameters, typically estimates, in its end-calculation of the habitat index called a "weighted useable area" (WUA), which is meant to reflect a combination of physical microhabitat quantity and quality (Waddle, 2001). Each modeled location in the PHABSIM model is independently scored for each fish species using a habitat suitability index (HSI) from 0 to 1, based on the life-stage of that species, and standardized species HSI habitat metrics (e.g., McMahon, 1982).

HSI models used here included the model for brook trout (Raleigh, 1982) and for brown trout (Raleigh, Zuckerman, & Nelson, 1986) as representative of the cold water fish guild. Although mottled sculpin were found in Augusta Creek during the survey, they are not modeled here because HSI curves for mottled sculpin were not available. Cool water guild species characterized using HSIs included blacknose dace (Trial, Stanley, Batcheller, Gebhart, & Maughan, 1983), white suckers (Twomey & Nelson, 1984), and creek chubs (McMahon, 1982).

PHABSIM has the additional functionality of using cross-section data put into the software program to calculate hydraulic estimates of depth and velocity that it then uses in its WUA calculation along with the characterized substrate found along each cross-section. In characterizing our study sites modeled daily discharge values calculated using SWAT for surface water and the GWIM database for groundwater, calculated by project collaborators at MSU (Bartholic, et al., 2007), were used to drive PHABSIM estimates of depth and velocity for the WUA calculation.

5.3.2.1 Modeling the Effects of Temperature

Since the impact of temperature changes to the available habitat of fishes was expected to be critical in our model scenarios, this factor had to be included in the WUA estimate. Based on the published HSI values for the species present in the modeled sub-watershed. Changes in habitat availability were calculated utilizing the measured water temperatures. These were integrated with the PHABSIM output *post hoc*, producing temperature-sensitive WUA relationships for each site (Figure 5.6):

$$WUA_i = \sum (v_i \times d_i \times S_i \times T_i) A_i$$

Where WUA_i is the weighted useable area across all cross-sectional segments, v_i is the species HSI value for velocity at cross-sectional segment *i*, d_i is the species HSI value for depth at cross-sectional segment *i*, S_i is the species HSI value for substrate type at cross-sectional segment *i*, A_i is the area of cross-sectional segment *i*, and T_i is the species HSI value for temperature at cross-sectional segment *i*.

Although it is possible to examine the daily changes in WUA by presenting corresponding daily temperature data that was measured, these relationships are characteristic of only those days on which temperature data were collected. While day-to-day assessments can be used to quantify measured impacts, they are less useful than generalized relationships to focus on overall trends and allow for a measure of predictability. Furthermore, recognizing that the range of temperature is likely to have a greater ecological effect than the mean temperature, an envelope of both expected upper and lower temperatures needed to be developed to evaluate the generalized range of temperature-driven impacts to habitat.

In order to create summarized WUA curve for each site that included temperatures, Generalized Additive Models (GAMs) were created for all pumping scenarios at each site using S-PLUS (S-PLUS, 2007). Based on the GAMs, each stream discharge/temperature relationship was split into two linear relationships based on discharge: a low-discharge relationship and a high-discharge relationship. Following this, Generalized Linear Models (GLMs) were constructed to produce linear equations predicting upper and lower temperature bounds (at 1 s.d.) at the three sites within the sub-watershed (Figure 5.13, Figure 5.14, Figure 5.15, and Figure 5.16). These predicted upper and lower bounds were finally used to create a summarized "envelope" that indicated the impacts of habitat availability.

5.3.3 Pumping Scenarios

In order to assess the validity of the legal presumption that no adverse resource impact would happen if pumping were to occur at distances greater than ¼ mile from the banks of a designated trout stream, three different groundwater pumping scenarios were modeled near the mid-basin site (Figure 5.3). These pumping scenarios consisted of a high-capacity well, pumping at 1 million gallons per day, at a distance of 0 mi (Scenario 1), 0.25

mi (Scenario 2), and 1 mi (Scenario 3) away from the banks of the stream. Collaborators at MSU conducted an assessment of the groundwater and surface water hydrology caused by these pumping scenarios (Abbas, et al., 2006; Abbas, Liao, Li, & Richard, 2010).

In the groundwater pumping scenarios, the impact of pumping on water temperature was predicted by adjusting each flow-dependent temperature curve for thermal energy loss based on energy balance assumptions using the following equation:

$$K'_F = \frac{M_O K_O + M'_G K_G + \frac{E_S}{4184}}{M_O + M'_G}$$

where K'_F is the temperature (Kelvin) of the water leaving the system, E_S is total energy entering the system (Joules), K_O is the temperature of the water (Kelvin) entering the system, K_G is the energy of the groundwater entering the system (Joules), M_O is mass (kg) of the water entering the system, M'_G is changed groundwater mass (kg) under each scenario, and 4148 is the specific heat of water (Joules/kg in Kelvin).

These changes in temperature were applied to the changes in the modeled surface water discharge for each of the three sub-watershed sites, and WUA assessments were produced using scenario-specific GAMs and GLMs.

5.3.4 Regulatory Implications for Augusta Creek

The rebuttable presumption in the PA33-2006 was operationalized in this investigation as a test of the modeled impacts to fish habitat caused by pumping scenarios of the 1 million gallons per day at three different distances from the banks of a designated trout stream. Characteristic fish populations were determined to be the fish species found during sampling and for which there were HSI materials available. The quarter-mile-butter conservation presumption was tested using the three scenario distances, which were chosen to incorporate an illegal distance (Scenario 1, 0 miles from the stream), the minimum legal distance under the rebuttable presumption (Scenario 2, ¼ mile from the stream), and a distance well beyond the minimum legal distance (Scenario 3, 1 mile from the stream). If a significant negative change in the WUA of fishes was seen in any scenario, this was interpreted as equivalent to an ARI, given the operationalization in this chapter of the definitions provided in PA33-2006.

5.4 Results

Without the inclusion of temperature, WUA and discharge were positively correlated (Figure 5.5), with greater water leading to greater habitat in most cases. Basic WUA analyses (Figure 5.5) at the upstream site show that any decrease of discharge in the region would decrease the WUAs for each of the five target species. At this site, the discharge values were not great enough to reach any apparent optimal discharge rate. In contrast, at the mid-basin site, the optimum brook trout WUA occurred at a discharge of 0.8 m^3/s, creek chubs at 0.7 m^3/s, and both brown trout and white suckers at 0.6 m^3/s, blacknose dace near 0.2 m^3/s, and declined to near zero at discharges above 0.65 m^3/s. At the downstream site, optimum brook trout discharge was 0.45 m^3/s, while creek chub optimum was 0.7 m^3/s, brown trout was 1.3 m^3/s, and blacknose dace was 0.3 m^3/s. White suckers displayed no optimum value, but had a minimum WUA at 0.6 m^3/s, increasing steadily at greater discharge values.

When daily temperature measurements were included, WUAs for coldwater species were no longer exhibited smooth relationships with discharge (Figure 5.6), and the daily-WUA availability for both the brook trout and brown trout changed significantly (Table

5.4). As mentioned previously, the mean July air temperature was higher than average. Combined with a lower-than-average discharge in the river, the observed water temperature range started on the descending-arm of brook trout habitat suitability. The daily-WUAs for the month of July 2005 reflect this, even to the extent of showing a few days where – due to water temperature – no habitat at all was available for brook trout. In contrast, the daily-WUAs of the blacknose dace, creek chub, and white sucker were not significantly different changed when corrected for temperature (Table 5.4, Figure 5.6).

5.4.1 General Additive Models of Discharge-Temperature Relationships

There was a generally logarithmic relationship between stream discharge and stream temperature (Figure 5.12). The fitted relationships had a very low standard error at lower discharge values, due to an abundance of data points. The high-discharge region of the curves consistently showed greater variation in the stream discharge/temperature relationship, due primarily to the lack of a lot of high flow data. However, the general trend in this region appeared relatively linear, with a very low slope.

5.4.1.1 WUAs with Generalized Temperature Impacts

The summarized-WUAs for both cold water guild species (brook trout and brown trout) showed clear differences between high temperature habitat availability and low temperature habitat availability. For both species, low temperatures provided greater habitat availability at all three sites. By contrast, the cool-water guild species' summarized-WUAs showed either total overlap or only minimal distinction at the upstream site, and minimal distinction at the mid-stream and downstream sites.

5.4.2 Modeled Daily Pumping Impacts on Cold Water Species

Each trout species reacted differently at each site to each pumping scenario (Table 5.4 and Table 5.5). Under all pumping scenarios, there were no significant differences from the no-pumping condition for the daily, temperature-inclusive WUAs (daily-WUAs) were seen for trout habitat at the upstream site (Figure 5.7 and Figure 5.8). Daily-WUAs for the recorded period ranged from 15,794 m^2/1000m to 117,066 m^2/1000m for brook trout habitat and 45,076 m^2/1000m to 44,536 m^2/1000m for brown trout habitat.

At the mid-basin site, Scenarios 1 and 2 had significant differences from the no-pumping scenario ($P<0.001$) in the daily-WUAs both brook trout and brown trout habitat, but pumping Scenario 3 had a significant difference ($P=0.095$) for only brook trout habitat. Daily-WUAs for the period ranged from 9,360 m^2/1000m to 36,837 m^2/1000m for brook trout and 25,130 m^2/1000m to 113,595 m^2/1000m for brown trout.

At the downstream site, Scenarios 1 and 2 had a significant difference from the no-pumping scenario ($P<0.001$) for brook trout habitat. Brown trout habitat was also significantly changed under Scenario 1 ($P<0.001$) and Scenario 2 ($P=0.001$), but not Scenario 3. Daily-WUAs for the period ranged from 22,339 m^2/1000m to 42,010 m^2/1000m for brook trout and 32,883 m^2/1000m to 81,882 m^2/1000m for brown trout.

5.4.3 Modeled Daily Pumping Impacts on Cool Water Species

Cool water species (blacknose dace, creek chub, white sucker) reacted differently to different pumping scenarios (Table 5.4 and Table 5.5). The majority of impacts to useable physical habitat among these fishes were due directly to changes in discharge, rather than temperature, except in the case of creek chubs, where temperature impacts appeared to also be significant.

No significant differences from the no-pumping scenario were seen under any pumping scenarios at the upstream site (Figure 5.9, Figure 5.10, and Figure 5.11). Daily-WUAs for the period ranged from 62,587 m^2/1000m to 63,892 m^2/1000m for blacknose dace, 97,471 m^2/1000m to 99,081 m^2/1000m for creek chubs, and 48,007 m^2/1000m to 48,189 m^2/1000m for white suckers.

Scenarios 1 and 2 had significant differences from the no-pumping scenario ($P<0.001$) for creek chub habitat at the mid-basin site, but not in Scenario 3. However, no other cool water species experienced significant diminutions in available habitat under any pumping scenario. Daily-WUAs for the period ranged from 10,171 m^2/1000m to 10,207 m^2/1000m for blacknose dace, 151,926 m^2/1000m to 168,734 m^2/1000m for creek chubs, and 119,274 m^2/1000m to 123,466 m^2/1000m for white suckers.

Scenarios 1 and 2 had significant differences from the no-pumping scenario ($P=0.001$ and $P=0.002$, respectively) for creek chubs the downstream site, but creek chub habitat was not significantly impacted under Scenario 3. Similar to the results of the mid-basin site, no other cool water species experiences significant diminutions in available habitat under any pumping scenario. Daily-WUAs for the period ranged from 84,912 m^2/1000m to 87,838 m^2/1000m for blacknose dace, 113,455 m^2/1000m to 118,699 m^2/1000m for creek chubs, and 29,395 m^2/1000m to 29,870 m^2/1000m for white suckers.

5.4.4 Summarized-WUAs

Scenario 1 shows various impacts to WUAs (Figure 5.17, Figure 5.18, Figure 5.19, Figure 5.20, and Figure 5.21). The upstream site showed effectively no impact from pumping under Scenario 1. Examining the impacts to available habitat for the different fishes at the mid-basin site and the downstream site, one observes that brook trout and brown trout WUAs are severely impacted by the pumping. The upper and lower available habitat estimates of the summarized-WUAs were greatly lowered for both of these species. At the downstream site, although the upper and lower bounds of the summarized-WUAs showed little change, the distribution based on the measured temperatures were much lower than in the baseline condition. However, in the mid-basin and downstream sites, the summarized-WUAs of blacknose dace, creek chub, and white sucker were not greatly changed.

Under pumping Scenario 2 (Figure 5.22, Figure 5.23, Figure 5.24, Figure 5.25, and Figure 5.26), there was little impact to the summarized-WUAs in the upstream site for all species. However, at the mid-basin site, there was a major loss of brook trout and brown trout habitat. Much of these impacts were diminished at the downstream site, though. Impacts to blacknose dace, creek chub, and white sucker were not greatly affected by pumping under Scenario 2 throughout the sub-watershed.

Under pumping Scenario 3 (Figure 5.27, Figure 5.28, Figure 5.29, Figure 5.30, and Figure 5.31), the WUAs for brown trout and book trout, at the upstream site showed no major change. However, at the mid-basin site showed declines although these impacts were not as severe as with the other pumping scenarios. Similarly, at the downstream site, the impacts from pumping were not severe enough to show any major difference from the baseline conditions. Similar to the other pumping scenarios, blacknose dace, creek chub, and white sucker were not greatly changed under Scenario 3 at none of the three sub-watershed sites.

5.4.5 Regulatory Assessment of the Proposed Pumping

Examining the impact of the pumping scenarios on the habitat of those fish found in the creek did show a large difference from the baseline condition under Scenario 1 (the illegal condition) at the mid-basin site and a smaller difference at the downstream site, corroborating the justification to deny pumping solely based on the diminution of BFY. The negative changes to fish habitat were similarly seen in Scenario 2 (the minimum legal distance condition). Pumping under Scenario 3 (the safely legal distance condition) did not show major impacts on summarized-WUAs at the mid-basin site nor at the downstream site compared to the respective baseline conditions, even for brown trout and brook trout, the species that are the most vulnerable to temperature increases caused by water withdrawals. However, when looking at daily-WUAs for Scenario 3, significant negative impacts were seen, at the mid-basin site.

5.5 Discussion

The implications of this WUA study initially indicated that the stream discharge levels seen during the July/August 2005 period would be generally optimal for brook trout, blacknose dace, and creek chubs, suboptimal for white suckers, and slightly below optimal for brown trout (Figure 5.5). However, the fish surveys conducted during that period did not indicate the presence of either brook or brown trout present at the Site 3. However, creek chub, blacknose dace, and white suckers were all found at the site (

Table 5.2). Although blacknose dace were by far the most predominant species found at the site, their presence would imply that the WUA estimates were reasonable for these species. The lack of any trout species indicated the importance of investigating the temperature impacts.

The results presented here are quite different from previous PHABSIM work on brook trout in Hunt Creek (located in northern Michigan), which indicated that impacts caused by surface water withdrawals had minimal impacts to brook trout populations in the creek at levels up to 50% reduction in summer stream flow (Baker & Coon, 1995). However, Baler & Coon's research did not include temperature as an implicit factor of the PHABSIM analysis – the critical tested factor in this case study – because temperature there did not significantly change due to surface water abstraction. This was because the study area in Hunt Creek is entirely groundwater-fed, has no upstream impoundments, and has comparatively little sun exposure compared to the study area in Augusta Creek. Unlike Hunt Creek, with its very stable and cold temperature regime (Baker & Coon, 1995), the conditions in Augusta Creek are at or near the upper limit of tolerance of salmonids during the summer. The majority of the declines seen were among brook trout and brown trout (Figure 5.6).

The WUA estimates indicate only the possibility of supporting a species, and often do not correlate directly with actual abundances. This is especially true when considering trout – a highly motile and stenothermal species – it is easy for these fishes to move to areas that are more optimal. Similarly, during a period of high WUA fluctuation, these fishes are not likely to move into the stream reach until such conditions stabilize. Finally, there may be other reasons why a species may have a projected high WUA but not be found during a sampling of that reach, including food web considerations, chemical imbalances, or physical barriers preventing migration to the studied area.

In this study, adult brook trout were a species of special concern. A small increase in temperature within the range found during July and August 2005 was enough to lead to a complete collapse in adult brook trout WUA for much of July and portions of August.

Both trout species were primarily affected by temperature, while cool water species were not adversely affected by temperature, save for a few days. Adult brook trout and brown trout both have HSIs describing a maximum temperature prior to mortality of 24°C (Raleigh, 1982; Raleigh, Zuckerman, & Nelson, 1986).

These results demonstrate that in transitional trout streams high-capacity water withdrawal operations are likely to have measurable impacts to steam environments both locally and for several miles upstream and downstream of its location. These impacts occur at a scale that can be large enough to radically alter the habitats of fish species. Furthermore, moving the pumping operation 1 mile away from the river still resulted in some impact to the stream, although it was greatly diminished compared to pumping immediately adjacent to the creek, and upstream and downstream effects were still discernible in the model.

If management is to have the goal of protecting characteristic fish populations within a stretch of stream, then focusing on mitigating the factor that has the greatest negative impact to habitat availability should be undertaken. As seen in the example of brook trout, the period of July and August 2005 had temperature as the limiting physical parameter. Understanding the mechanical relationship between the amount of groundwater withdrawal within a particular region and the expected temperature change resulting from different pumping scenarios can greatly change the impacts to an area – as shown in both trout species' WUA responses due to the well locations in Scenarios 1, 2, and 3.

It was not possible to assess the validity of this model beyond its reliance on generally accepted habitat modeling protocols, nor predict the behavioral changes of fishes in the occurrence of the proposed groundwater pumping operation. However, the significant change in brook trout and brown trout WUA in Scenarios 1 and 2 at both the mid-basin and downstream sites, and the impacts of Scenario 3 at the mid-basin site indicate, with a high level of certainty, the direction and magnitude of the response of brook and brown trout to the modeled scenarios.

5.5.1 Pumping Allowance for the Various Scenarios

One of the recognized problems of the state's regulatory groundwater model is that it may not adequately model the conditions at small scales (Zorn, Seelbach, & Rutherford, 2012). This could prove to be problematic for some determinations based on the automated decision tool, especially in systems that are less robust, such as cold-transitional stream systems. Fortunately for the case of Augusta Creek, the state groundwater regulation requires that – regardless of the size of withdrawals – any pumping taking place in cold-transitional-type rivers and streams must undergo a site-specific review (Hamilton & Seelbach, 2010). The case study of Augusta Creek provides an example of an examination of determining local-level groundwater conditions as well as determining the impacts of high-capacity pumping at three different distances away from the creek in an area that would fall under the designation of a cold-transitional stream, and one requiring a site-specific review.

Based both on the groundwater abstraction results together with predicted habitat change results, it is possible to conclude that groundwater pumping has a significant negative impact on the fish habitat of locally sampled fishes under Scenario 1 (the illegal distance). Furthermore, the level of impacts under Scenario 2 (the minimum legal distance) were almost identical to those seen under Scenario 1. This finding rebuts the quarter-mile-distance conservation presumption of PA33-2006.

In addition an examination of Scenario 3 (the safely legal distance) found that the generalized modeled impacts to trout species might not be significant. However, the modeled impacts seen in the daily-WUAs indicate that the withdrawals may still cause significant negative impacts to available fish habitat.

5.6 Conclusion

This chapter was conducted as part of a Great Lakes Protection Fund project (Bartholic, et al., 2007) to investigate – among other things – the effects of large-scale groundwater withdrawal on marginal trout streams in Michigan. The findings of this chapter – together with the findings of the larger Great Lakes Protection Fund project and other similar projects – were incorporated into the scientific framework adopted by the Technical Advisory Council as they developed the science underlying the Water Withdrawal Assessment Tool (WWAT). The process of developing WWAT is described in Chapter 4.

It is important to stress that the results of this study are unique to the modeled sub-watershed of Augusta Creek, and are not necessarily applicable to other streams in Michigan or the Midwest. The reductions of brown trout and brook trout WUAs were modeled to occur with the installation of a 1MGD well in very specific local groundwater flow conditions. Due to the physical conditions of this sub-watershed, significant increases in temperature and decreases in discharge resulted in significant declines in the WUAs. If this analysis was conducted in lower reaches of Augusta Creek, where groundwater flow is dominated by regional flow of groundwater to the Kalamazoo River (Abbas, et al., 2006), it is likely that very little impact to WUA would have been seen, even with the placement of a similar-sized pumping operation. Furthermore, one must not make the assumption that the water discharge/temperature relationship described in the GAM analyses will continue along the same trajectory at greater levels of dewatering (i.e., below the measured and modeled limits) or at higher discharge levels (i.e., at greater flood levels).

It is also important to recognize that WUA is not directly related to with the statistical modeling of fish abundances that was used by the state in defining “characteristic fish populations” (Zorn, Seelbach, & Rutherford, 2012). However, by collecting site-specific information, I was able to determine the community of fishes that were expected to be found in the modeled region. By examining the effects of the pumping on the sampled fish species, I could produce a determination of the changes to the habitat of those species known to occur in the creek, as opposed to relying on changes in relative abundance of fish species that were statistically determined to occur in an area based on state-wide metrics.

Although physical habitat is important in determining fish abundance and distribution in a variety of habitats, other biotic and abiotic factors can influence fish abundance and distribution in streams (Bolby & Roff, 1986; Chapman, 1966; Gorman & Karr, 1978; Latta, 1965; Sheldon, 1968). There may be situations in which the physical parameters for a particular species are optimal, but no evidence of this species may be present during a fish diversity survey. Other factors which could change under reduced flow conditions are predation risk, disease transmission rates, oxygen concentration, competitive interactions, and food availability. The magnitudes of these changes are likely to be dependent on the magnitude of whatever flow were to occur.

Another possible concern with this method is that it may produce a conservative estimate of temperature change. In dewatering experiments in groundwater systems, there is evidence of cumulative temperature change downstream of a water withdrawal (Nuhfer & Baker, 2004). However, in the methodology used above, each site's temperatures were derived as an energy-balance relationship based on measured temperature and the expected change in groundwater at the site due to pumping. There was no site-to-site interactions, even though they have downstream influences, as were modeled in the state's regulatory model (Zorn, Seelbach, & Rutherford, 2012).

Finally, neither the state's model nor the methodology of this chapter assume that changes to the fundamental parameters of the model – save from groundwater pumping – will occur. Changes from climatic warming to altered precipitation timing and intensity will have direct implications on parameters such as groundwater temperature and low-flow yield. Land-cover change could have impacts on the effective catchment area, especially if intra-basin water diversions occur (such as with storm sewer or waste water treatment facility discharges). However, these changes fall outside the scope of the Michigan water conservation legislation, and are therefore not considered here, either. (These are considered in Chapter 6 in the context of the Muskegon River). Recognizing that near and distant future changes to the environment will affect the fundamentals of any regulatory model ought to be an important part of regulatory analysis, especially if one wishes to examine the long-term effects of environmental laws.

Based on a geographic assessment of the continued abundance of brook trout within its native range in the Eastern United States that didn't specifically account for groundwater availability (Hudy, Thieling, Gillespie, & Smith, 2008), the percentage of forested land was positively associated with intact populations, whereas the percentage of agricultural land was negative associated with intact populations. This correlative association points to the regulatory effect that maintaining or restoring forests can have on water temperatures, due to relatively higher levels of cooling through evapotranspiration and shading and relatively lower levels of overland runoff. Although forested land-use will provide diminishing temperature-moderating effects as the waterway's width increases, in relatively small tributary systems like Augusta Creak, which has significant amounts of agricultural lands, forested shading can provide significant water cooling (Johnson S. L., 2004), even if only the stream banks are forested (Brown & Krygier, 1970).

The impacts on water temperature from shading and groundwater inputs are different. Shading lowers maximum water-temperatures, whereas the effects of alluvial substrate and groundwater inputs diminishes the daily water-temperature variation (Johnson S. L., 2004). This difference in water-temperature moderation indicates that a decrease in groundwater inputs, such as those caused by large scale groundwater extraction, will create greater variation in the daily water-temperatures of a small stream system like Augusta Creek, even if a forested margin were added or an upstream area forested. These impacts, though, are not included in the results of this chapter, which examines only the impact of groundwater withdrawals on average stream discharge and water temperature.

5.7 Tables

Table 5.1. Summary statistics of July and August water temperatures collected at nine locations throughout the Augusta Creek watershed.

				July Temperature (ºC)			August Temperature (ºC)		
Site #	Site Description	Lat.	Long.	Min	Max	Max Daily Diff	Min	Max	Max Daily Diff
1	B Ave E (Trib)	42.41	-85.31	12.5	24	10.5	12	23.5	9
2	45th St (Trib)	42.40	-85.33	17	30	8	15.5	30	9.5
3	Luce/Baseline (Trib)	42.42	-85.33	11.5	23	6.5	13	21	5
4	44th St (Trib)	42.41	-85.34	15	27.5	10.5	12.5	26.5	9
5	Osborne Rd	42.47	-85.35	21.5	29.5	7.5	18.5	27	4
6	Cobb Rd	42.46	-85.34	12.5	27	11.5	12.5	27.5	10
7	Lepper/43rd St	42.42	-85.35	19	26	4	16	25	5
8	M89	42.37	-85.36	15	27	10.5	13.5	25	6.5
9	EF Ave E	42.35	-85.36	22.5	28.5	4	19.5	27.5	4.5

Table 5.2. Abundance list of species caught during electrofishing at temperature collection sites throughout the upper portions of the Augusta Creek watershed. Stream class designations based on catchment basing area and fish communities. At Site 3 ("downstream site" in the sub-watershed), stream class designation additionally based on modeled July water temperature.

Site (Site #)	Stream Class at Site	Fish Caught	Number	HSI Availability
Lepper Rd (7)	Cold-transitional stream	Blacknose Dace	61	Yes
		Creek Chub	12	Yes
		Johnny Darter	4	No
		Mottled Sculpin	4	No
		Northern	4	No
		Hogsucker	13	No
		Rainbow Darter	3	Yes
		White Sucker		
Cobb Rd (6)	Cool stream	Creek Chub	1	Yes
		Johnny Darter	3	No
		Largemouth Bass	1	Yes
		White Sucker	1	Yes
Osborne Rd (5)	Warm stream	Bluegill	1	Yes
		Creek Chub	5	Yes
		Largemouth Bass	8	Yes
		Grass Pickerel	1	Yes
Luce Rd (3)	Cold stream	Brook Trout	5	Yes
45th St (2)	Warm stream	Largemouth Bass	16	Yes
B Av (1)	Warm stream	Creek Chub	1	Yes
		Green Sunfish	1	Yes

Table 5.3. Temperature boundary equations for the three locations and four scenarios. Each discharge-temperature relationship is broken into a low-discharge section and a high-discharge section.

Location	Scenario	Temp	Q	Equation
Upstream	No Pump	Low	Low	$T = -2.383Q^2+12.17Q+12.305$
			High	$T = -0.2947Q^2+0.543Q+18.774$
		High	Low	$T = 2.383Q^2+8.4844Q+17.551$
			High	$T = 0.2947Q^2-0.5891Q+23.075$
	A	Low	Low	$T = -2.3836Q^2+12.17Q+12.306$
			High	$T = -0.2947Q^2+0.543+18.774$
		High	Low	$T = 2.3836Q^2+8.4836Q+17.552$
			High	$T = 0.2947Q^2-0.5891Q+23.075$
	B	Low	Low	$T = -2.1417Q^2+12.418Q+12.403$
			High	$T = -0.3157Q^2+0.4762Q+18.905$
		High	Low	$T = 2.1417Q^2+9.2229Q+17.531$
			High	$T = 0.3157Q^2-0.7545Q+23.273$
	C	Low	Low	$T = -2.383Q^2+12.127Q+12.415$
			High	$T = -0.3157Q^2+0.4825Q+18.901$
		High	Low	$T = 2.383Q^2+8.5273Q+17.628$
			High	$T = 0.3157Q^2-0.7608Q+23.28$
Mid-basin	No Pump	Low	Low	$T = -2.6884Q^2+11.701Q+14.085$
			High	$T = -0.6548Q^2+1.1005Q+20.311$
		High	Low	$T = 2.6884Q^2+7.4733Q+19.472$
			High	$T = -0.085Q^4+0.32Q^3+0.13Q^2-0.87+24.84$
	A	Low	Low	$T = -2.6884Q^2+11.561Q+17.564$
			High	$T = -0.6335Q^2+0.4874Q+24.221$
		High	Low	$T = 2.6884Q^2+7.6131Q+22.844$
			High	$T = 0.6335Q^2-1.9142Q+28.919$
	B	Low	Low	$T = -2.6884Q^2+11.561Q+17.563$
			High	$T = -0.6335Q^2+0.4874Q+24.22$
		High	Low	$T = 2.6884Q^2+7.6131Q+22.844$
			High	$T = 0.6335Q^2-1.9142Q+28.918$
	C	Low	Low	$T = -2.6884Q^2+11.658Q+14.606$
			High	$T = -0.6335Q^2+0.5102Q+21.463$
		High	Low	$T = 2.6884Q^2+7.5163Q+19.959$
			High	$T = 0.6335Q^2-1.937Q+26.204$
Downstream	No Pump	Low	Low	$T = -1.901Q^2+10.923Q+13.122$
			High	$T = -0.4146Q^2+2.42Q+18.165$
		High	Low	$T = 1.901Q^2+6.3618Q+20.466$
			High	$T = 0.4146Q^2+0.4495Q+24.875$
	A	Low	Low	$T = 8.4583Q+14.006$
			High	$T = -0.1878Q^2+1.707Q+18.984$
		High	Low	$T = 8.2459*Q+20.095$
			High	$T = 0.1878Q^2+0.8117Q+24.997$
	B	Low	Low	$T = -0.7395Q^2+9.9164Q+14.088$
			High	$T = -0.2357Q^2+1.6537Q+19.366$
		High	Low	$T = 0.7395Q^2+7.2073Q+20.524$
			High	$T = 0.2357Q^2+0.5143Q+25.555$
	C	Low	Low	$T = -1.6598Q^2+9.6815Q+14.029$
			High	$T = -0.5363Q^2+2.209Q+19.338$
		High	Low	$T = 1.6598Q^2+5.8617Q+21.095$
			High	$T = 0.5363Q^2-0.3917Q+26.523$

Table 5.4. T-test results comparing WUAs calculated without water temperature vs. WUAs calculated with water temperature for each sub-watershed site, fish species, and pumping scenario.

		No Pumping		Scenario A		Scenario B		Scenario C	
	Species	T-test	P	T-test	P	T-test	P	T-test	P
Upstream	Brook Trout	9.216	0.000	9.216	0.000	9.733	0.000	9.460	0.000
	Brown Trout	0.275	0.785	0.275	0.785	0.536	0.594	0.375	0.709
	Blacknose Dace	0.000	1.000	0.000	1.000	0.275	0.784	0.106	0.918
	Creek Chub	0.100	0.920	0.100	0.920	0.343	0.733	0.191	0.850
	White Sucker	1.290	0.203	1.290	0.203	1.017	0.314	1.240	0.221
Mid-basin	Brook Trout	24.848	0.000	81.996	0.000	81.893	0.000	27.996	0.000
	Brown Trout	4.348	0.000	30.460	0.000	30.455	0.000	5.544	0.000
	Blacknose Dace	0.001	0.999	0.264	0.792	0.265	0.792	0.241	0.811
	Creek Chub	0.151	0.881	7.497	0.000	7.495	0.000	0.515	0.609
	White Sucker	0.234	0.816	2.073	0.043	2.072	0.043	0.308	0.759
Downstream	Brook Trout	8.723	0.000	15.669	0.000	15.368	0.000	8.318	0.000
	Brown Trout	5.358	0.000	12.502	0.000	12.210	0.000	5.064	0.000
	Blacknose Dace	0.075	0.940	0.850	0.399	0.782	0.438	0.027	0.979
	Creek Chub	0.439	0.662	3.998	0.000	3.817	0.000	0.356	0.724
	White Sucker	0.720	0.943	0.490	0.626	0.477	0.635	0.093	0.926

Table 5.5. Changes in WUA of fishes due to groundwater pumping for each sub-watershed sites, fish species, and pumping scenario.

	Species	No Pump WUA	Scenario A WUA	Scenario A % change	Scenario B WUA	Scenario B % change	Scenario C WUA	Scenario C % change
Upstream	Blacknose Dace	63,892	63,892	0.00%	62,587	-2.04%	63,403	-0.77%
	Creek Chub	99,081	99,081	0.00%	97,471	-1.63%	98,485	-0.60%
	White Sucker	48,007	48,007	0.00%	48,189	0.38%	48,042	0.07%
	Brook Trout	117,066	117,066	0.00%	115,794	-1.09%	116,580	-0.42%
	Brown Trout	45,076	45,076	0.00%	44,536	-1.20%	44,821	-0.56%
Mid-basin	Blacknose Dace	9,846	10,206	3.66%	10,207	3.66%	10.171	3.29%
	Creek Chub	169,673	151,926	-10.46%	151,929	-10.46%	168,734	-0.55%
	White Sucker	123,635	119,274	-3.53%	119,275	-3.53%	123,466	-0.14%
	Brook Trout	41,632	9,358	-77.52%	9,360	-77.52%	36,837	-11.52%
	Brown Trout	126,779	25,130	-80.18%	25,134	-80.17%	113,595	-10.40%
Downstream	Blacknose Dace	87,678	84,912	-3.15%	84,168	-2.86%	87,838	0.18%
	Creek Chub	118,605	113,455	-4.34%	113,757	-4.09%	118,699	0.08%
	White Sucker	29,896	29,395	-1.68%	29,410	-1.63%	29,870	-0.09%
	Brook Trout	40,640	22,339	-45.03%	22,938	-43.56%	42,010	3.37%
	Brown Trout	78,514	32,883	-58.12%	34,302	-56.31%	81,882	4.29%

5.8 Figures

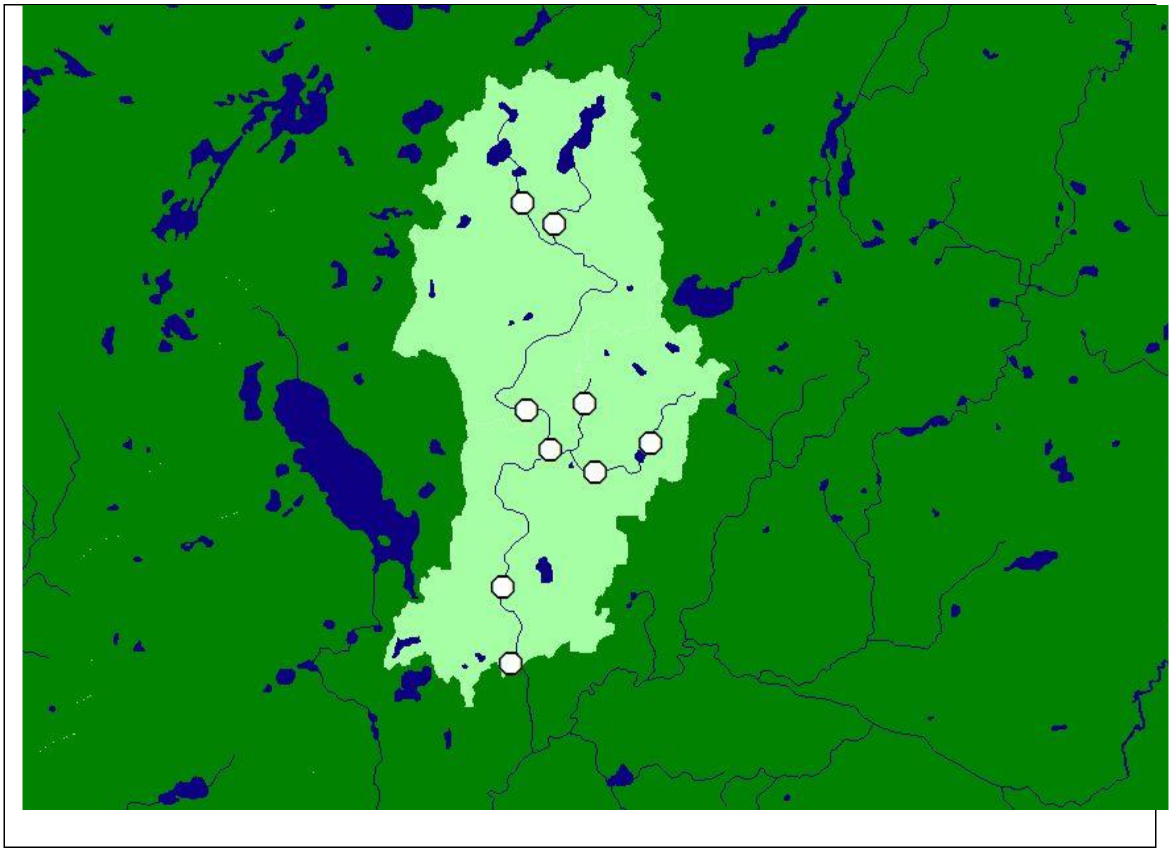


Figure 5.1. The location of Augusta Creek showing the nine sampling locations within the watershed.

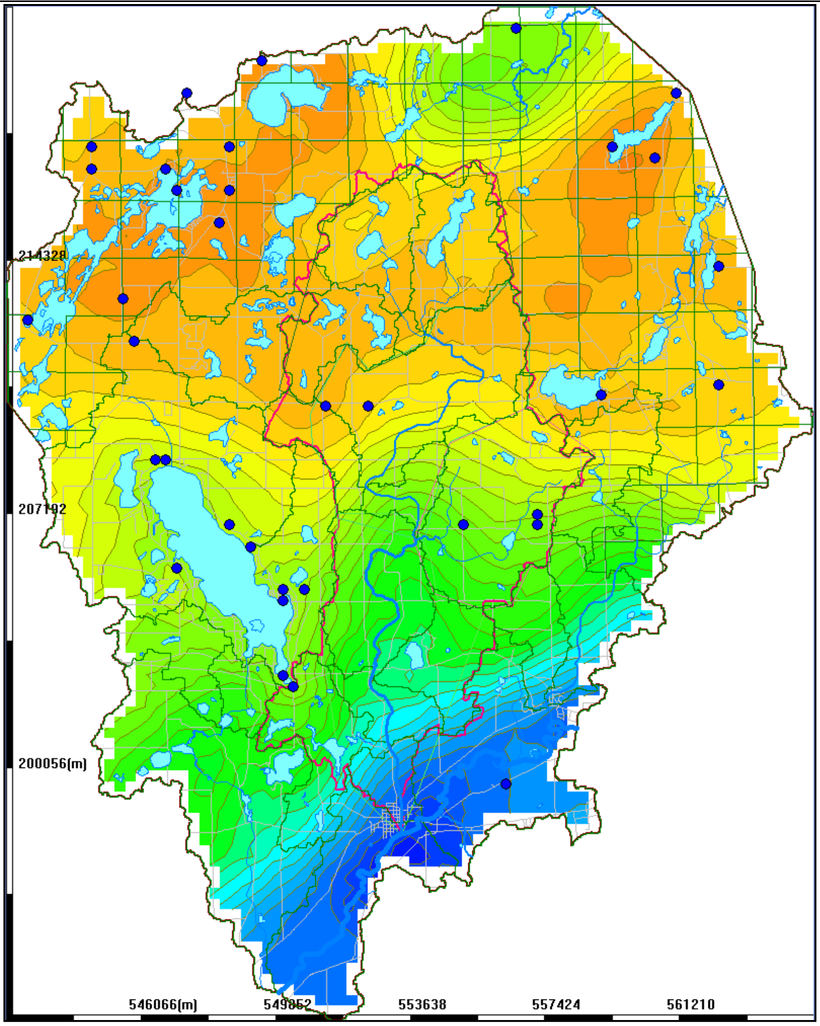


Figure 5.2. Regional groundwater flow dominates the lower portion of Augusta Creek due to the influence of Gull Lake and the relatively steep slope from Gull Lake to the Kalamazoo River. (Figure from Abbas, et al. (2006))

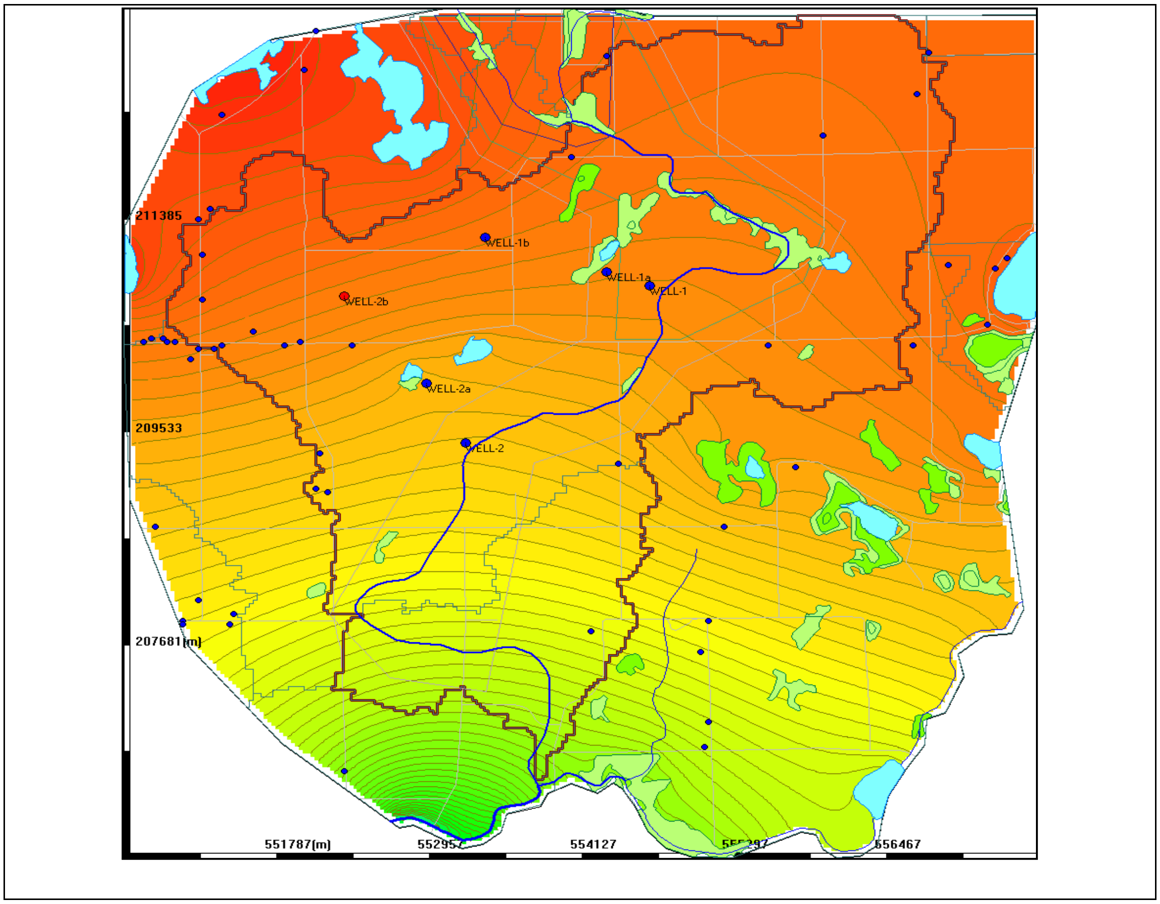


Figure 5.3. Delimitation of a sub-watershed within the upper reaches of Augusta Creek showing topography of groundwater. In this region of the watershed, groundwater flow is not influenced by Gull Lake. (Figure from Abbas, et al. (2006))

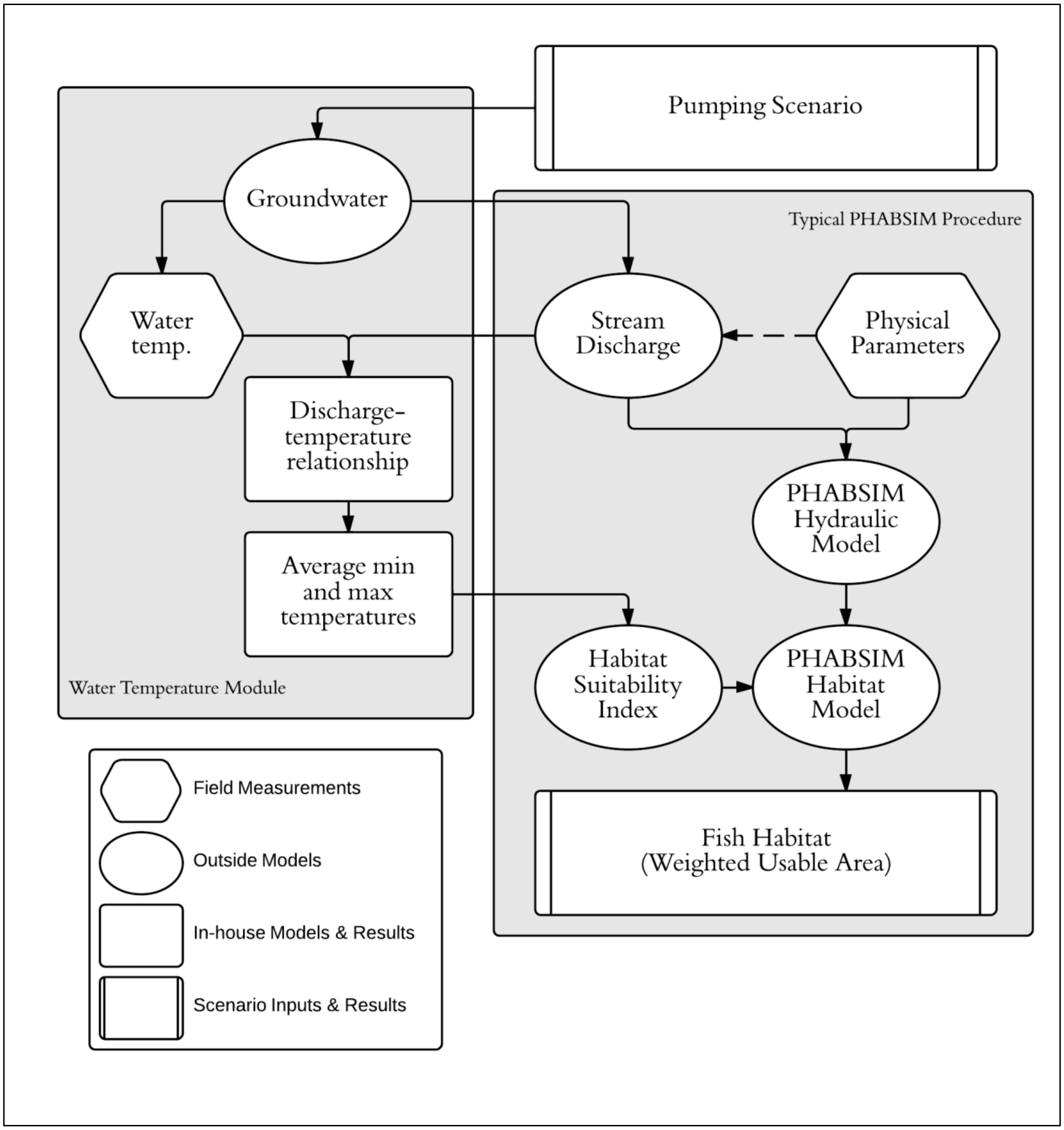


Figure 5.4. Schematic representation of the process used to derive the various WUA results.

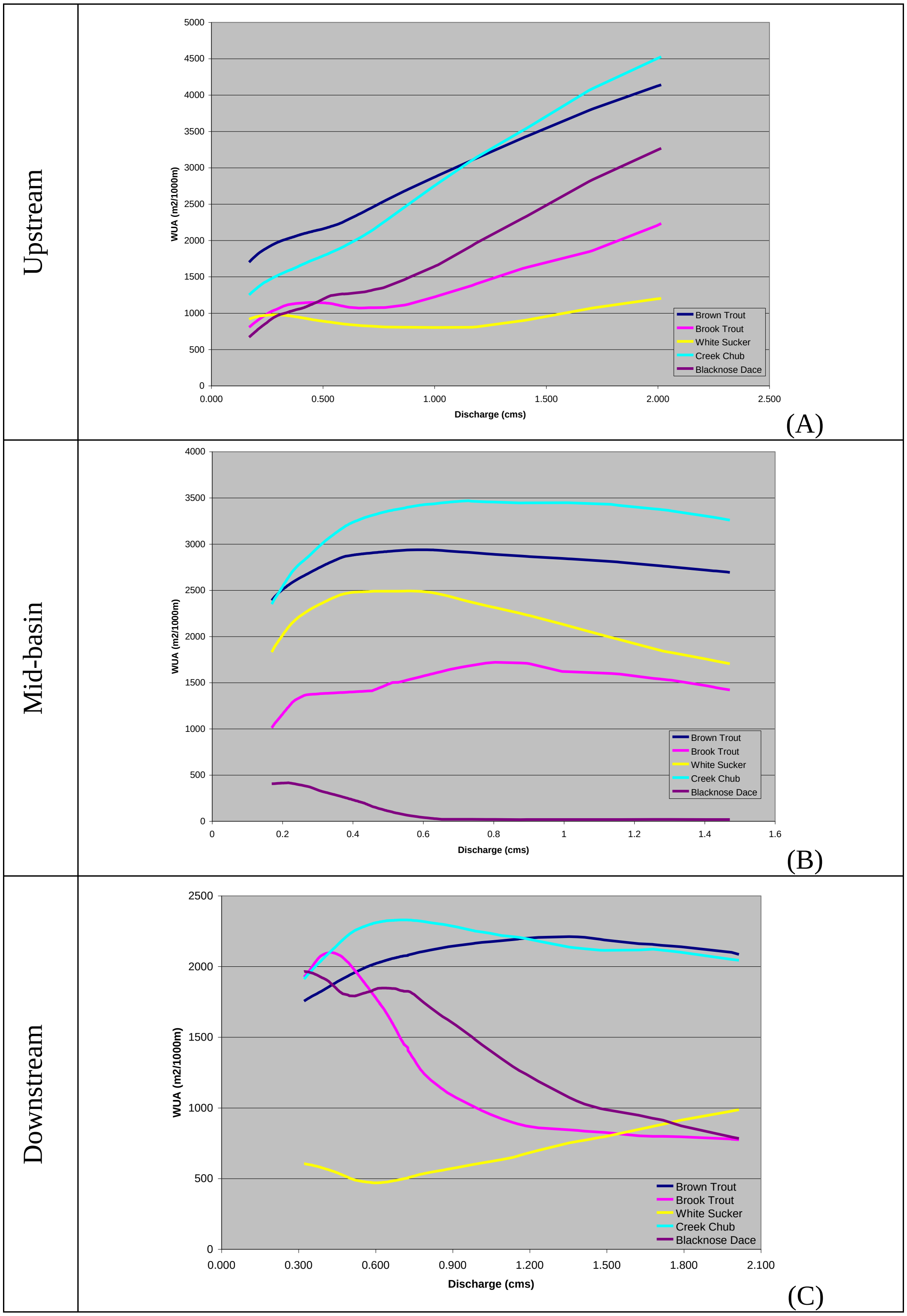


Figure 5.5. Weighted usable area curves (WUAs) derived using calculated depth, velocity, and substrate for the upstream (A), mid-basin (B), and downstream (C) sites within the selected sub-watershed.

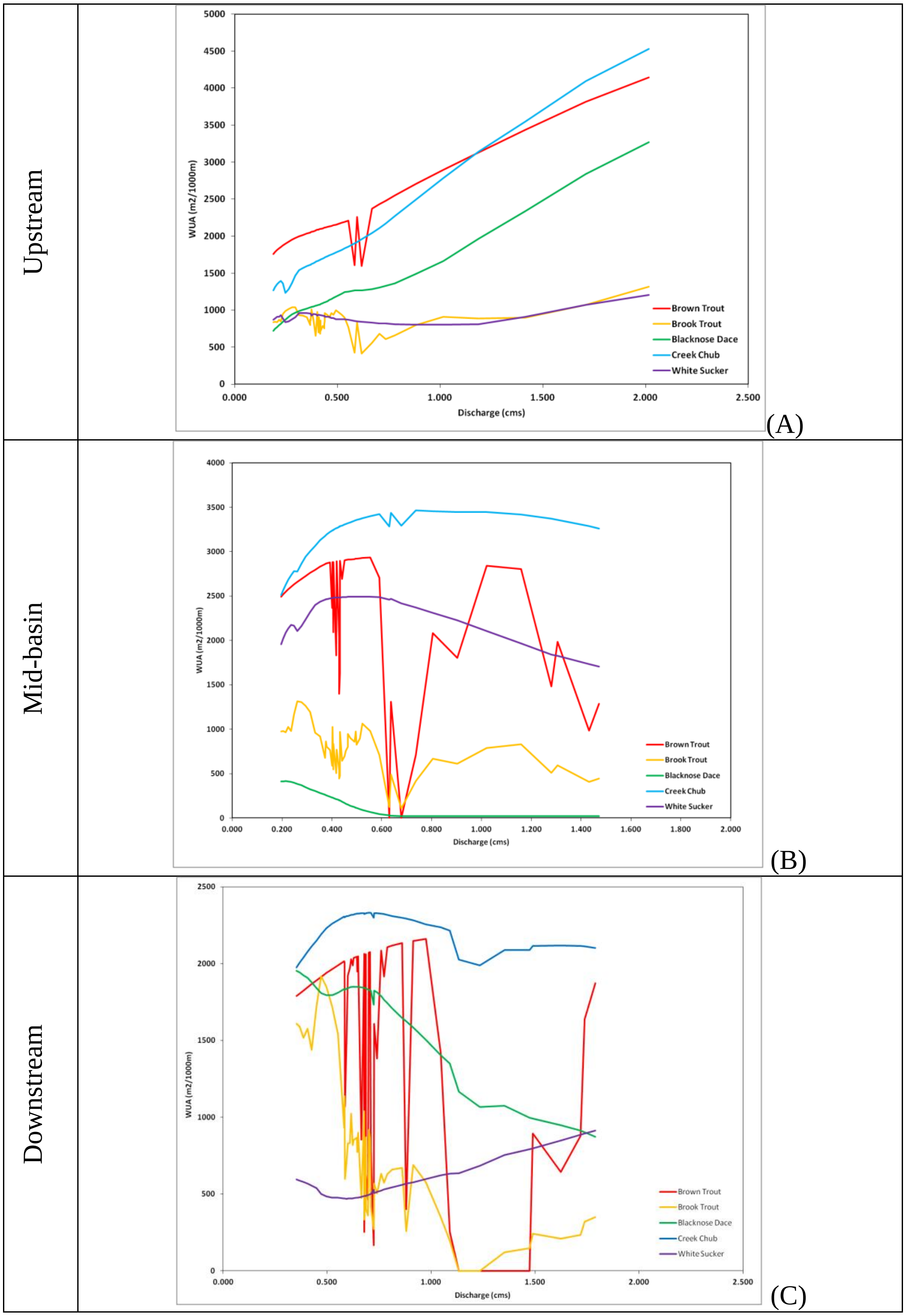


Figure 5.6. Weighted usable area curves (WUAs) derived using calculated depth, velocity, substrate, and temperature for the upstream (A), mid-basin (B), and downstream (C) sites within the selected sub-watershed.

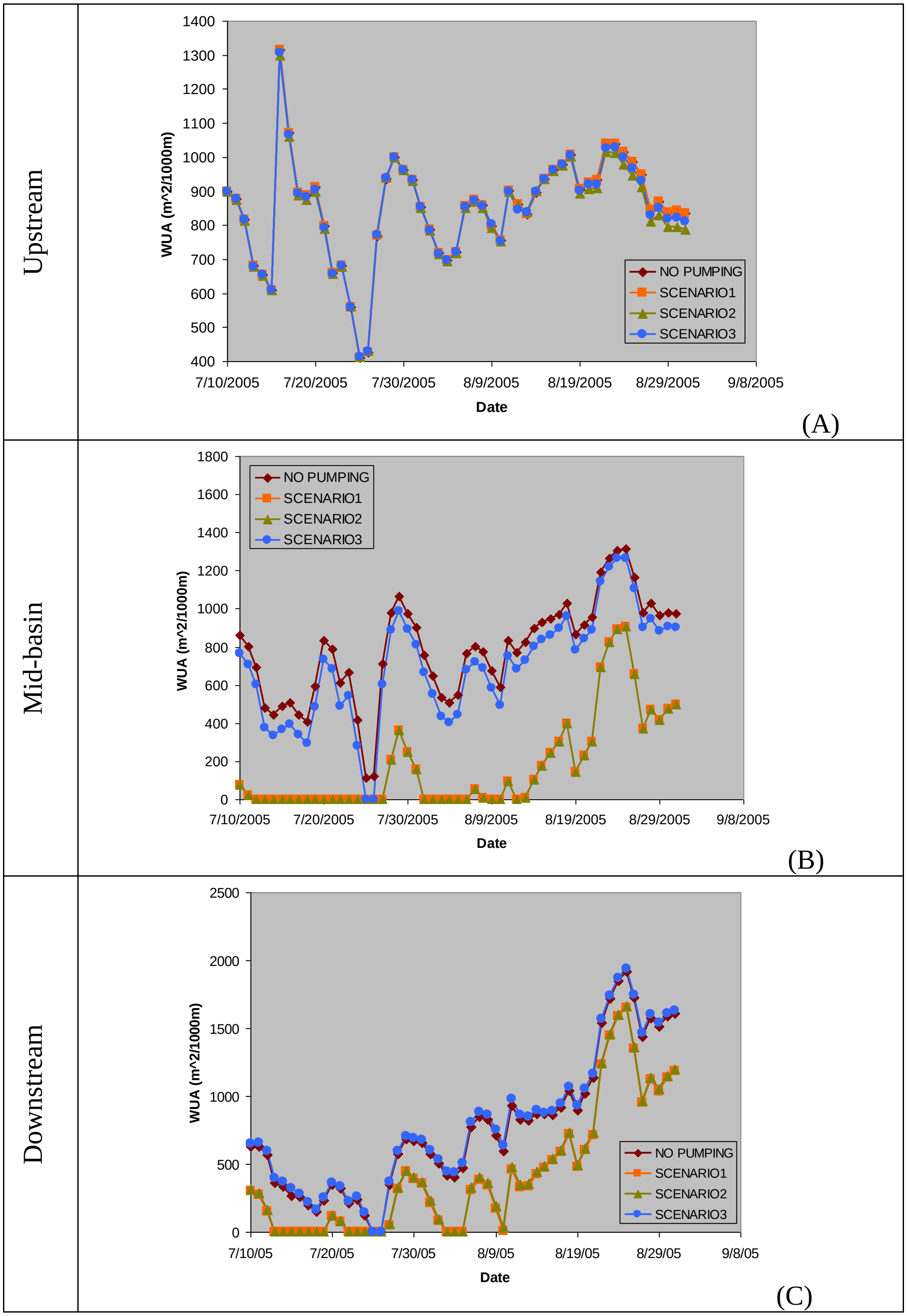


Figure 5.7. Daily-WUAs for adult brook trout under no-pumping, and the three pumping scenarios at the upstream (A), mid-basin (B), and downstream (C) sites.

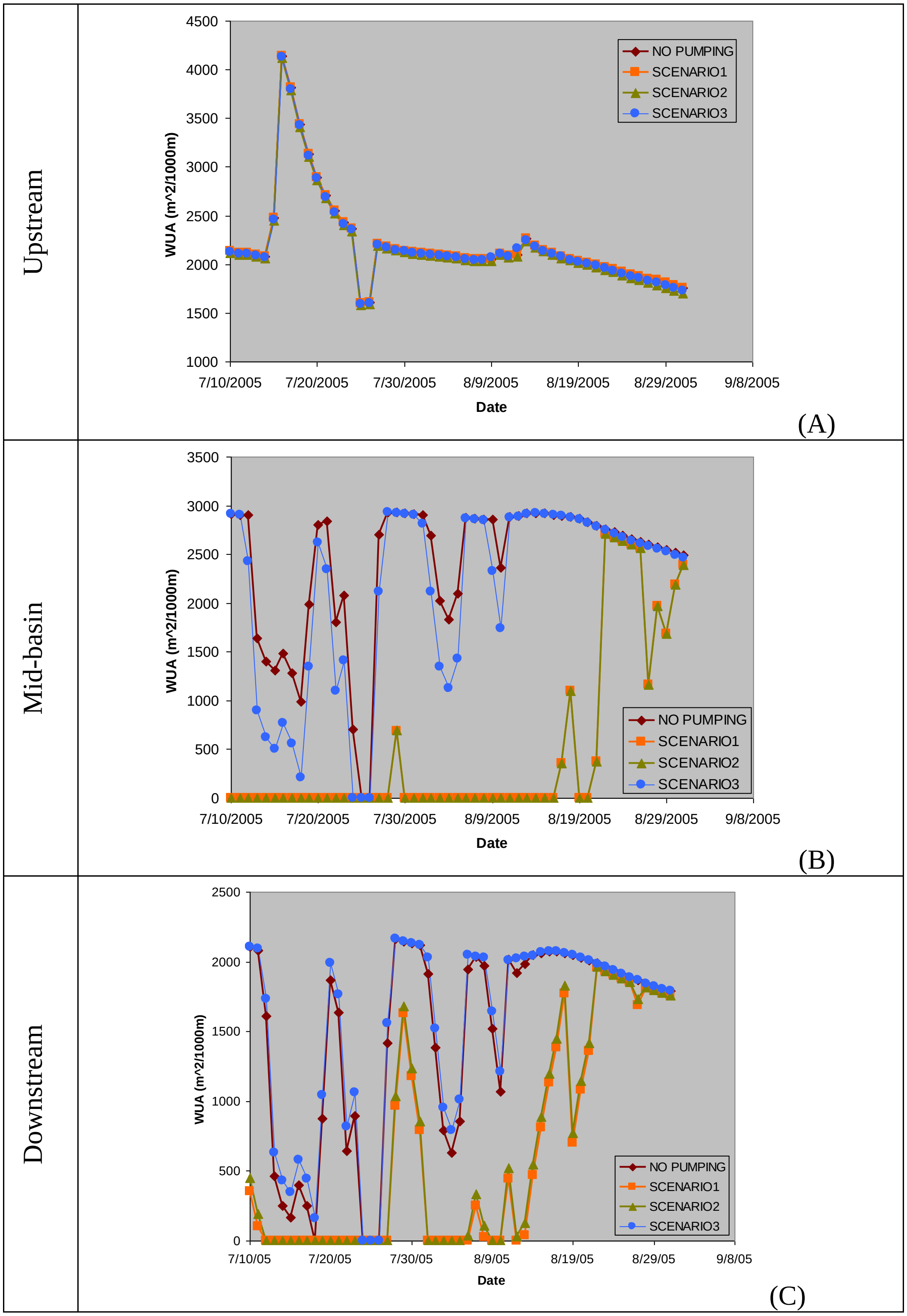


Figure 5.8. Daily-WUAs for adult brown trout under no-pumping, and the three pumping scenarios at the upstream (A), mid-basin (B), and downstream (C) sites.

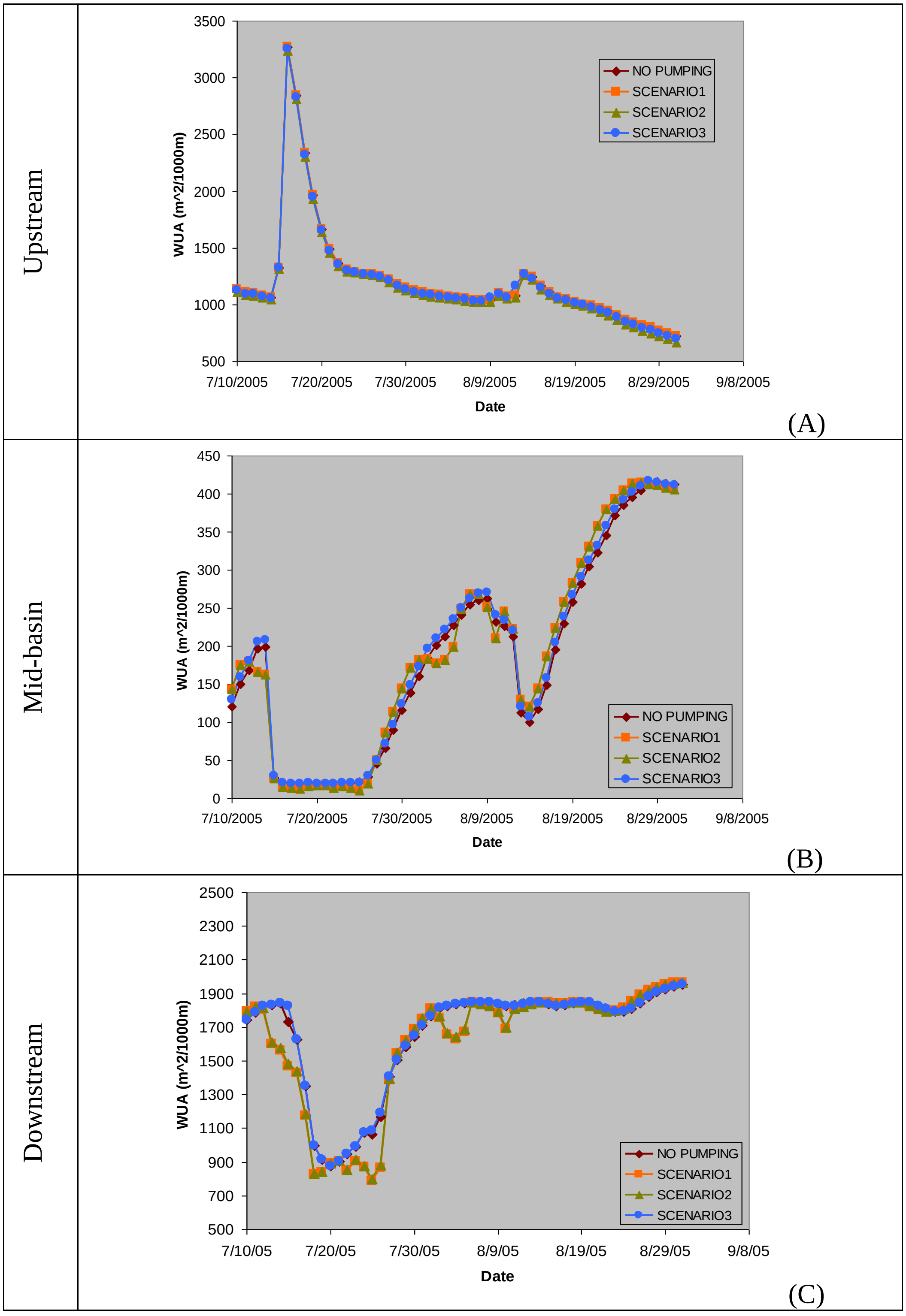


Figure 5.9. Daily-WUAs for blacknose dace under no-pumping, and the three pumping scenarios at the upstream (A), mid-basin (B), and downstream (C) sites.

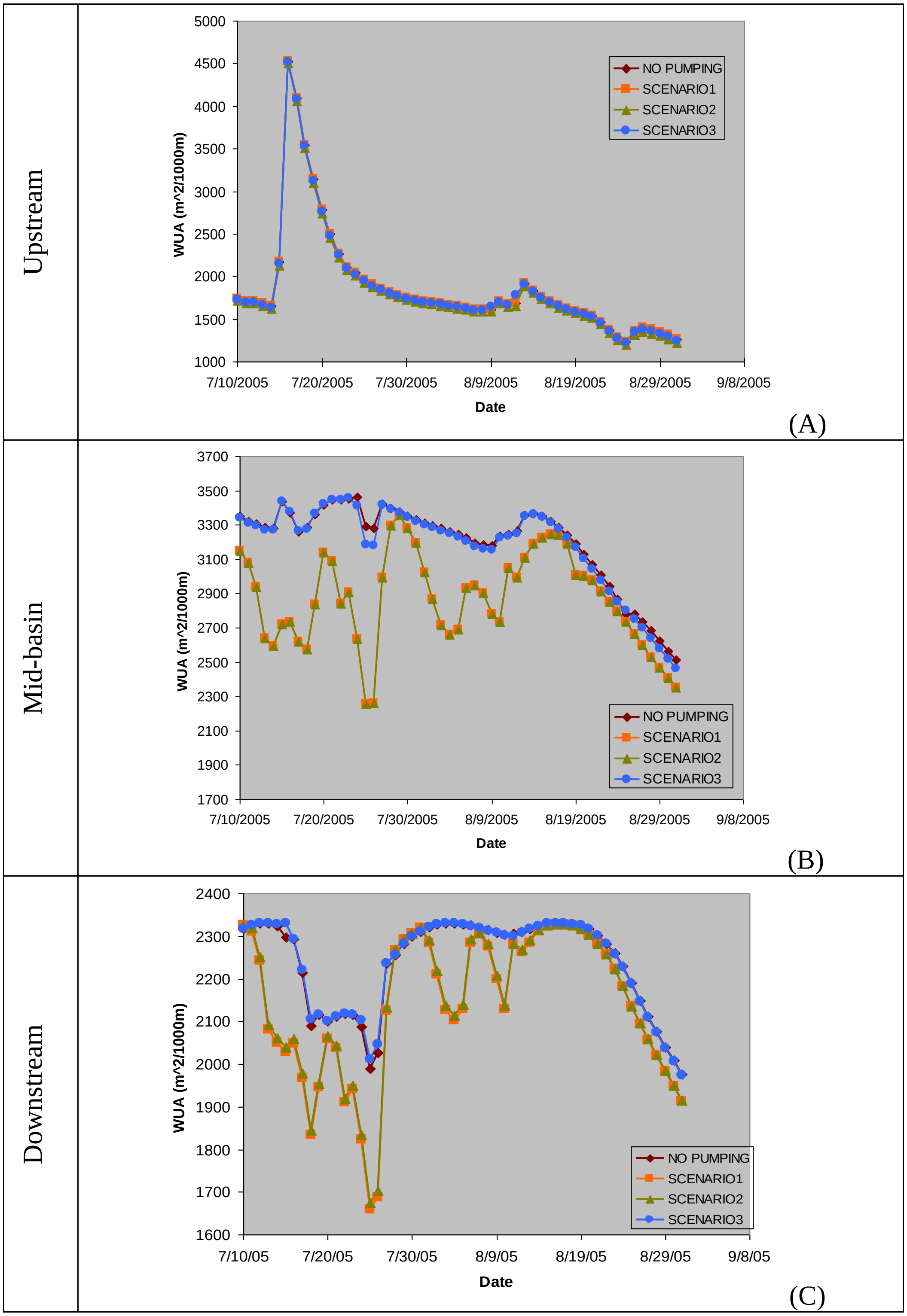


Figure 5.10. Daily-WUAs for creek chubs under no-pumping, and the three pumping scenarios at the upstream (A), mid-basin (B), and downstream (C) sites.

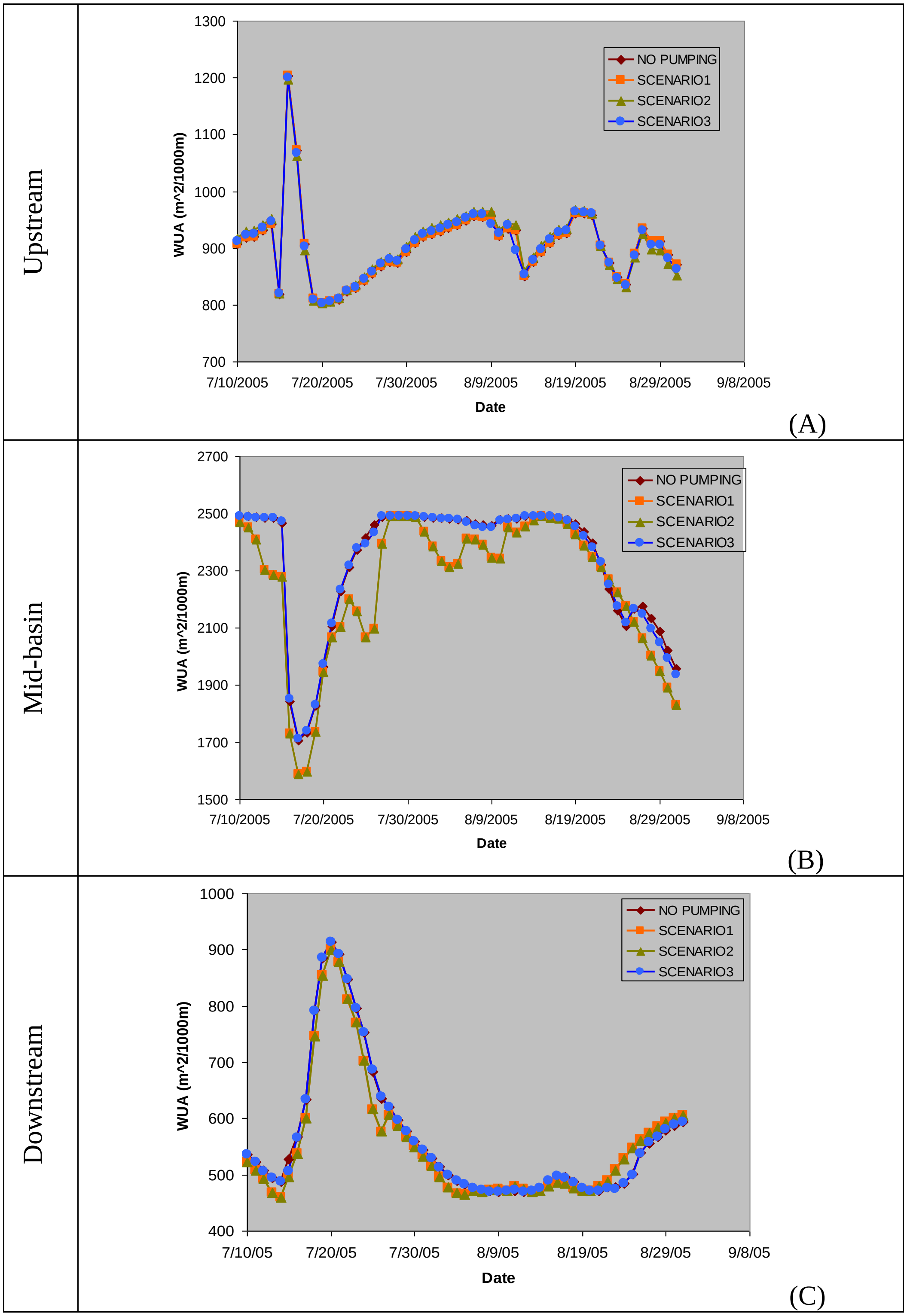


Figure 5.11. Daily-WUAs for white suckers under no-pumping, and the three pumping scenarios at the upstream (A), mid-basin (B), and downstream (C) sites.

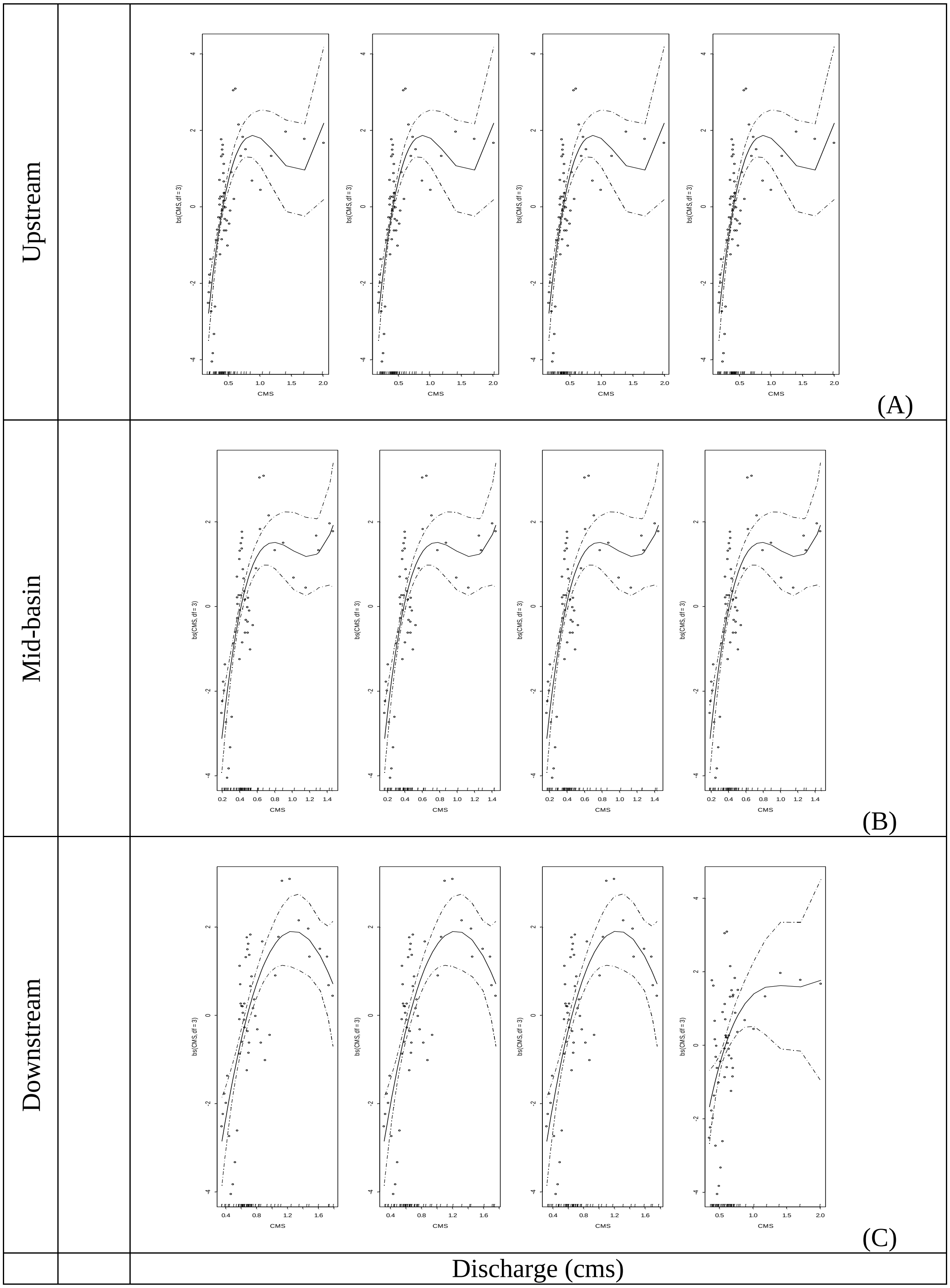


Figure 5.12. Generalized Additive Models (GAMs) of the relationship between discharge (x-axis) and water temperature (y-axis) at the upstream (A), mid-basin (B), and downstream (C) sites.

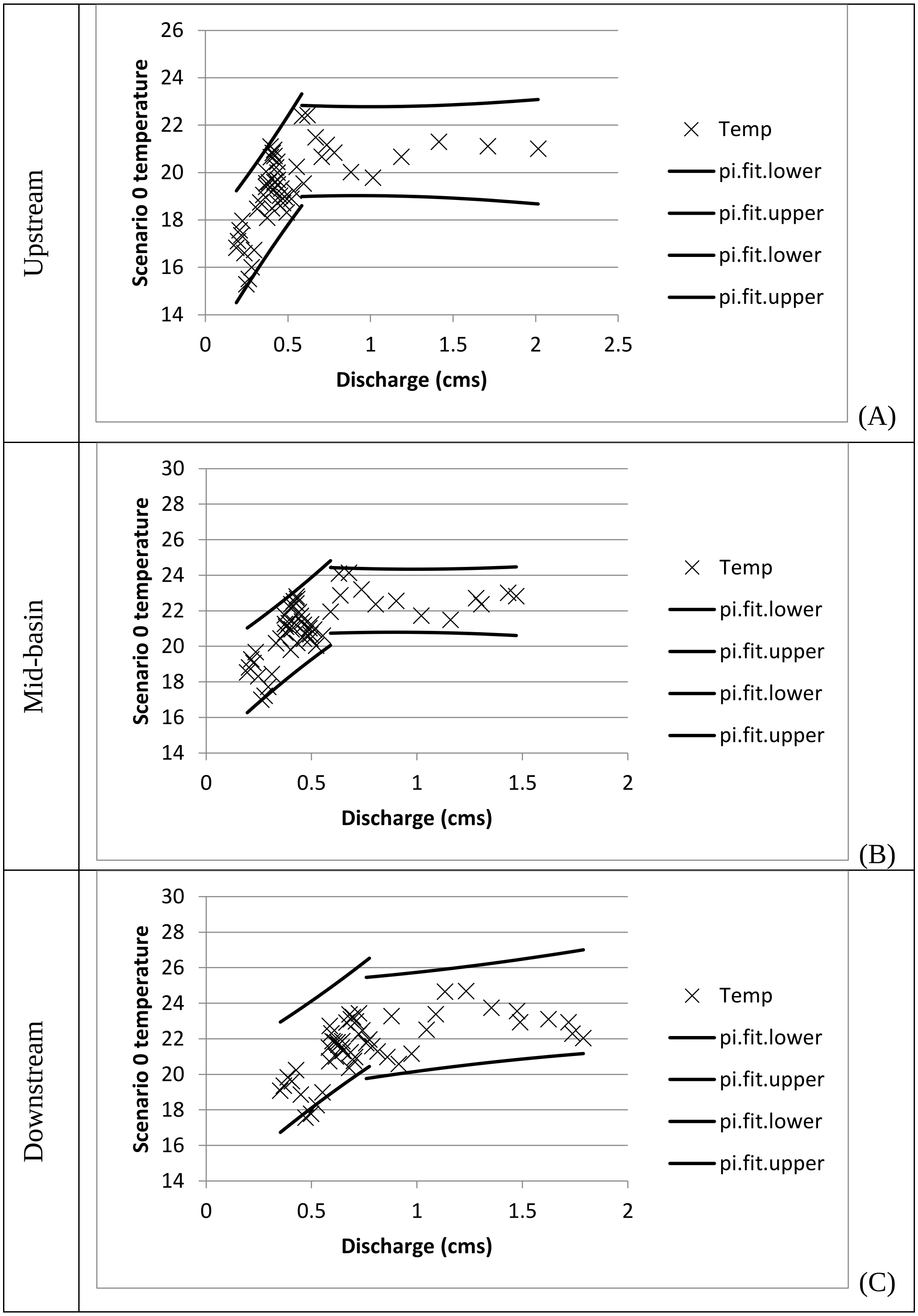


Figure 5.13. Generalized Linear Models (GLMs) – at +/-1 standard deviation of the mean – of the relationship between discharge (x-axis) and water temperature (y-axis) at the upstream (A), mid-basin (B), and downstream (C) sites to provide upper and lower bounds of expected summer temperatures in the baseline (i.e., no pumping) condition.

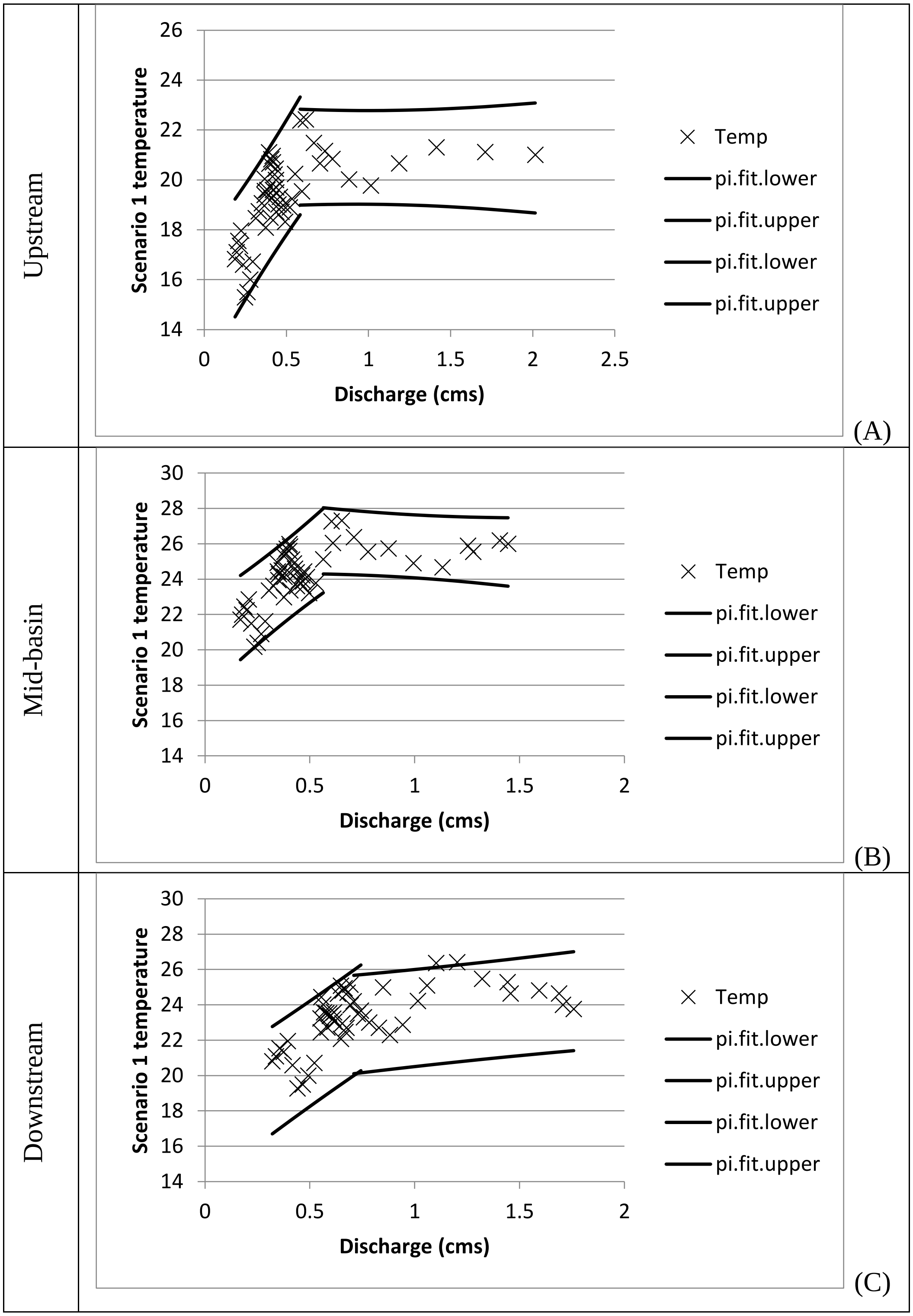


Figure 5.14. Generalized Linear Models (GLMs) – at +/-1 standard deviation of the mean – of the relationship between discharge (x-axis) and water temperature (y-axis) at the upstream (A), mid-basin (B), and downstream (C) sites to provide upper and lower bounds of expected summer temperatures under Scenario 1.

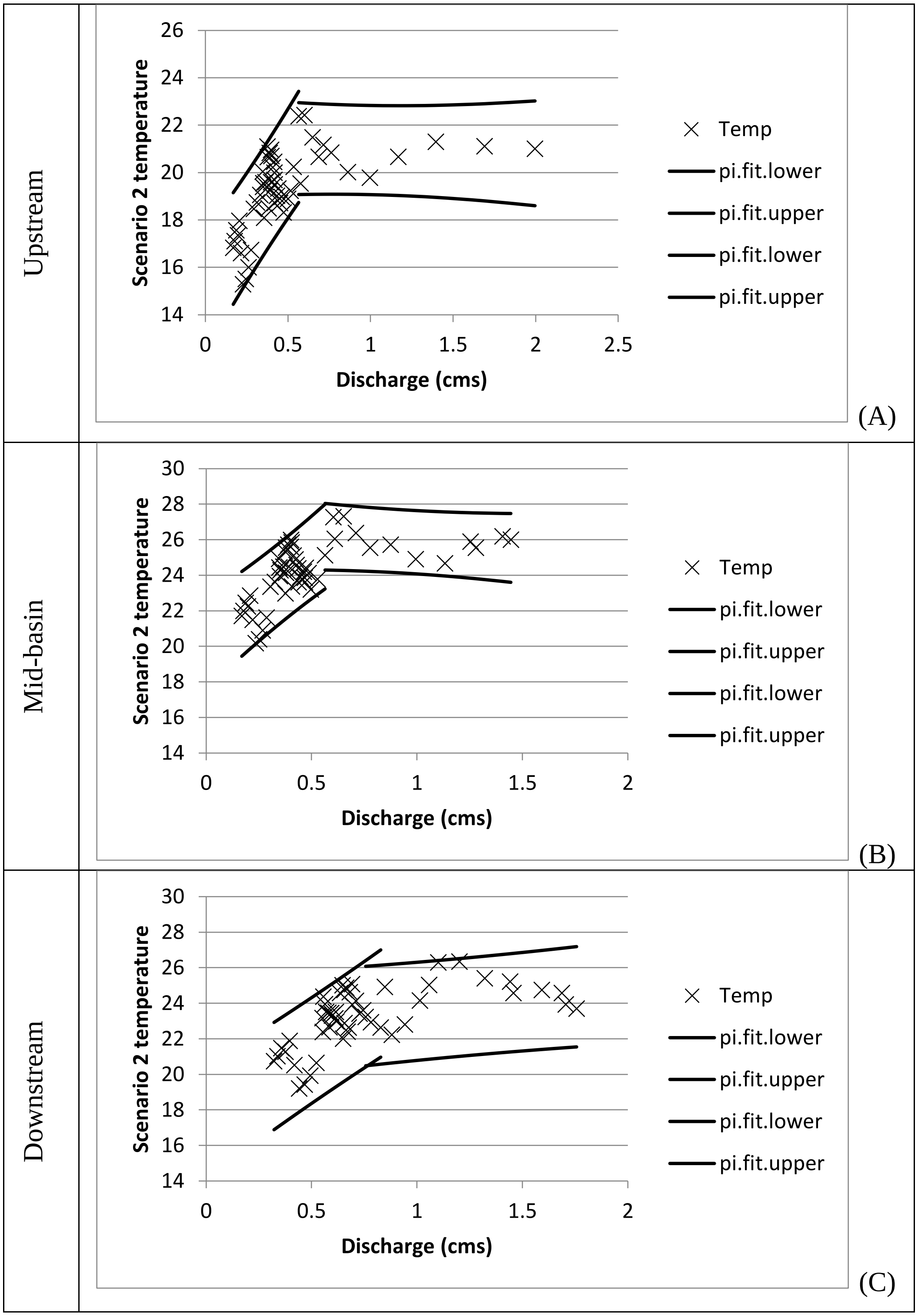


Figure 5.15. Generalized Linear Models (GLMs) – at +/-1 standard deviation of the mean – of the relationship between discharge (x-axis) and water temperature (y-axis) at the upstream (A), mid-basin (B), and downstream (C) sites to provide upper and lower bounds of expected summer temperatures under Scenario 2.

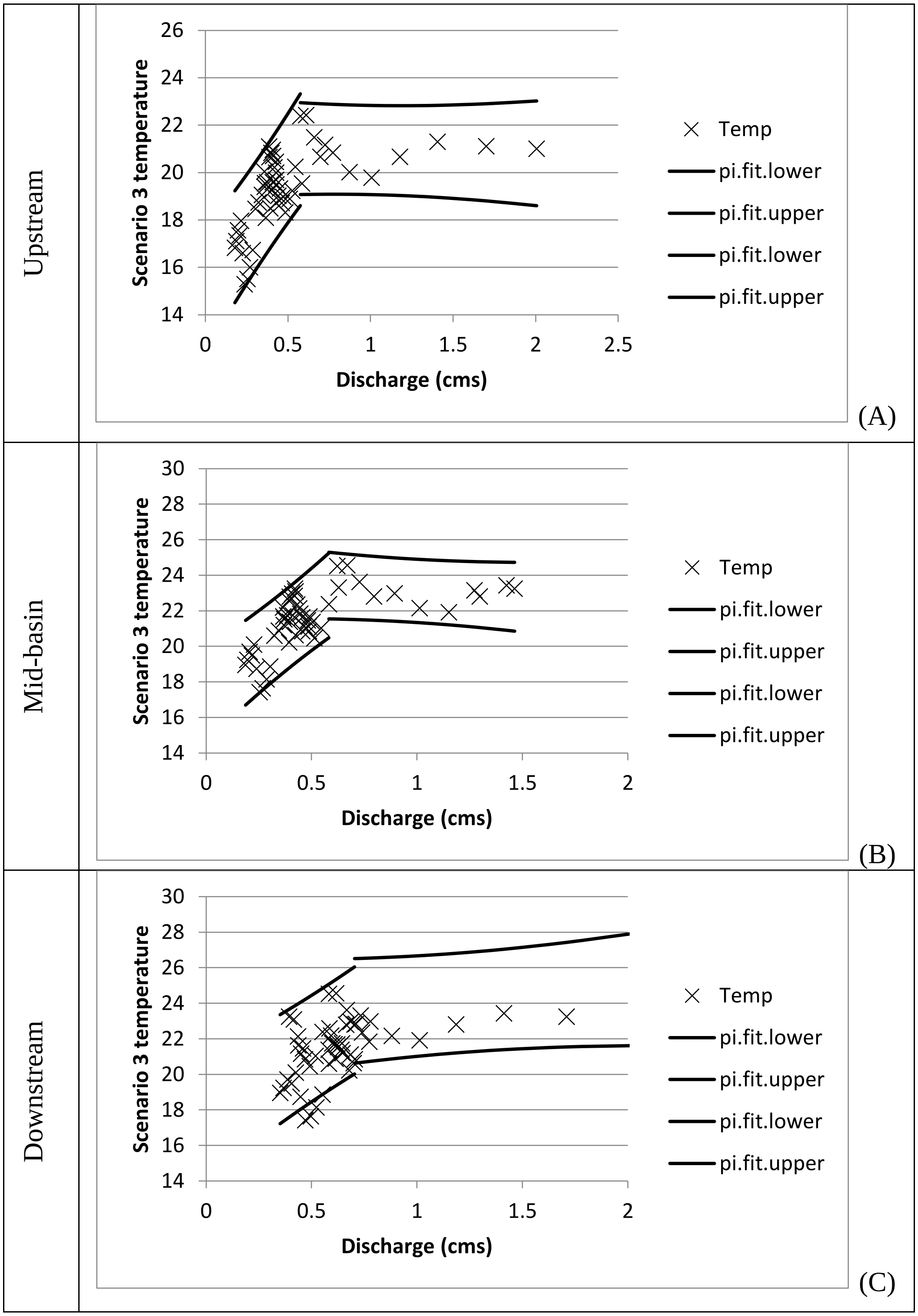


Figure 5.16. Generalized Linear Models (GLMs) – at +/-1 standard deviation of the mean – of the relationship between discharge (x-axis) and water temperature (y-axis) at the upstream (A), mid-basin (B), and downstream (C) sites to provide upper and lower bounds of expected summer temperatures under Scenario 3.

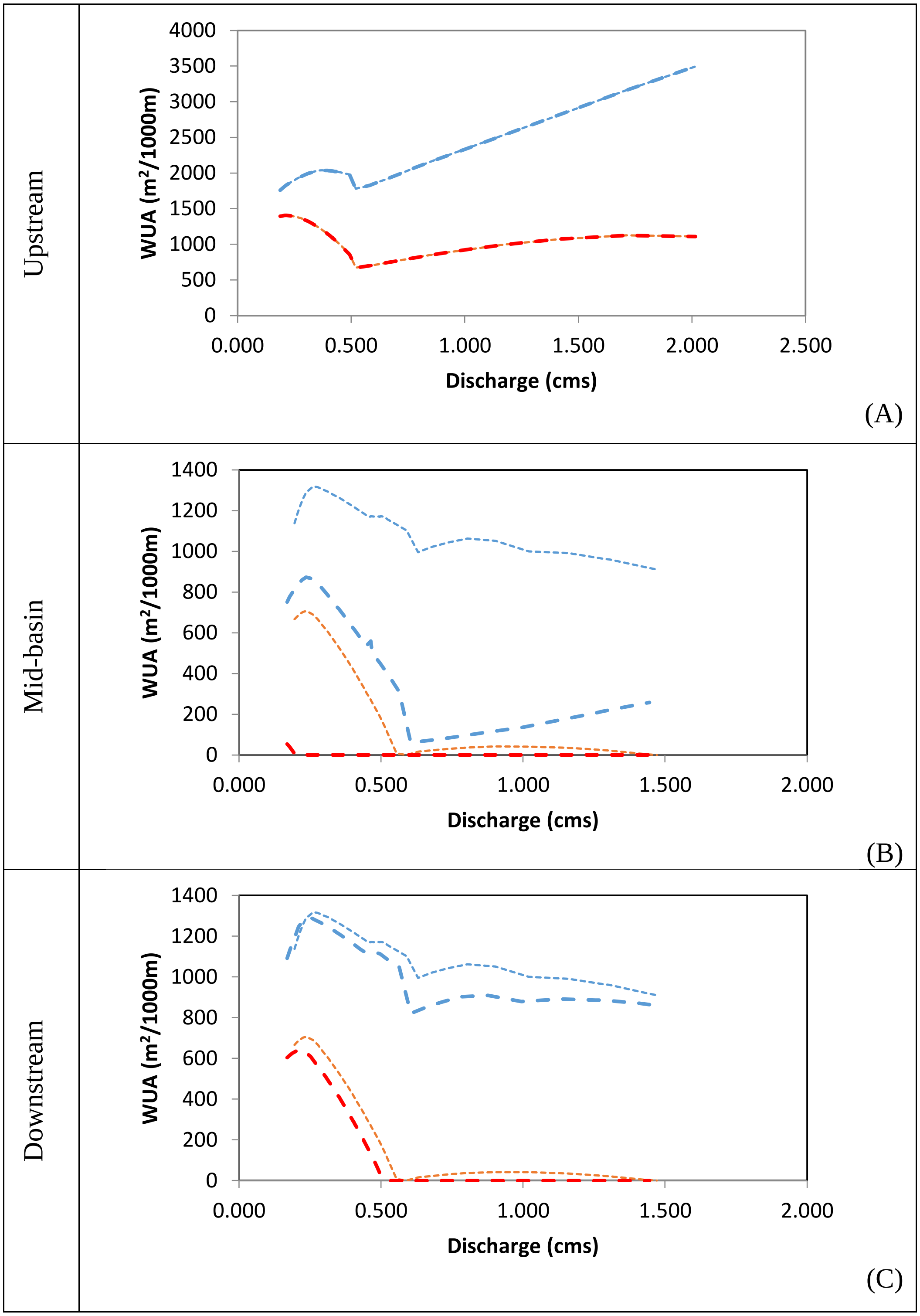


Figure 5.17. Brook trout summarized-WUA curves for Scenario 1 pumping conditions (dashed lines) against the baseline condition (dotted lines) at the upstream (A), mid-basin (B), and downstream (C) sites.

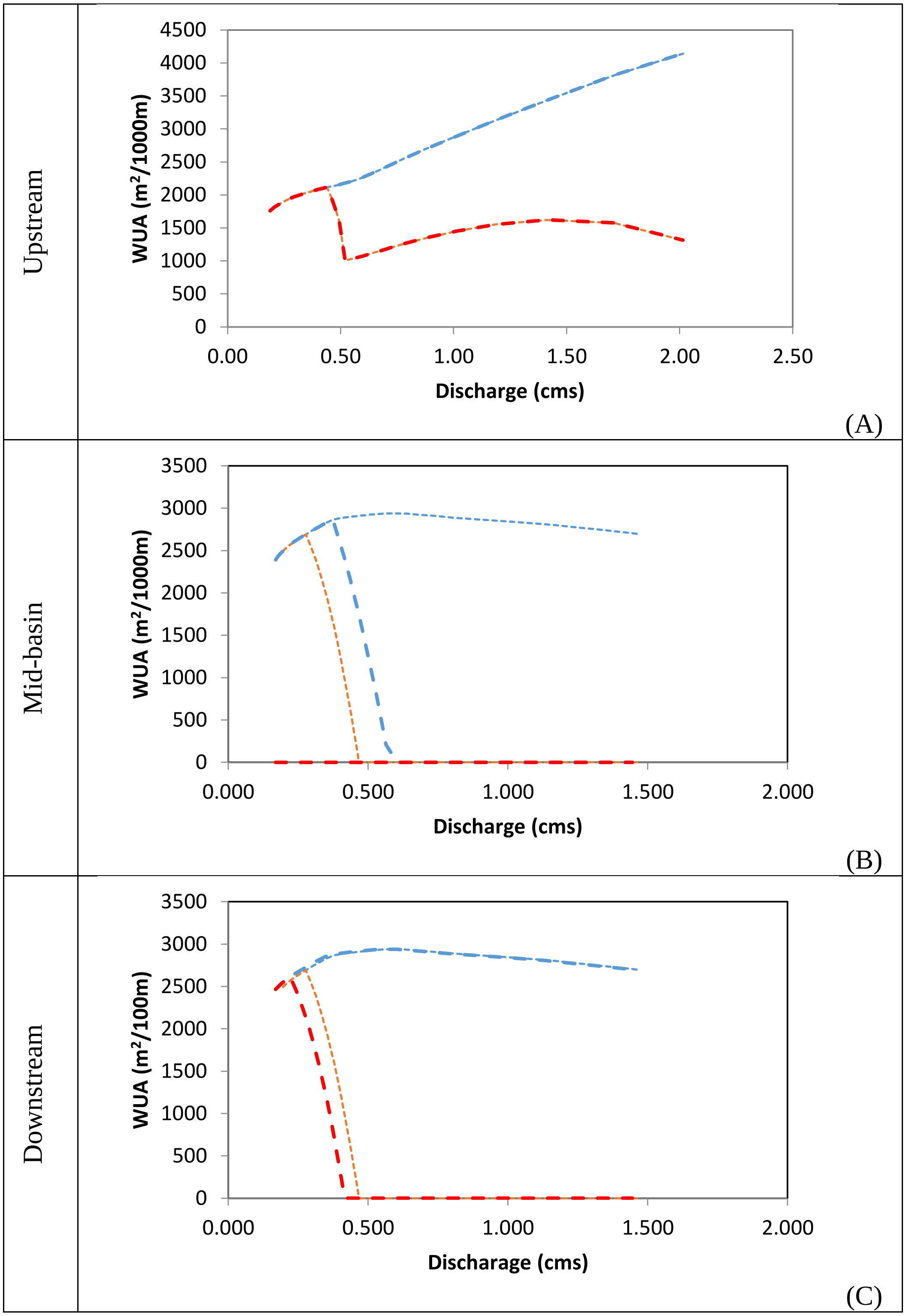


Figure 5.18. Brown trout summarized-WUA curves for Scenario 1 pumping conditions (dashed lines) against the baseline condition (dotted lines) at the upstream (A), mid-basin (B), and downstream (C) sites.

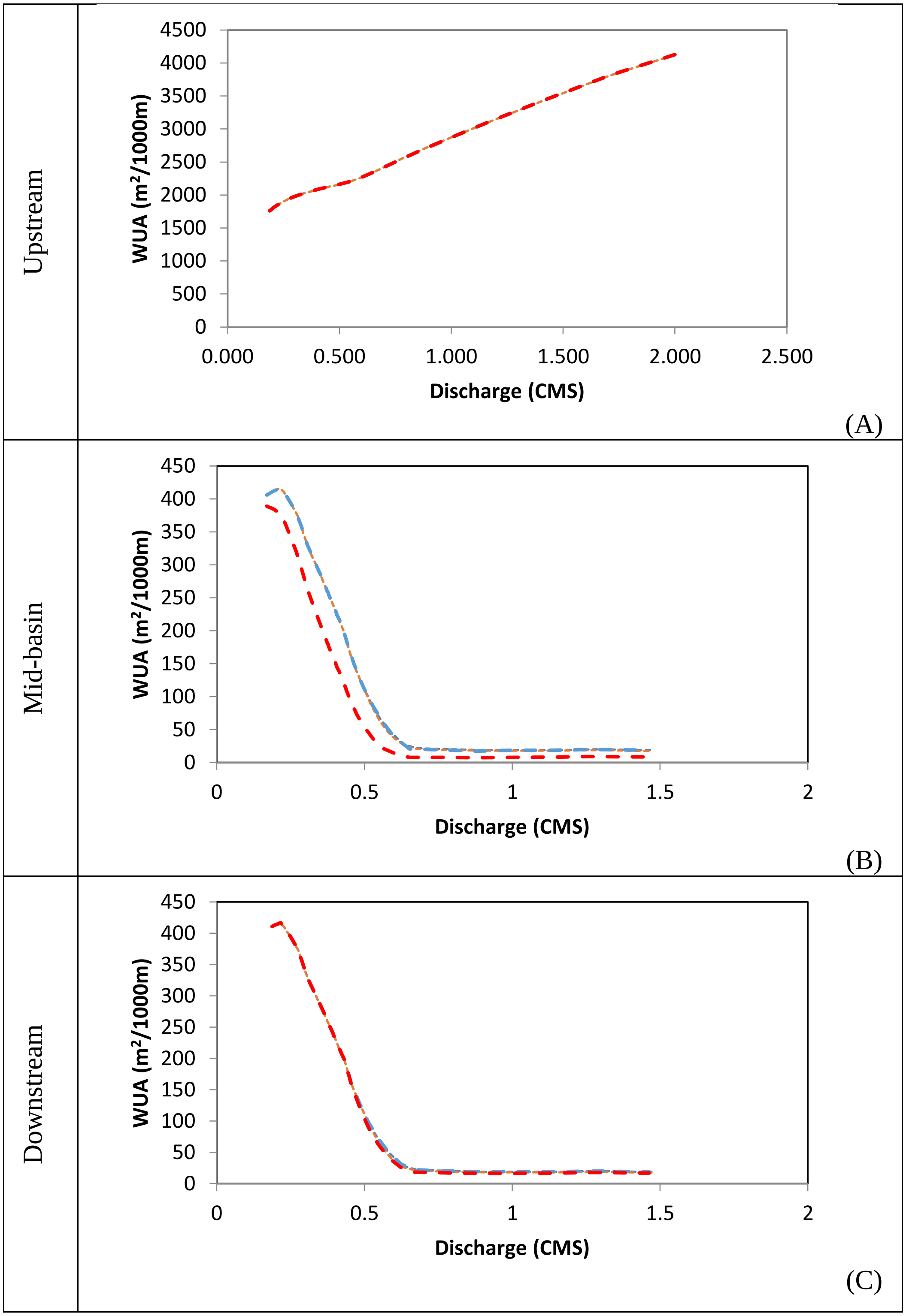


Figure 5.19. Blacknose dace summarized-WUA curves for Scenario 1 pumping conditions (dashed lines) against the baseline condition (dotted lines) at the upstream (A), mid-basin (B), and downstream (C) sites.

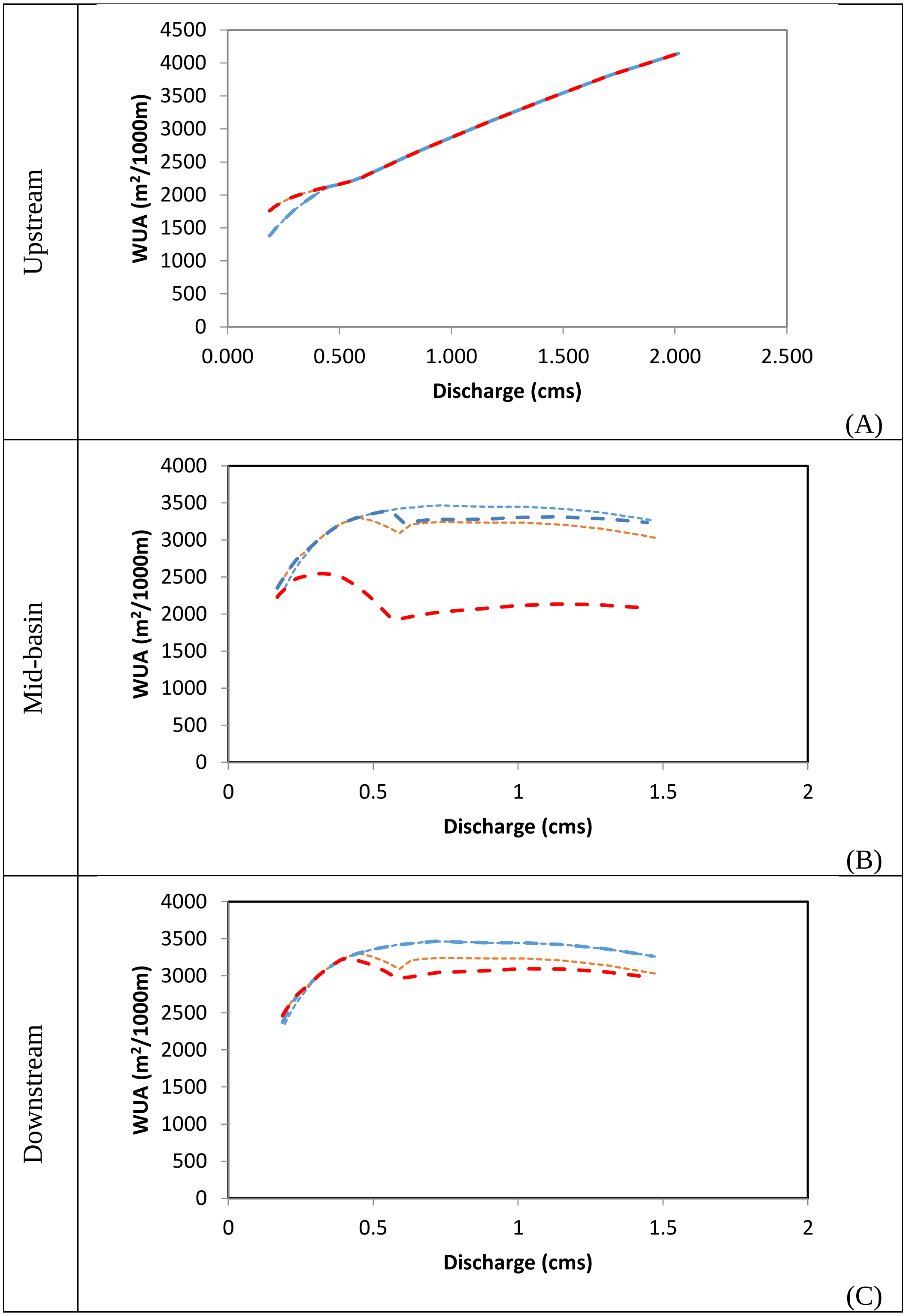


Figure 5.20. Creek chub summarized-WUA curves for Scenario 1 pumping conditions (dashed lines) against the baseline condition (dotted lines) at the upstream (A), mid-basin (B), and downstream (C) sites.

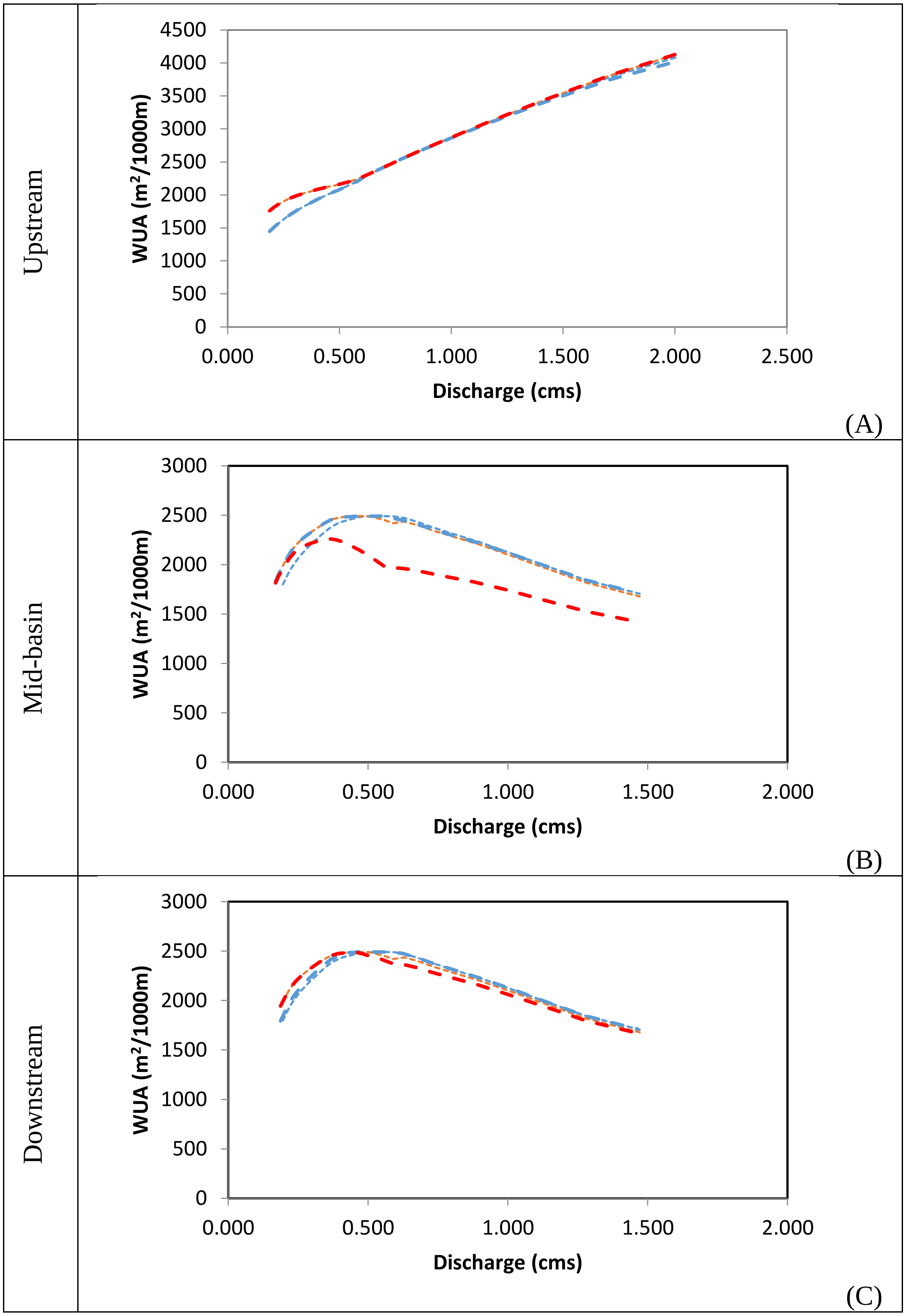


Figure 5.21. White sucker summarized-WUA curves for Scenario 1 pumping conditions (dashed lines) against the baseline condition (dotted lines) at the upstream (A), mid-basin (B), and downstream (C) sites.

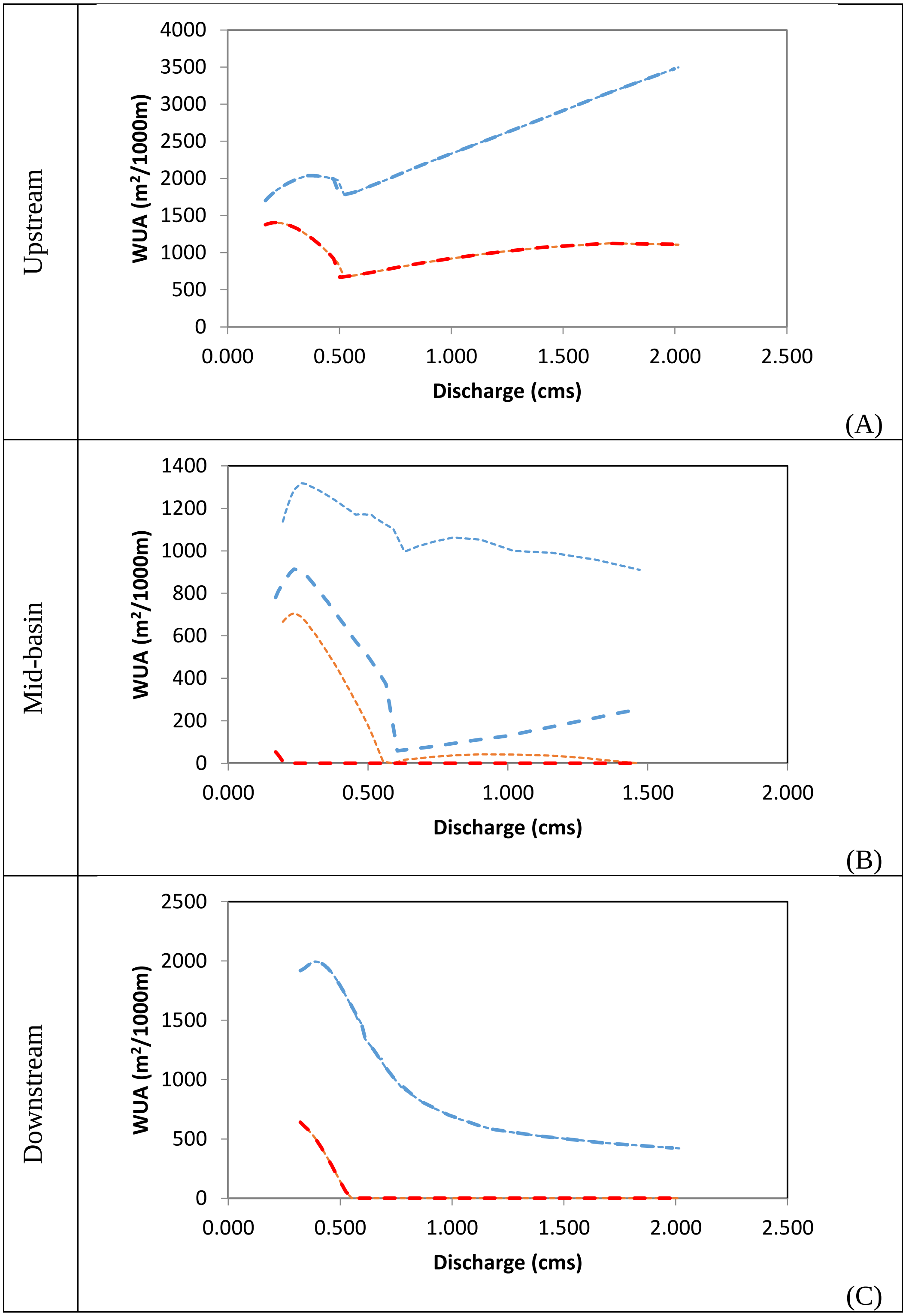


Figure 5.22. Brook trout summarized-WUA curves for Scenario 2 pumping conditions (dashed lines) against the baseline condition (dotted lines) at the upstream (A), mid-basin (B), and downstream (C) sites.

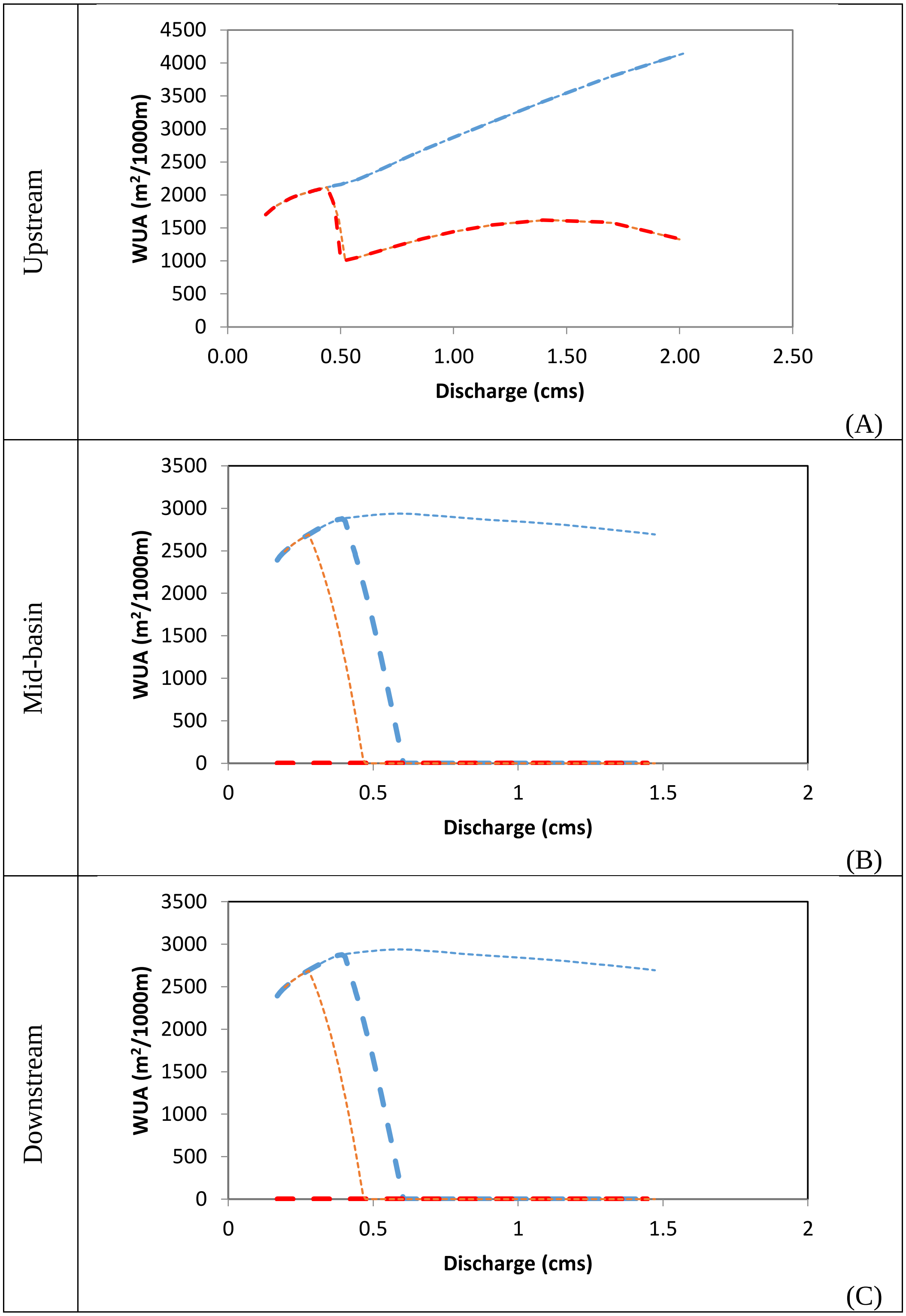


Figure 5.23. Brown trout summarized-WUA curves for Scenario 2 pumping conditions (dashed lines) against the baseline condition (dotted lines) at the upstream (A), mid-basin (B), and downstream (C) sites.

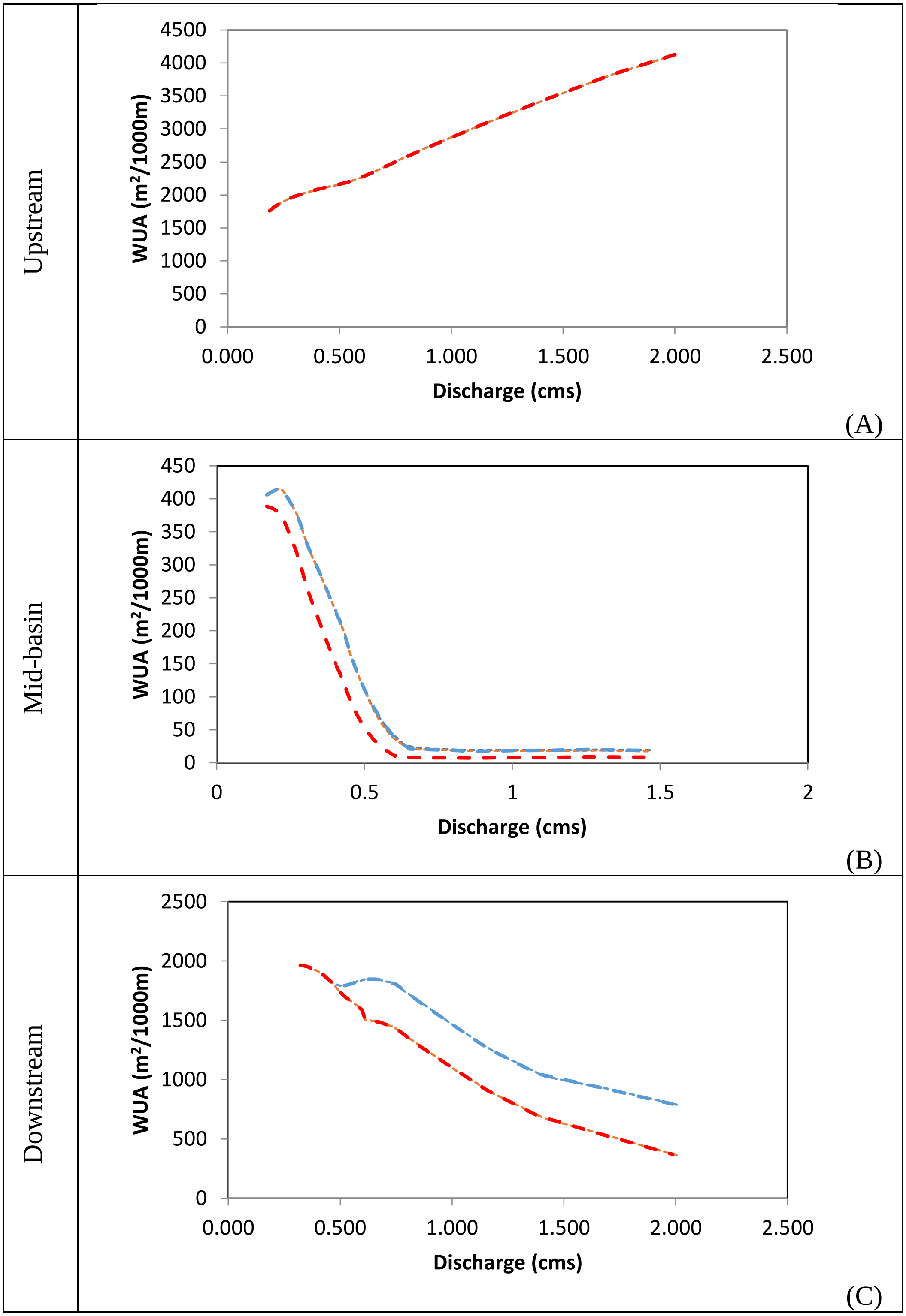


Figure 5.24. Blacknose dace summarized-WUA curves for Scenario 2 pumping conditions (dashed lines) against the baseline condition (dotted lines) at the upstream (A), mid-basin (B), and downstream (C) sites.

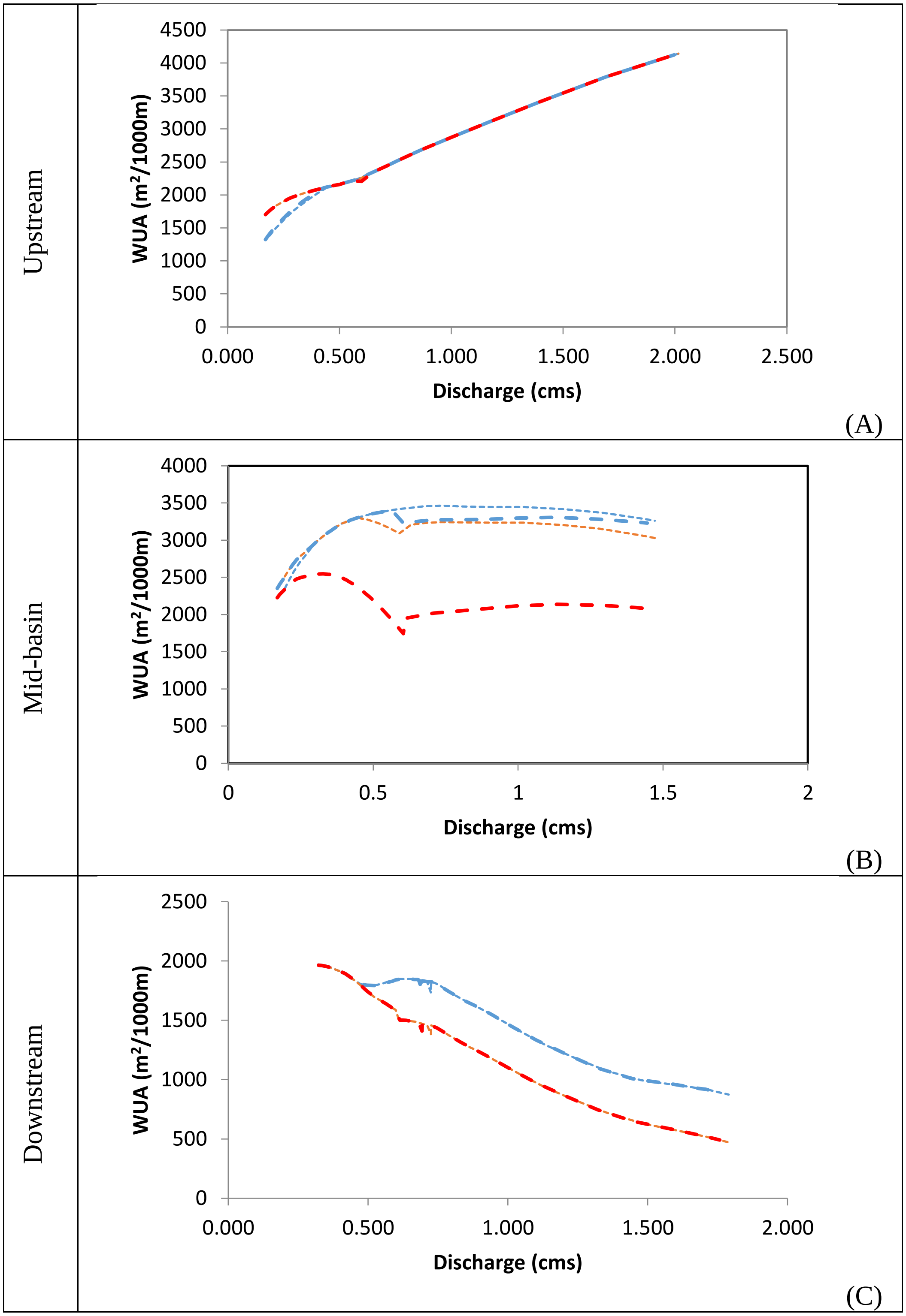


Figure 5.25. Creek chub summarized-WUA curves for Scenario 2 pumping conditions (dashed lines) against the baseline condition (dotted lines) at the upstream (A), mid-basin (B), and downstream (C) sites.

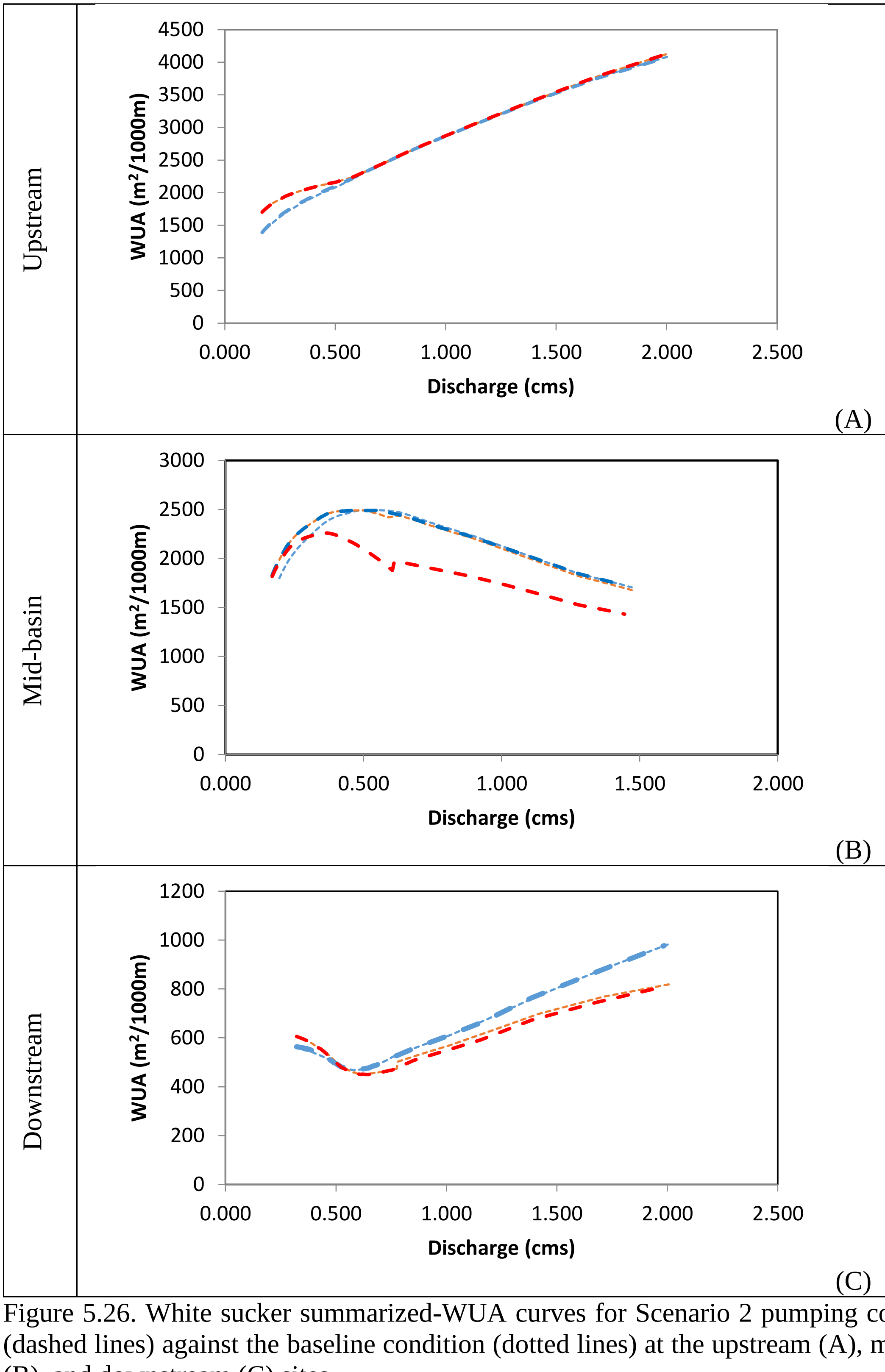


Figure 5.26. White sucker summarized-WUA curves for Scenario 2 pumping conditions (dashed lines) against the baseline condition (dotted lines) at the upstream (A), mid-basin (B), and downstream (C) sites.

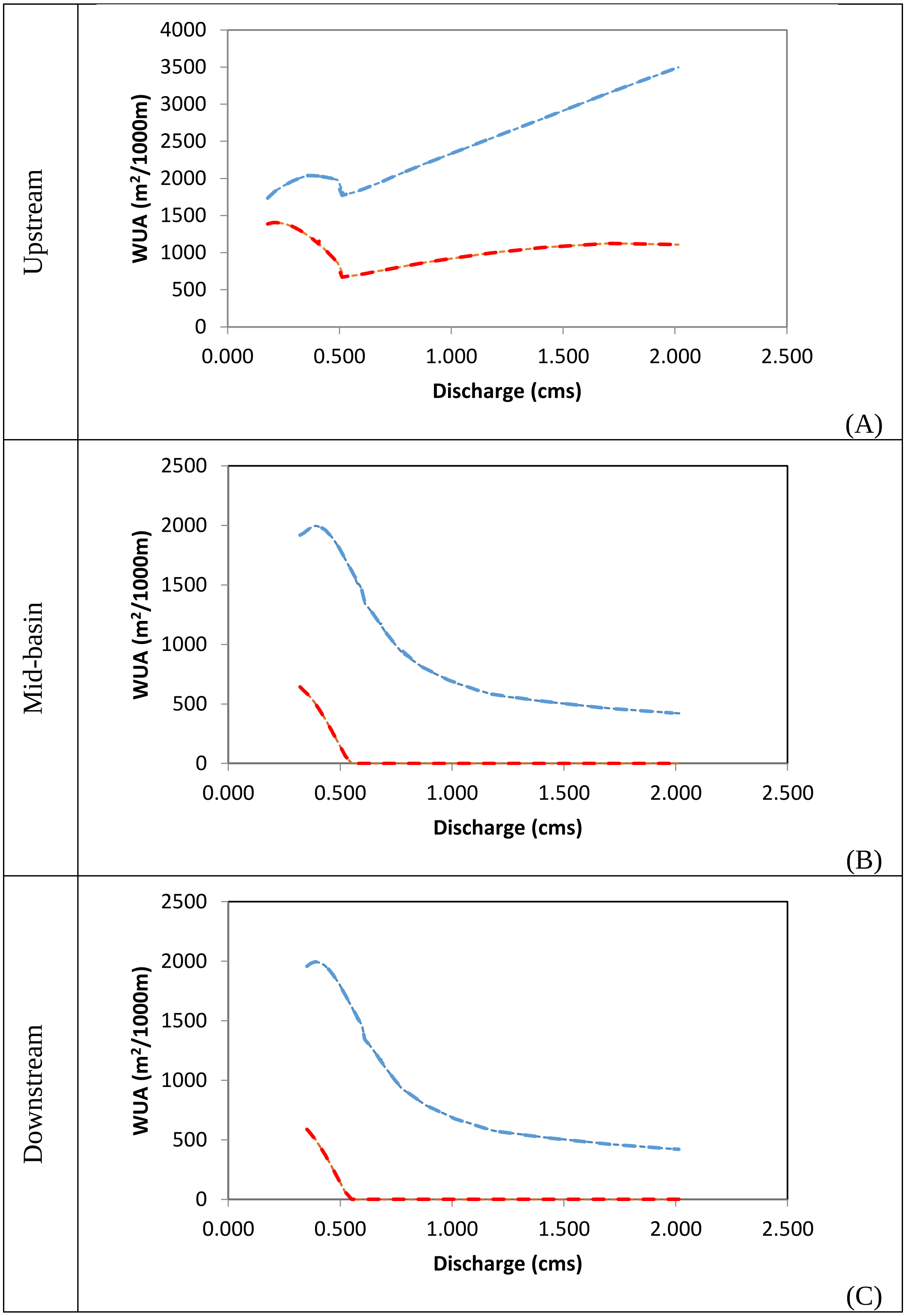


Figure 5.27. Brook trout summarized-WUA curves for Scenario 3 pumping conditions (dashed lines) against the baseline condition (dotted lines) at the upstream (A), mid-basin (B), and downstream (C) sites.

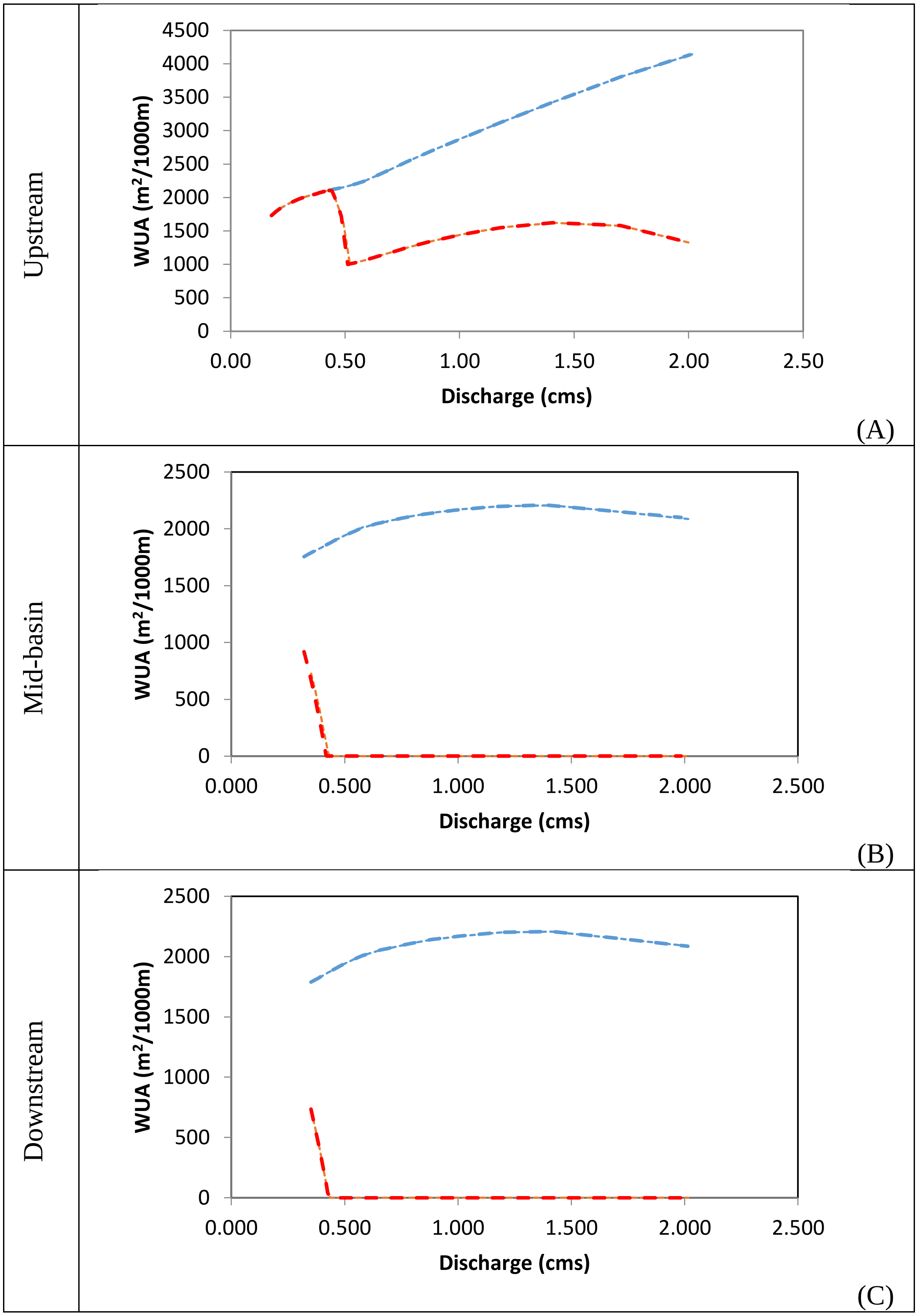


Figure 5.28. Brown trout summarized-WUA curves for Scenario 3 pumping conditions (dashed lines) against the baseline condition (dotted lines) at the upstream (A), mid-basin (B), and downstream (C) sites.

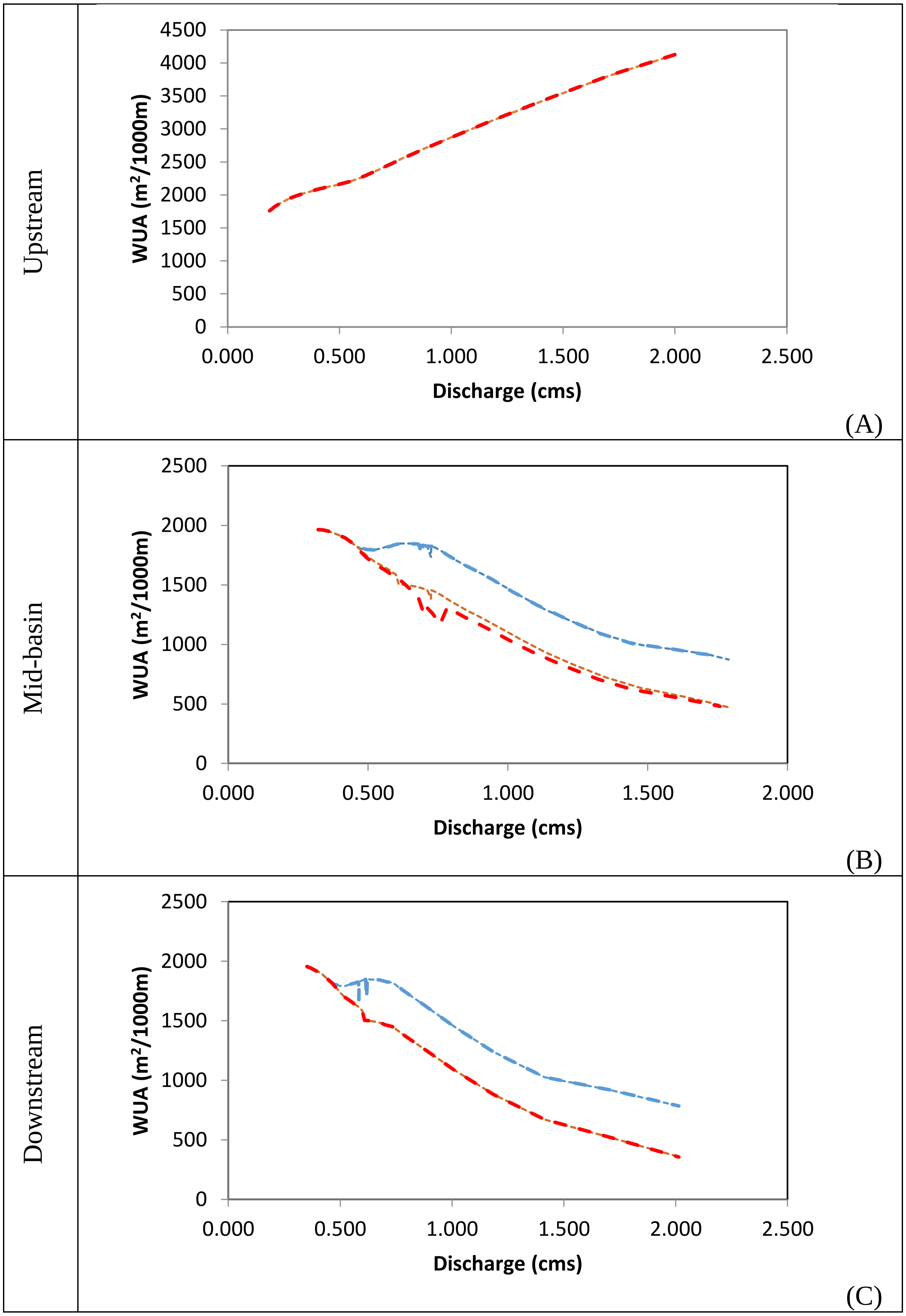


Figure 5.29. Blacknose dace summarized-WUA curves for Scenario 3 pumping conditions (dashed lines) against the baseline condition (dotted lines) at the upstream (A), mid-basin (B), and downstream (C) sites.

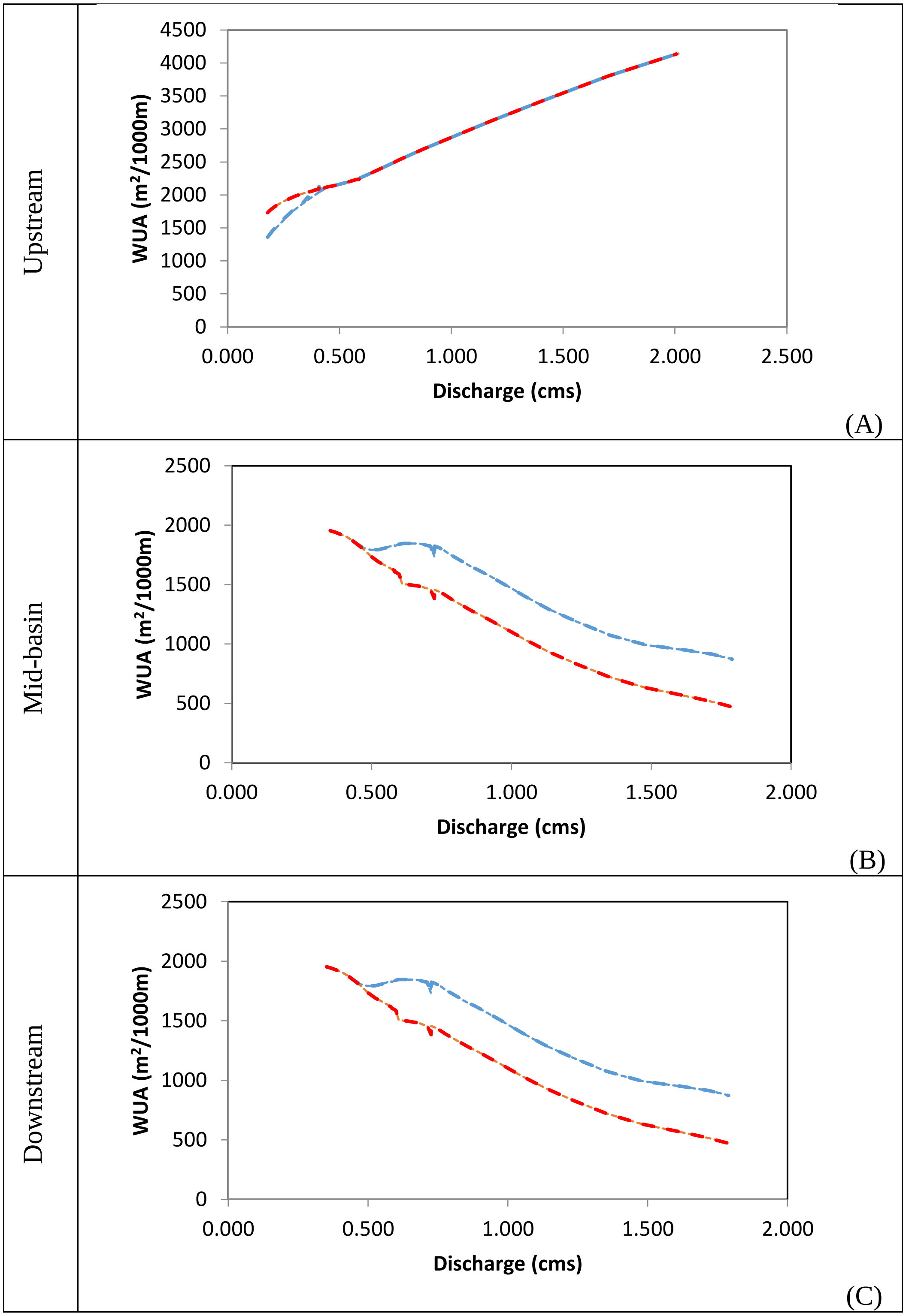


Figure 5.30. Creek chub summarized-WUA curves for Scenario 3 pumping conditions (dashed lines) against the baseline condition (dotted lines) at the upstream (A), mid-basin (B), and downstream (C) sites.

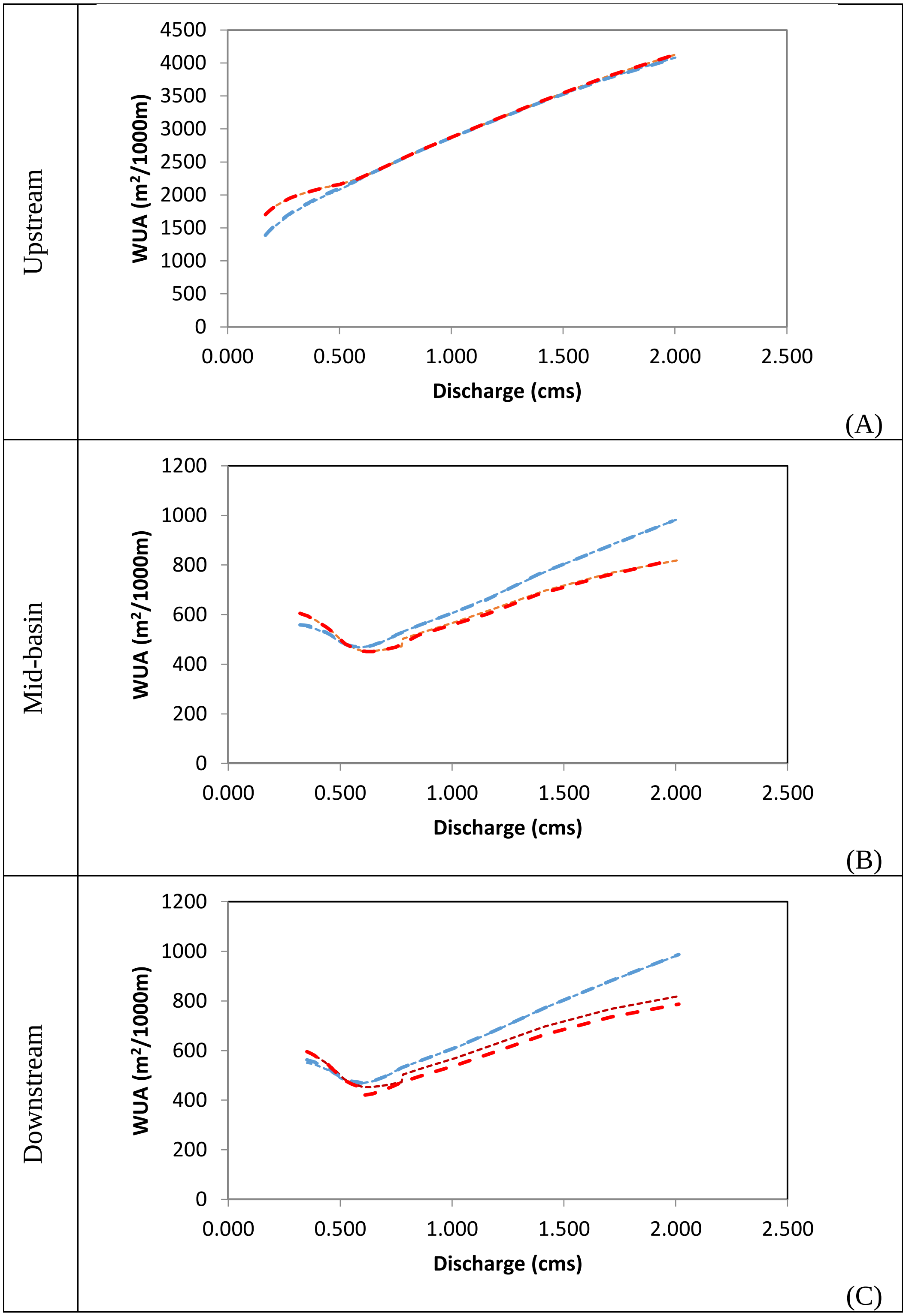


Figure 5.31. White sucker summarized-WUA curves for Scenario 3 pumping conditions (dashed lines) against the baseline condition (dotted lines) at the upstream (A), mid-basin (B), and downstream (C) sites.

CHAPTER VI:

Modeling the impacts of change on water withdrawal regulation in large Michigan watershed.

6.1 Abstract

In 2008, the Michigan Legislature ratified a PA185 to implement the state's science-based water withdrawal assessment tool, including a stipulation that only withdrawals greater than 100,000 gpd would require registration with the MDEQ. The threshold of 100,000 gpd creates a new regulatory landscape in which a property-owner could pump water up to that amount without being required to register the withdrawal or being subject to direct regulation in the future. This chapter examines the potential impact of such un-regulated groundwater withdrawals as a way to test of the conservation presumption of Michigan's new groundwater conservation law. Michigan's 100,000 gpd threshold and Minnesota's 10,000 gpd threshold are also compared.

6.2 Introduction

In 2008, the states surrounding the Great Lakes – together with the Canadian provinces of Ontario and Quebec – signed the Great Lakes-St. Lawrence River Basin Water Resources Compact (the Great Lakes Compact) into law. This inter-state (and effectively international, see Section 3.3.2 for more information) Compact required each party state (and province) to create evidence-based regulatory systems to conserve the water resources of the Great Lakes and prevent large-scale diversions from the Great Lakes-St. Lawrence River basin.

In 2006, the state of Michigan ratified the Great Lakes Compact as law. As a separate measure, in 2008 the state instituted its water conservation statute (Public Act 185 of 2008, PA185-2008) (Michigan State Legislature, 2006). This act created the first legislative regulation in state law that directly set limits to water withdrawals while also attempting to maintain the general legal framework "reasonable use" and of riparianism (see Chapter 3 for more information on reasonable use and riparianism). Briefly, PA185-2008 classifies all the rivers of the state into one of eleven river types and sets an objectively measurable, science-based procedure for defining an adverse resource impact, an analogue of an unreasonable use for each river type (Hamilton & Seelbach, 2011).

An early legal assessment of the Great Lakes Compact (Dobornos, 2010) pointed out the importance of setting a regulatory threshold which is low enough to protect the resource from cumulative pumping from smaller-than-regulated wells. The regulatory standard in the State of Michigan presently has a threshold of 100,000 gallons per day (gpd; PA185-2008). If this law is to be an effective conservation law, then it follows that it is important that it actually conserve water resources as intended, even under unsual or changing regulatory contexts. Furthermore, the law should be based on a framework that is consistent with the physical processes that govern the condition of that resource, and not on political exigencies (Dobornos, 2010).

PA185-2008 seeks to conserve Michigan's water resources by regulating any planned withdrawal of a capacity greater than 100,000 gpd. I propose here to test this conservation presumption by exploring the potential implications of cumulative unregulated water withdrawals that fall just under the regulatory threshold, what I term "cumulative occult withdrawals." A 2004 Michigan Department of Environmental Quality water-use census (MDEQ, 2004) confirms that the water pumping capacity needed to irrigate several common crops is roughly 100,000 gpd per 180 acres; the average size of a Michigan farm (Table 6.1). This suggests that any large increase in water demand by agricultural users might be met by many wells which fall below the state's new regulatory threshold. Furthermore, the increase of water-use registrations of more than 100,000 gpd since 2009 have been concentrated in agricultural areas, especially in Southwestern Michigan (See Chapter 4). With the recognition that many farmers are thinking about how the new regulatory landscape will impact their irrigation decisions, and that many forms of irrigated agriculture can take place at rates approaching the reporting standard, it is reasonable to ask whether PA185-2008 could actually meet its conservation objectives under a scenario of large-scale increases in un-regulated (referred to here as *occult*) agricultural withdrawals. Testing the efficacy of the new regulatory system in the face of this potential challenge is even more important given the historical evidence that environmental laws have often produced unintended negative environmental outcomes. Typically this occurs when rational actors modify their behavior to take advantage of a relatively liberal regulatory landscape, with the net effect of blunting environmental protection outcomes (Auffhammer & Kellogg, 2011). Indeed, case studies have shown that water conservation regulations can even result in increased overall irrigative water use (Carolan, 2006; Pfeiffer & Lin, 2010).

To that end, I have made use of available modeling resources to conduct a theoretical "stress-test" of Michigan's new water conservation law. My goal is to determine the extent to which the laws' (and in a larger context the compact's) conservation goals might be threatened by "worse-case" scenarios of occult agricultural withdrawals.

6.2.1.1 Adaptability of the Regulation

The physical landscape through which the regulated waters flow is changing. The land-use patterns of today will not be maintained tomorrow. Agricultural lands will change in size, distribution and abundance, and agricultural water utilization patterns will also change as larger social forces create different incentives for agriculture. Alongside land-use changes, it is reasonable to expect that climatic changes will alter the meteorological conditions that affect hydrology across the State. In the Muskegon River watershed as elsewhere in the state, the expectation for climate change is currently that average temperatures and precipitation will both increase. Combined with expected changes to land-use patterns, the increased temperatures and precipitation will significantly alter the hydrologic characteristics of river flows, as well as groundwater availability, and characteristic fish faunas (Wiley, et al., 2010).A fundamental problem for future Michigan policy-makers, regulators, and legal analysts will be to determine the how commitments to water conservation can be maintained in the face of regional hydrologic change not directly or immediately caused by human consumptive withdrawal. The law as it stands has a few mechanisms for adapting to basic changes in water availability. It does currently require that estimates of the amount of water flowing in Michigan's rivers be regularly updated. If this updating accurately reflects the changing amounts of water available and is frequent enough to track rates of natural hydrologic change, then there is the potential for the regulatory system to adapt, and state regulators to adaptively manage Michigan's water resources, through time. However, while regular updating of flow estimates is a necessary (logically and legally) condition for adaptive management, it is not a sufficient condition. This is because the regulatory model employed by Michigan law specifies water availability in terms of flow rates to be maintained in specific classes of Michigan rivers. If the overall hydrologic regime in the states changes, then changes are also likely in the way specific river segments should be classified. But, unlike the regular updates to the water availability assessment called for in the statue, the reclassification of the river segments is not statutorily required. Furthermore, the issue of the reclassification of river-type currently presents a legal conundrum for the Michigan Department of Environmental Quality (MDEQ), the government agency tasked with this laws' enforcement. Since the question of how to re-classify any particular river reach (or series of reaches) is not addressed in the existing legislation, there is no legal basis for the regulatory agency to distinguish between changes in river-type caused directly by ground or surface water withdrawal as opposed to changes caused indirectly by landscape or climatic change. In short, as it now stands only the process of site-specific review provides any legal mechanism to change the existing river-type definitions. (See Chapter 4 for more information.) Unfortunately if the underlying river-type classifications cannot be updated as hydrologic conditions change, then adaptive management of Michigan's water resources is at risk, as is the conservation presumption of the statue.

6.2.2 Chapter Objectives

This chapter conducts three tests of inherent assumptions of WWAT as regards water conservation – the presumption upon which PA185-2008 was based. First is to determine whether the reporting threshold of 100,000 gpd is sufficient to ensure that cumulative occult withdrawals do not cause ARIs anywhere in the Muskegon River Watershed at the present time, in a future with projected land-use change, and in a future with projected land-use and climate change. Second is to determine the comparative impact that a 10,000 gpd regulatory threshold – as is used in Minnesota – will have on the creation of ARIs caused by cumulative occult pumping. The third and final objective is to explore how adaptive governance will affect the determination of ARIs in the future.

6.3 Methods

6.3.1 Stress-Testing the Conservation Presumption

In order to test the conservation presumption of PA185-2008 I designed and executed a series of modeling experiments in which I applied levels of un-regulated (i.e., occult, in the sense of being unseen by the regulatory process) agricultural pumping across a series of hydrologic (water supply) and regulatory (degrees of adaptive governance) scenarios. My objective is to quantify in a real Michigan watershed the range of possible environmental impacts that extreme levels of occult withdrawal might cause presently and in a changing future. I chose to examine the extreme case here (as opposed to the most likely or predictable future in terms of rates of water withdrawal), because I am interested in testing, *en extremis*, the strength of the conservation presumption of the law. In other words, I have applied an admittedly extreme but certainly possible future rate of agricultural pumping as a kind of "stress test" to evaluate the potential performance of the law and the management regime it has created. .

In order to perform this exercise, I needed a hydrologic model that could both model responses to the simulated occult withdrawals I planned to evaluate and also simulate reasonable future changes in hydrology and river flows that would require a degree of regulatory adaptation. Toward this end, I chose to employ the Muskegon River multi-model MREMS (Wiley, et al., 2010), and incorporate existing future hydrologic scenarios associated with changing land-use and changing climate. Adapting WWAT rules and processes to the MREMS modeling environment allowed me to apply a standardized set of pumping stresses to the Muskegon River basin and to explore how these and various levels of future regulatory adaptation "conserve" resource integrity. My metric of conservation success here is the same metric identified in PA185-2008: the avoidance of ARI's (and more broadly the minimization of river segments pushed into problematic "Policy Zones"; see Section 6.3.3).

In order to develop a "stress" level of pumping for these experiments the agricultural land areas of each of the 41 MREMS sub-watershed units were summarized using ArcMap v10 (ESRI). In order to allocate pumping rates to agricultural lands, the total agricultural acreage in each sub-watershed was divided into 180-acre units, roughly the average size of Michigan farms (USDA, 2009) , and each of these average-farm size units were assigned a value of groundwater extraction referred to here as a pumping regime. Each of four pumping regimes (Table 6.3) reflects a different level of pumping stress. The first pumping regime ("MI standard") has all average-farm units pumping at 99,999 gpd (i.e., 1 gpd less than the State of Michigan's regulatory standard of 100,000 gpd). This pumping regime is current management policy in the State of Michigan.

The second pumping regime ("MN standard") has all average-farm units pumping at 9,999 gpd (i.e., one gallon less than the State of Minnesota's regulatory standard of 10,000 gpd). This pumping regime tests how the conservation presumption of the law might be met with a regulatory standard that is ten times stricter than the current one for the State of Michigan.

Two further pumping regimes were conducted to assess the impacts of a longitudinal gradient to the adoption of irrigated agriculture. They are described in full detail in Appendix 4.1: "Graded MI Standard and Graded MN Standard.

6.3.2 Study Area: The Muskegon River Watershed

The Muskegon River, which flows into Lake Michigan, is located in the western Lower Peninsula of Michigan. It is the second longest river in the state, with over 90 tributary systems, and it flows roughly south-southwest from its headwaters in the Higgins, Houghton, and Mitchell-Cadillac chain of lakes, dropping a total of 175 m over its course to Muskegon Lake and – from there – to Lake Michigan (AWRI, 2002).

In 1998, roughly 40% of the land area in the watershed was agricultural land, with most of the agricultural lands distributed toward the middle of the length of the watershed (Figure 6.3). In 2004, a total of 17.78 MGD of water was withdrawn for agricultural purposes in the watershed, of which 13.55 MGD was withdrawn from groundwater (MDEQ, 2004).

The watershed is currently located in the humid and temperate climate Zone, and, during the period of 1899 to 2007, received an average of 83 cm of rainfall annually (AWRI, 2002). Furthermore, since the hydrologic source of the Muskegon River is derived significantly from groundwater sources (Kendal & Hyndman, 2007; Ray, Pijanowski, Kendall, & Hyndman, 2012), within this climate Zone this means that the river system is dominated by cool and cold-water fish assemblages (Wehrly, Wiley, & Seelbach, 2003; Zorn, Seelbach, & Wiley, 2002).

The Muskegon River Ecological Modeling System (MREMS) is used here to model hydrologic outcomes of the various pumping, land-use and climate scenarios explored in this paper (Figure 6.2). MREMS divides the entire Muskegon River watershed into forty-one channel segments within corresponding sub-watersheds (Figure 6.3). MREMS is a “multi-model” that integrates and synchronizes various physical and biological models encompassing the entirety of the Muskegon River ecosystem at different spatial and temporal domains (Wiley, et al., 2010). The hydrologic and water temperature simulations are central to this analysis and in MREMS are based principally on coupled outputs from ILHM (Hyndman, Kendall, & Welty, 2007), HEC-HMS version 3.5 (ACoE, 2010), and RPSTM (Cheng, 2010).

6.3.3 Description of the WWAT system

The State of Michigan has developed an online, automated assessment tool, called the Water Withdrawal Assessment Tool (WWAT), to act as an initial screening step for determining the likelihood of whether a proposed withdrawal would cause an adverse resource impact (ARI) by using underlying empirical relationships between changes in the index flow and changes in characteristic fish communities (Figure 6.1).

Briefly, river units in the state are categorized into river types, based on the upstream drainage area of the river unit (into “streams,” “small rivers,” and “large rivers”) and the mean July water temperature of that unit (into “cold,” “cold-transitional,” “cool,” and “warm”). This provides a potential of twelve river types, but since no cold large rivers exist, based on the defining criteria, Michigan’s rivers fall into eleven river types.

For each river type, there is a characteristic fish curve that describes how characteristic fishes change in abundance as the index flow diminishes. It is from these declining characteristic fish curves that the determination of whether an adverse resource impact will likely occur is made. Declines in the index flow also circumscribe other “policy (action) Zones,” in which various governance actions are prescribed, including requiring an immediate site-specific review of a withdrawal request and informing existing registered large or smaller-scale water users about a new water use within the basin (Hamilton & Seelbach, 2011).

6.3.4 Hydrologic Scenarios

The hydrologic scenarios used here, which incorporate land-use and climate change, were developed as a part of an earlier study (Wiley, et al., 2010). Scenario 1 examines water availability and regulation under the “present-day” land-use and climate, utilizing a land-use assessment from 1998 and climate patterns from 1975-2005. Scenario 2 examines water regulation and availability in a possible future, circa 2070, based on an assumption of an active conservation of agricultural lands while allowing urban areas to continue to grow as modeled by Land Transformation Model v.3, a neural net-based land-use change simulator (Pijanowski, Brown, Manik, & Shellito, 2002). In Scenario 2, the climate series is the same as in Scenario 1. Scenario 3 uses the same future land-use as Scenario 2, but includes a future climate as well (Wiley, et al., 2010), based on a downscaling of the A1B climate scenario (IPCC, 2007).

6.3.5 Regulatory Adaptation Scenarios

Regulatory adaptation scenarios assess the impact actively adapting the regulatory framework to the changing physical environments encountered through time. There are two key components of the WWAT that affect the regulation of Michigan waters: the "river-type classification" and the "water accounting," and these are calculated independently in WWAT. The river-type classification is determined from a state-wide model empirically-derived model of mean July water temperature and the upstream drainage area of a particular river unit. The river-type classification ultimately determines both the allowable percent-of-index flow that can be withdrawn and the Policy Zones associated with specific withdrawal levels (see Section 6.3.3 for more information). The index flow is the estimated Q90 for July, and that initial water accounting is determined by a MDEQ-developed hydrologic model (Hamilton, Sorrell, & Holtschlag, 2008). The total amount of water legally available for withdrawal is given by the index flow – determined by WWAT's hydrologic model (Hamilton, Sorrell, & Holtschlag, 2008) – multiplied by the allowable withdrawal proportion specified for that particular river-type.

I will examine five possible adaptive governance scenarios. Each scenario explores the impacts of various degrees of updating (i) the river-type classification and (ii) water accounting, in order to retain a regulatory perception (which I will refer to as the regulatory model) of physical conditions as consistent with changing future conditions as possible. These different regulatory models will be combined with each of the three hydrologic scenarios described above to explore the impacts of different levels of regulatory adaptation.

Two regulatory adaptation scenarios (“A” and “C”) use the river-types as currently specified by MDEQ for the Muskegon River, and harmonized to the river structure of MREMS. In the “A” scenarios, the current river-type classification and water accounting of WWAT itself are used. In the “C” scenarios, the current WWAT river-type classification is retained but water accounting is updated to reflect future hydrologic conditions as modeled in the land-use and climate scenarios. Results from the “C” scenarios are explored in detail in

Appendix 4.2: “Type ‘C’ Scenarios in the Michigan Standard.

In the “B,” “D,” and “E” scenarios, the river-type and index-flow estimates are based on MREMS-derived temperature and flow data (Figure 6.2). Scenario B applies “present-day” (circa 1998) results from MREMS to the river-type classification and water accounting to each of the present-day and future physical scenarios. The assessment of the present-day condition (Scenario 1B), this is considered to be “fully adaptive,” since the governance is based directly on the physical models of the present day. In contrast, the assessments of both futures (Scenarios 2B and 3B) are considered to be “non-adaptive,” since no part of future governance is based on the physical models of the respective futures. Scenario D also applies the “present-day” river-type classification but applies water accounting based of the predicted hydrology of the respective future physical scenarios. These scenarios (Scenario 2D and 3D) are considered to be “partially adaptive,” since the water accounting is based on the respective future physical model, even though the river-type classification is not. Finally, in Scenario E, both the river-type classification and the water accounting are updated to reflect future changes in hydrology and temperature. These scenarios (Scenario 2E and 3E) are considered to be “fully adaptive,” since the governance is based directly on the physical models of the respective future conditions (analogously like Scenario 1B).

6.3.6 Modeling occult withdrawals

For each scenario, a base condition of no pumping was modeled. The discharge data from this base condition determined July to be the month with the lowest monthly discharges, and the median July discharge was defined as the index flow for each model assessment.

The impacts of the four pumping regimes were assessed with the cumulative sub-watershed pumping volumes being subtracted from the groundwater record in the MREMS model. The resulting median July discharge values were used as the index flow value to characterize the pumping effects of each regime. The percent change in the index flow caused by each pumping regime was then calculated based on the physical and regulatory parameters of the various scenarios. The Policy Zones into which each river unit fell after withdrawals (see Section 6.3.3) were then assigned, based on the physical and regulation parameters of the scenario. The resulting Policy Zone distribution was then mapped (ArcMap), and the total number of river miles of each Policy Zone was tabulated. In addition to the assessment of the number of river miles affected by occult pumping, I also asses the degree to which of the availability of remaining water resources corresponded to the regulatory view of water availability. I will call a lack of correspondence “allocation error” and use it as a secondary metric of conservation of success.

6.4 Results

6.4.1 Summary of the Modeled River Systems

Of the 619 river miles in the Muskegon model, 178.59 (29%) are at present classified by the WWAT system as “streams,” 165.27 (27%) are classified as “small rivers,” and 274.85 miles (44%) are classified as “large rivers.” Likewise, 99.14 river miles (16%) are classified as “cold water,” 65.76 miles (11%) are classified as “cold-transitional water," 380.09 miles (61%) are classified as "cool water," and 73.72 miles (12%) are classified as "warm water" in WWAT's designations for the Muskegon River. Using the MDEQ definitions and MREMS modeled flows and temperatures for the current land-use and climate gave an overall similar but somewhat cooler interpretation of the Muskegon River. The future land-use change scenario had a decreased number of river miles of colder and cool water and an increased number of river miles of cold-transitional and warm water. In contrast, the future land-use and climate change scenario transformed the Muskegon River into a warm-water system everywhere but a few creeks (Table 6.4, Figure 6.4).

6.4.2 Impacts from Occult Pumping under Current Flow Regimes

Under Scenario 1A, the occult withdrawal in the Muskegon River watershed would have led to 360.56 river miles (58%) being classified as Policy Zone D, 122.45 miles (20%) as Zone C, and 29.30 (5%) miles as Zone B. The remaining 136.40 river miles (22%) would have remained as Zone A. Similarly, when using the MREMS model of current regulatory and hydrologic conditions (Scenario 1B), 394.00 river miles (64%) would be in Zone D, 82.92 river miles (13%) in Zone C, and 5.39 (1%) in Zone B. The remaining 136.40 river miles (22%) would remain in Zone A.

Scenarios 1A and 1B saw 98% and 91% of the maximum regulated water availability removed, due to cumulative occult pumping, with only 0.79 cms and 2.48 cms left available, respectively (Table 6.5, Figure 6.13A).

6.4.3 Cumulative Occult Pumping Impacts in Future Scenarios

In the future-scenario of land-use change with full adaptation (Scenario 2E), the number of river miles in Zone D was 317.27 (51%), Zone C has 124.99 (20%), Zone B has 55.45 (9%), and Zone A has 121.00 (20%). In addition, 84% of the maximum regulated water availability was removed, due to cumulative occult pumping, leaving 8.42 cms (Table 6.5).

In the future-scenario of land-use and climate change with full adaptation (Scenario 3E), the number of river miles in Zone D diminishes dramatically to 83.68 (14%), Zone C drops to 10.71 (2%), and Zone B grows to 251.23 river miles (41%), and Zone A grows to 273.08 river miles (44%). In addition, 47% of the maximum regulated waster availability was removed, due to cumulative occult pumping, leaving 26.77 cms (Table 6.5).

6.4.4 Cumulative Occult Pumping and Alternative Governance

The assessment of partially adaptive governance using the MRMES river-type classification (Scenario 2D) had 396.93 river miles (64%) being in Zone D, only 18.86 (3%) and 46.34 river miles (7%) in Zone C and Zone B, respectively, and 156.57 river miles (25%) remaining classified as Zone A. Furthermore, Scenario 2D indicates that roughly 80% of the maximum water availabilities were withdrawn (Figure 6.13B), leaving 9.92 cms (Table 6.5).

Partially adaptive governance scenario 3D found 287.13 (46%) would be classified as Zone D, 10.71 (1%) as Zone C, 45.61 river miles (7%) as Zone B, and 275.26 river miles (44%) as Zone A. Furthermore, under future land-use and future climate, Scenarios 3B and

3D indicate that roughly 45% of the maximum water availabilities were withdrawn, leaving 26.75 cms and 21.87 cms, respectively (Figure 6.13C).

Of the non-adaptive governance scenarios, 2A, 2B, 3A and 3B, almost the entirety of the watershed (580.52 river miles, 94%) was classified as Zone A, with the remainder (38.18 river miles, 6%) classified as Zone D. Furthermore, the actual water availabilities prior to and following occult pumping were 3.1 to 4.7 times greater than their maximum water availabilities (Figure 6.13B, C).

6.4.5 Policy Zones: MN Standard

In contrast to the Michigan Standard, the Minnesota Standard consistently showed fewer river miles as Zones B, C, or D. However, even with a regulation threshold of one-tenth that of Michigan's, incidences of entering Zone D did occur, with 12.74 river miles (2%) and 82.38 river miles (13%) under Scenario 1A and Scenario 1B (Figure 6.7), respectively. The future-land-use-only scenarios also showed incidences of Zone D with Scenario 2C (166.96 river miles, 27%), Scenario 2D (328.65 river miles, 53%, Figure 6.8), and Scenario 2E (207.51 river miles, 34%, Figure 6.9). In contrast, the future-land-use-and-climate scenarios showed either no water incidences of Zone D in Scenarios 3B and 3E or only minor incidences in Scenario 3D (17.77 river miles, 3%). Minor numbers of river miles in Zone B and C also occurred, with the greatest number of Zone B in Scenario 3D (281.47 river miles, 45%), and Zone C in Scenarios 2D and 2E (14.09, 2%).

In all cases, under the Minnesota standard, the amount of water availability after occult pumping was greater than under the Michigan Standard, with 11% and 14% withdrawals for Scenarios 1A and 1B, respectively, roughly 43% withdrawal across

Scenarios 2C, 2D, and 2E, and roughly 7% withdrawals across Scenarios 3C, 3D, and 3E. Similar to their analogues under the Michigan Standard, Scenarios 2A, 2B, 3A, and 3B under the Minnesota Standard were roughly 3 to 4.7 times greater than their maximum water availabilities (Table 6.6, Figure 6.14).

6.5 Discussion

Michigan's water conservation law provides for an on-line permitting tool which estimates the amounts of water available to be withdrawn from any watershed without causing an adverse resource impact (ARI). These estimates of water availability – and ostensibly the water being protected through the law – could help both regulators and users in planning for future investments involving substantial water use. However, as per Dobornos, any newly regulated water user might need to be wary of the cumulative effect of *regulatory occult* water withdrawals. Since no withdraw less than 100,000 gpd needs to be registered with the State, and there is currently no mechanism to require withdrawals of less than 100,000 gpd to become registered (let alone regulated), regulated users may be negatively affected by the cumulative impact of occult withdrawals. In other words, the physical availability of water is not contingent upon the regulations that govern it, but on actual water balances in a basin. Clearly, in any decision-making process aimed at understanding what an ecologically "safe" level of withdrawal might be, needs to recognize the possibility of occult withdrawals (Dobornos, 2010).

6.5.1 Assessment of the Conservation Presumption

The results of these simulation studies indicate that the conservation presumption of PA185-2008 is in real danger of allowing the Muskegon River to be killed a death by a thousand cuts, since it is possible that unregulated irrigators can individually make decisions that amount to cumulative water withdrawals of threatening proportions. Under the current MI regulatory standard, if all agricultural lands in the Muskegon River watershed (assuming a farm size of 180 acres) were to individually withdraw up to the limit of 100,000 gpd, water availability to other users and the legally protected characteristic fish communities can be expected to be dramatically impacted. Using the current regulated river-type definitions, 331 river miles (53%) of mainstem and primary tributaries should fall in Policy Zone D (an ARI), 122.45 (20%) in Policy Zone C, and 23.30 river miles (4%) in Policy Zone B, and the values are not greatly different when looking at the MREMS-derived Scenario 1B, leaving only 0.79 cms of the original 37.17 cms available for withdrawal (Table 6.5). All of these impacts occur without a single gallon per day needing to be reported to the state, since all modeled pumping occurs just below the regulatory threshold. This implies that no governance actions described in Policy Zones B, C, and D can be undertaken in order to conserve or restore the degraded condition of the river. Furthermore, the State may continue to allow larger regulated pumping activities to go ahead in regions of the watershed that have – by statutory definition of physical conditions – become adversely impacted or significantly on its way to being adversely impacted.

6.5.1.1 Assessment of the Minnesota Standard

If the regulatory threshold of Michigan Standard of 100,000 gpd fails the conservation presumption, one option is to significantly lower the threshold (Dobornos, 2010). However, even at a regulatory standard of 10,000 gpd – like that of Minnesota – the difference in the amounts of water withdrawn, and the types of resultant Policy Zone entry are not a one-tenth impact. There are still areas where the river reach moves out of Policy Zone A and even into Policy Zone D. Under the Minnesota standard, however, there are very few river-units that move into all the way to Policy Zone D. The amount of this shift is different, though, depending on which hydrologic model is used to assess flow frequencies (WWAT or MREMS); with either 598.4 river miles (WWAT) or 283.21 river miles (MREMS) remaining in Policy Zone A (Figure 6.7). In future land-use and climate scenarios, the number of river miles that remain in Policy Zone A may remain at about half (304.9 river miles, Scenario 2E) or may remain entirely in Zone A (Scenario 3E, Figure 6.7).

6.5.1.2 The Conservation Presumption in the Future

This potential impact of occult water extraction was not limited to the current-day climatic and land-use conditions. Simulating a fully adapted governance condition to a future with either an altered land-use pattern (Scenario 2E) or with both an altered land-use pattern and an altered climatic condition (Scenario 3E), the conservation presumption still did not hold at the 100,000 gpd regulatory limit (Table 6.5, Figure 6.5), although the number of river miles that remained in Zone A was 273 (44%), while the number of river miles in an ARI was only 84 (14%, Figure 6.5).

6.5.2 The Effect of Adaptive Governance on River-Type Assessment

Futures with altered land-use patterns and/or climate patterns present a potential for the misallocation of water resources due to non-adapted or partially adapted governance. In this case, failure to update both the water accounting and the segment classification of river types to reflect changed hydrologic conditions, will create misinterpretations of both water availability and existing conservation status as well as misallocation of regulated usage. This misallocation will likely cause an assessment that more water is available than the physical system could actually withstand.

In the modeled scenarios, future land-use and climate change had significant impacts on the thermal and hydrologic regimes of the Muskegon River. WWAT determines the allowable percent-withdrawal based on the river-type classification of each river reach, and the allowable maximum withdrawals of cool-water and warm-water rivers are higher than cold-water and cold-transitional rivers. Therefore, the future scenarios for the Muskegon River indicate that there will be more water available to be withdrawn, since the Muskegon River will become a warmer and wetter river. Indeed, Scenario 3E under the Michigan Standard shows a relatively low number of river miles in Zone D and a relatively higher number of river miles in Zones A and B, specifically because the entirety of the Muskegon River will have become a warm-water river.

It is clear that when water quantity regulation continues to utilize water accounting and river-type assessments that are non-adaptive, then few river miles become classified as an ARI, regardless of the amount of water actually withdrawn in the watershed (Figure 6.6). When the maximum regulated water availability does not represent the physical amounts of water available, then the physical amount of water available, given the limits imposed by the regulations, is actually *greater* than the amount of water expected to be managed under the regulatory level (e.g., Figure 6.13, Scenario 3B), and the system appears to show an *underutilization* of the available water. However, when the water accounting is updated to match the water availability of the future physical scenario (e.g., Figure 6.13, Scenario 3D), then the impact of occult pumping starts to become visible. The fully adapted condition, though, indicates the actual impacts from cumulative occult pumping. In order to maintain a fully adapted governance scenario, though, requires that the water temperature and index flow values in the regulatory model (Figure 6.1) be updated to match the changing physical reality. The implications of such updates, though, will carry their own significance.

6.5.3 Implications of Physical Changes on WWAT

If we recognize that the future condition of the Muskegon River watershed will be different from today, due to significant changes in land-use and/or climate, it is undeniable that the characteristics that define the Muskegon River within WWAT will also need to change, or else risk the effects of non-adaptive governance. However, the implications of these changes extend beyond the empirical relationships lying at the foundation of WWAT. Changes in land-use and climate will likely have non-linear effects on the input factors used in WWAT (Figure 6.1).

6.5.3.1 Implications of Water Temperature Change

If there is increased overland flow and lower amounts of shading, the water temperature of the river will rise (Brown & Krygier, 1970; Johnson S. L., 2004). Similarly, if there is an increase in the average air temperature, the temperature of the groundwater will rise, causing the river water temperature to also rise. In addition, if the volume of water in the channel and the volume of water entering the channel through groundwater were to diminish significantly, the water temperature will rise and the river chemistry will change (see Chapter 5).

With changes in the physical characteristics of rivers comes changes in the structure of fish communities, characterized in WWAT by the fish curves (Hamilton & Seelbach, 2011). Directly speaking, an increase in water temperature caused by land-use and/or climate change will change the river-type – and thus the fish curve assignment – of a channel.

A future of climate and land-use change will see the Muskegon River shift from being a groundwater-fed cool- and cold-water river to being a groundwater-fed warm-water river. The significance behind this shift is monumental. Historically, groundwater-rich rivers in Michigan are characteristically cold water brooks and streams and cool-water main channel rivers, whereas groundwater-poor rivers are characteristically warm-water systems. Under Michigan's conservation law, cold- and cold-transitional rivers have relatively strict conservation standards in comparison to cool- and warm-water rivers. This means that, while warm-water and cool-water systems have relatively less groundwater available than cold-water systems, they are far more permissive in the percent withdrawals allowed to be taken. Since river-type is defined by July mean water temperature and not as a direct measurement of the groundwater-surface water interaction, as rivers become increasingly warmer, and groundwater-rich systems become increasingly warm-water dominated, a shift in river-type classification will mean a major increase in the amount of water that can be withdrawn from previously cold- and cold-transitional rivers before an assessment of an ARI is presumed. However, unless the fish curves themselves are reassessed, ARI assessments might no longer be associated with fish community responses to changes in water withdrawal, since the ecohydrologic relationships themselves will likely be changed.

The ecohydrologic relationships undergirding WWAT describe slow-moving warm-water systems and fast-moving cold-water systems. As the hydrology shifts from fast-moving cold-water systems to fast-moving warm-water systems, the fish communities inhabiting these systems will have a fundamentally different fish curve than that seen in the current slow-moving warm-water systems currently described in the regulatory fish curves. A warm and wetter future will need to account for the inherent changes in the ecohydrolic relationships through new sets of fish curves or even new categories of river-type.

6.5.3.2 Recalculating Water Availability

Altered land-use and climate patterns will significantly alter the amount of water entering the channel, and determining what ought to be considered the "natural" flow of the river must be done in order to determine whether water is being allocated efficiently (e.g., as in Scenarios 3E) or inefficiently (e.g., as in Scenarios 3A or 3B). In order to govern the resource equitably, the logic of the existing policy requires that water availability assessments need to appropriately account for existing water users – both registered and occult uses – and associate those values with the appropriate river-type classification. Although much of the mismatch between the future scenario's physically available water and the water governance system's regulatory view was diminished with adaptive updating of only the water accounting (i.e., when moving from Scenario 3B to 3D), managing the river's water quantity based on a river-type classification that matched the physical river that it was governing (i.e., fully adapted) would make for a more coherent basis for conservation. Therefore, any recalculation of water availability should also include a reclassification of each river reach's river-type.

6.5.3.3 Changing the Allowable Water Withdrawal Amounts

The assessments of this chapter presume that the underlying methods of determining the standards of water conservation do not change. However, it is possible to change the allowable rates of pumping for each river-type, since the considerations of conservation for the various river-types was contingent upon the shared cultural values of the members of the various advisory councils that created the WWAT and provided recommendations to the Michigan Legislature. In the context of Michigan, this meant that cold-water and cold-transitional water rivers were to be given a stricter conservation presumption than cool and warm water rivers. Through the policy discussions that informed the social boundaries within which the scientific basis of the WWAT was implemented, the importance of cold-water fish species, especially trout, were highlighted in comparison to the less-socially privileged cool-water minnows and warm-water sunfishes. As a conservation tool, the WWAT, like any other conservation tool, inherently includes this social valuation system, whether or not they are explicitly stated (Gasparatos, 2010).

However, if climate change were to alter the characteristics of Michigan's rivers from cold-water trout-dominated rivers to cool-water minnow-dominated rivers or even warm-water bass-dominated rivers, it is not strange to expect that future cultural identities and conservation priorities will likewise change. In such a future – even if they were to remain with an analogue to the WWAT – the allowable limits for water withdrawal may be changed as an assertion of that future's priorities. In short, the long-term impacts of the river-type considerations on future social values associated with conservation of different types of fish communities could easily shape the way in which future water conservation regulations are determined.

6.6 Overall Conclusions

The findings of this chapter should not in any way be construed as an indictment of Michigan's water conservation law, the Water Withdrawal Assessment Tool, the current process of overseeing water withdrawals in the State of Michigan, nor of the process through which the WWAT was formulated. This chapter is instead meant as a rigorous test of certain assumptions within the WWAT as well as a test of the logic of the regulations promulgated due to the passage of PA185-2008. The test indicates that cumulative unregulated water withdrawals may have impacts throughout the watershed, even at rates as low as 9,999 gpd/180-acre farm. However, others have already suspected that this would be a problem (Dobornos, 2010). My analysis gives an indication of the quantitative scale of this problem, *probatis extremis*. It also clearly indicates failures stemming from not pursuing adaptive governance to rationally manage our waters. This issue too had already been anticipated (See Section 4.6.3); my analysis here provides some examples *ad extremis* of the potential degree of the departure from the law's stated objective of conservation in its own context of the Great Lakes Compact.

In the end, though, the regulation of the waters of the State of Michigan (and, through the Great Lakes Compact, the waters of the Great Lakes and St. Lawrence River) must reflect the values of the society living under the law, the scientific understandings of the time, and our capacity to merge that scientific understanding with a system of rational regulations. Our goal is to maximize the potential social gain while minimizing the social pain. This chapter is meant to highlight some of the areas in which further work needs be done to improve the system that was installed in 2009.

6.7 Future Questions

The findings of this chapter raise several interesting questions about conservation that lie at the intersection between science, policy, and law. For example, how can one determine whether a change in the water availability is caused by the natural outcome of an altered hydrology and altered climate, or by regulated and occult groundwater withdrawals? An associated question is whether any observed changes in water temperature is a consequence of pumping or of wider-scale natural processes, and when should updates to river-type be made to ensure any adaptive governance structure? After all, as more water withdrawals occur, the theoretical divide between the "natural" condition and the encountered condition increases, and the interests of maintaining an adaptive governance system geared toward water conservation must determine whether observed environmental changes are "natural" or "man-made."

Furthermore, when trying to untangle the direct human-induced changes from the natural results of larger-scale processes to pursue adaptive governance, the Michigan Department of Environmental Quality will face a politically thorny question: for what purpose is the water being conserved? If the interests of conservation lie in predictability of the water withdrawal limits, then there may be political pressure for non-adaptive governance. If, on the other hand, conservation is tied together with the physical system being governed, then the system may be pushed toward a fully adaptive regime.

Finally, there is the legal question of whether the determination of an ARI is legally equivalent or analogous to the common-law concept of "unreasonable use." If the two are deemed to be effectively equivalent, then the associated questions of whether Michigan's enactment of the Great Lakes Compact does effectively combine surface water and groundwater and – if so – whether this means that groundwater is now part of the public trust (see Chapter 3). Furthermore, if the ARI is determined to be effectively equivalent to the concept of "unreasonable use," the WWAT – together with site-specific reviews – could form the basis for a water-use market (see Section **Error! Reference source not found.**). If, on the other hand, the determination of an ARI is fount to not be legally equivalent to an "unreasonable use," then it raises the question of the very legitimacy of the process through which Michigan is pursuing its duty to Great Lakes conservation.

6.8 Limitations of the Study

6.8.1 Farm Size

I assumed for the purpose of estimating maximum occult irrigation demand that all farms throughout the watershed were 180 acres, based on the average reported size of Michigan Farms being 179 acres (USDA, 2009). However, based on the 2002 irrigative water use assessment (MDEQ, 2004), the average size of farm that was reporting irrigative agriculture was 470 acres (64 farms reporting, 30,071 irrigated acres reported), which is 2.6 times larger than the statewide average. The findings of this chapter possibly overestimates the occult water withdrawal, since the water withdrawal law applies separately to each individual property, and the reporting threshold is 100,000 GPD for each property, which means that larger farms must use less water per acre than my assumed 180-acre farm if they do not wish to cross the reporting threshold. However, this could also mean that agricultural properties smaller than 180 acres could withdraw far more water per acre than my modeled farms, without crossing the reporting threshold.

In order to provide a more precise assessment of the potential impact of occult agricultural withdrawals within the Muskegon River watershed, it would be necessary to assess agricultural land-use by property ownership. Such an assessment would control for the variation inherent in the calculation of the average while also making the assessment more representative of the potential regulatory landscape created by land-use, land-area, and property ownership.

6.8.2 Temperature Change Due to Water Withdrawals

This chapter did not investigate the impacts to water temperature change due to water withdrawal itself. Although a previous chapter of this dissertation (Chapter 5) explicitly explored the cumulative impacts of water withdrawal on water temperature, and those changes in water temperature on changes in available habitat of characteristic fish fauna, the spatial scale and geographic extent covered in this chapter made such attempts impossible. However, previous work that was used to develop the water temperature estimates for MREMS indicate that there would be substantial ecosystem change due to temperature changes caused by water withdrawals (Cheng, 2010).

6.8.3 Fish Community Change Due to Landscape Changes

Although it is likely that fish communities will change as the temperature and discharge change. However, the chapter used the existing legal definitions for determining river-type, and thus determining the fish community response due to water withdrawals. Physical scenario 3 – land-use and climate change – indicated that almost the entire Muskegon River watershed will become a warm-water system, but it will remain a groundwater-fed fast-flowing river, creating a river-type that is not characteristic of Michigan warm-water systems. The fish curves that would become associated with such a river system are unlikely to be characterized by the existing warm-water fish curves. Furthermore, future social protections for such groundwater-fed warm-water rivers may well prove to be significantly different from those conserving the current warm-water systems.

6.9 Appendices

6.9.1 Appendix 4.1: "Graded MI Standard and Graded MN Standard"

6.9.1.1 Methodology

In addition to the MI Standard and MN Standard pumping regimes (Section 6.3.1), two additional pumping regimes were generated. These make the assumption that pumping rates will vary within the Muskegon River watershed, primarily along a south-to-north gradient, following the general trend of diminished farming as one moves from the south of the watershed (100% adoption) to the north of the watershed (0% adoption). To that end, the third and fourth pumping regimes ("Graded MI standard" and "Graded MN standard," respectively) multiply the modeled irrigation rate (99,999 gpd and 9,999 gpd) by the adoption rate based on the south-to-north gradient. These final two pumping regimes test the conservation standard while simultaneously applying a likely limit to additional irrigation withdrawals. It is important to note that all modeled withdrawals of all four pumping regimes are at rates below the regulatory threshold and would need to be registered with or reported to the State of Michigan.

6.9.1.2 Results

In general the results of the Graded Michigan Standard were roughly similar to those of the Michigan Standard, as are the results of the Graded Minnesota Standard with the Minnesota Standard (see above), with two notable exceptions. The results of Scenario 1A in the Graded Michigan Standard (Figure 6.9) show far fewer river miles in Zone D

(120.33) and Zone C (18.60) and far more river miles in Zone B (206.70) and Zone A (273.07), when compared to Scenario 1A for the Michigan Standard. In addition, the results of Scenario 3E in the Graded Michigan Standard have roughly half the number of river miles in Zone D (41.28), about one-tenth the river miles in Zone B (27.26), and roughly double the river miles in Zone A (550.16) compared to its Michigan Standard analogue.

Under the Graded MI Standard, many of the scenarios showed a far greater amount of water remaining than in the analogous scenarios under the Michigan Standard. For example, in Scenarios 1A and 1B, the remaining water available after occult pumping was 17.42 cms and 13.84 cms, or 53% and 52% of the maximum regulated water availability, respectively. Across Scenarios 2C, 2D, and 2E, roughly 61% of the maximum regulate water availabilities were withdrawn. Finally, across Scenarios 3C, 3D, and 3E, roughly 25% of the maximum regulated water availabilities were withdrawn (Table 6.6, Figure 6.15). The values for Scenarios 2A, 2B, 3A, and 3B were in rough accordance with their analogues in the Michigan Standard.

The scenarios of the Graded Minnesota Standard generally agreed with their analogue scenarios in the Minnesota Standard with regard to the miles of river outside of Zone A (Figure 6.11, Figure 6.12) and with regard to magnitudes of water available after occult pumping (Table 6.6, Figure 6.16).

6.9.1.3 Discussion

The differences between the standard regimes and the respective graded standard (i.e., the difference between the MI Standard and the Graded MI Standard) showed relatively modest differences in many of the scenarios, due to the geographic distribution of agricultural lands within the watershed. As seen in Figure 6.3, a large proportion of the existing agricultural lands are situated in the tributary watersheds in the southern part of the watershed, where the gradation models assume a higher rate of adoption of irrigation. In contrast, in the northern portions of the watershed, there are fewer sub-watershed areas in which additional irrigation is expected to be adopted. Since the MREMS modeling has a lower spatial resolution in the northern watershed, the relatively smaller number of modeled tributaries in the northern part of the model also contributes to the modest differences between the standard and the graded standard.

6.9.2 Appendix 4.2: "Type 'C' Scenarios in the Michigan Standard"

6.9.2.1 Results

In the assessment of partially adaptive governance using the WWAT river-classification (Scenario 2C), 292.35 river miles (47%) are classified as an Zone D, 112.95 river miles (18%) as Zone C, and 60.83 river miles (10%) as Zone B, based on water withdrawal volumes, leaving 152.57 river miles (25%) remaining as Zone A. Of the 51.02 cms that the regulations say are available for pumping, 8.94 cms remain after occult pumping, indicating an 82% allocation error (Table 6.5).

Partially adaptive governance scenario 3C found that 330.56 river miles (53%) would be classified as Zone D, 122.45 river miles (20%) as Zone C, and 29.30 river miles (5%) as Zone B, based on water withdrawal volumes. The remaining 136.40 river miles (22%) would remain in Zone A. Of the 50.07 cms that the regulations say are available for pumping, 26.75 cms remain after occult pumping, indicating a 46% allocation error (Table 6.5).

6.10 Tables

Table 6.1. Agricultural irrigation use in Michigan in 2006 (from MDoA) and estimates of irrigated water use standardized to a 180-acre farm.

Crop Type	# farms reporting	Irrigated acres	2006 Estimated water withdrawal (mgd)	GPD/180-acre farm
Corn (all types)	806	190,099	75.89	71,858
Soybeans	439	83,996	46.69	100,055
Potatoes	103	37,928	27.8	131,934
Nursery & Greenhouse Crops	140	18,417	17.4	170,060

Table 6.2. Twelve model scenarios between land-use, climate, river-type classification and water accounting. Current [1] refers to WWAT based scenarios. Current [2] refers to MREMS based scenarios

		Government Regulation Scenarios				
		Current [1] river class Current [1] water accounting	Current [2] river class Current [2] water accounting	Current [1] river class updated water accounting	Current [2] river class updated water accounting	updated river class updated water accounting
Land-use and Climate Scenarios	Current land-use Current climate	Scenario 1A	Scenario 1B	-	-	-
	Future land-use Current climate	Scenario 2A	Scenario 2B	Scenario 2C	Scenario 2D	Scenario 2E
	Future land-use Future climate	Scenario 3A	Scenario 3B	Scenario 3C	Scenario 3D	Scenario 3E

All the Graded scenarios are explored in Appendix 4.1: "Graded MI Standard and Graded MN Standard." Under the Michigan Standard, Scenarios 2C and 3C are explored in Appendix 4.2: "Type 'C' Scenarios in the Michigan Standard."

Table 6.3. Groundwater withdrawal under four tested occult pumping regimes. The impacts of pumping under the Graded MI Standard and the Graded MN Standard are explored in Appendix 4.1: "Graded MI Standard and Graded MN Standard.

	MI Standard (gpd)	Graded MI Standard (gpd)	MN Standard (gpd)	Graded MN Standard (gpd)
Current land-use	171,967,932	98,502,841	17,195,246	9,849,398
Future land-use	98,521,403	53,165,968	9,851,254	5,316,118

Table 6.4. Descriptive statistics of the number of river miles under each river temperature classification, with percent-difference from the WWAT classification.

Scenario(s)	Cold (% diff.)	Cold-transitional (% diff.)	Cool (% diff.)	Warm (% diff.)
WWAT classification (A and B types)	99.14	65.76	380.09	73.72
MREMS classification (C and D types)	131.55 (+32.69%)	299.24 (+355.05%)	114.18 (-69.96%)	73.73 (+0.01%)
Updated classification for land-use change (2E)	9.98 (-89.93%)	137.54 (+109.15%)	100.43 (-73.58%)	370.75 (+402.92%)
Updated classification for land-use and climate change (3E)	0 (-100.00%)	0 (-100.00%)	29.92 (-92.13%)	588.78 (+698.67%)

Table 6.5. Availability of water resources under each scenario, including actual water available – based on the scenario-specific regulations – before and after occult pumping.

Scenario	Maximum Regulated Water Available (cms)	Modeled Water Available PRIOR to Occult Pumping (cms)	Modeled Water Available AFTER Occult Pumping (cms)	Allocation Error |%diff|	Miles (%) Under ARI
Scenario 1A	37.17	37.17	0.79	97.87%	330 (53%)
Scenario 1B	28.85	28.85	2.48	91.40%	394 (64%)
Scenario 2A	36.58	174.04	125.65	132.29%	38 (6%)
Scenario 2B	28.85	165.69	117.29	167.76%	38 (6%)
Scenario 2C	51.02	51.02	8.94	82.48%	292 (47%)
Scenario 2D	40.21	40.21	9.92	75.33%	397 (64%)
Scenario 2E	51.04	51.04	8.42	83.50%	317 (51%)
Scenario 3A	36.58	163.14	138.7	66.81%	38 (6%)
Scenario 3B	28.85	154.79	130.34	84.75%	38 (6%)
Scenario 3C	50.07	50.07	26.75	46.57%	331 (53%)
Scenario 3D	39.62	39.62	21.87	44.80%	287 (46%)
Scenario 3E	50.84	50.84	26.77	47.34%	84 (14%)

"Maximum Regulated Water Available" is the maximum amount that the regulation allows to be removed. "Modeled Water Available PRIOR to Occult Pumping" is the amount of water that is predicted to be physically and regulatorily available prior to occult pumping. "Modeled Water Available AFTER Occult Pumping" is the amount of water that is predicted to be physically and regulatorily available after cumulative occult pumping. "Allocation Error" is the absolute percent-difference between the first and third columns. "Miles (%) Under ARI" is the sum total of river miles (and percent of the total number of river miles) under an ARI.

Table 6.6. Availability of water resources under each pumping regime

Scenario	Maximum Regulated Water Availability (cms)	Modeled Water Availability AFTER occult pumping (cms)			
		Michigan standard	Michigan graded standard	Minnesota standard	Minnesota graded standard
Scenario 1A	37.17	0.79	17.42	34.37	34.92
Scenario 1B	28.85	2.48	13.83	26.64	26.64
Scenario 2A	36.58	125.65	137.53	148.79	148.79
Scenario 2B	28.85	117.29	129.17	140.44	140.44
Scenario 2C	51.02	8.94	19.43	29.63	30.05
Scenario 2D	40.21	9.92	17.23	24.40	24.40
Scenario 2E	51.04	8.42	18.91	29.39	29.39
Scenario 3A	36.58	138.7	150.87	161.60	161.60
Scenario 3B	28.85	130.34	142.52	153.24	153.24
Scenario 3C	50.07	26.75	38.73	48.53	49.27
Scenario 3D	39.62	21.87	29.50	38.08	38.08
Scenario 3E	50.84	26.77	38.75	49.29	49.29

6.11 Figures

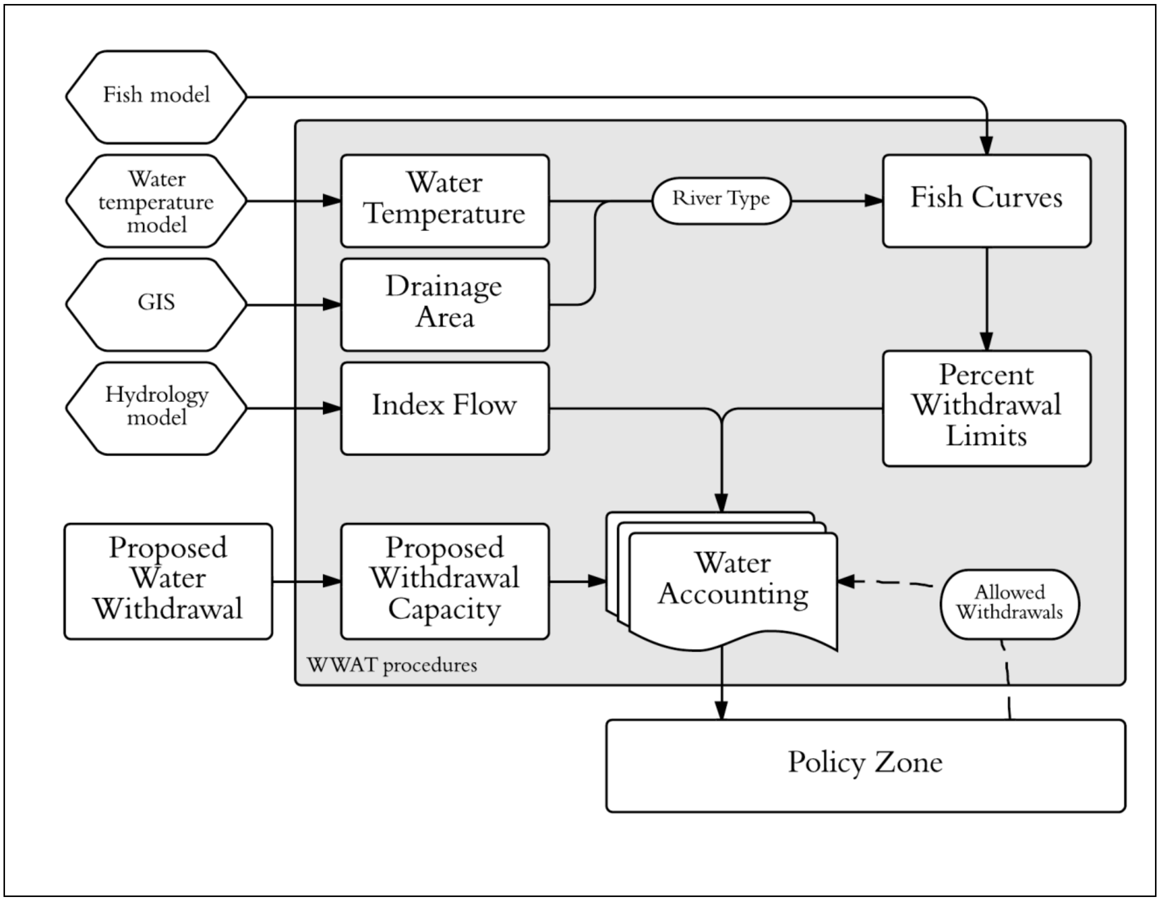


Figure 6.1. Schematic of how WWAT determines the allowable withdrawal for a river reach and how the Policy Zone determination is due to a proposed water withdrawal.

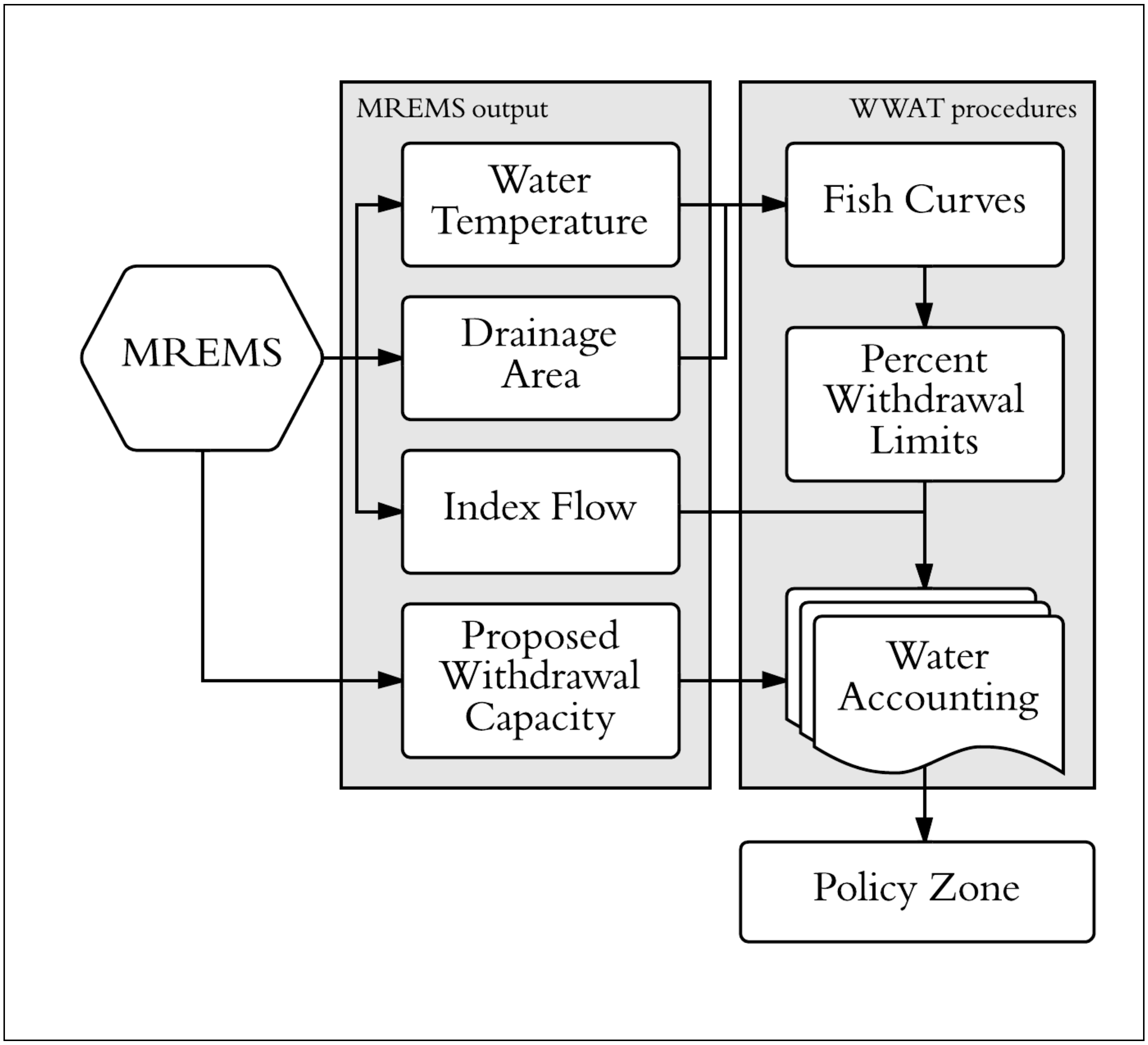


Figure 6.2. Schematic of how various types of MREMS output utilize the definitions of WWAT to model the impacts of land-use and climate change on the allowable water withdrawal as well as the determination of Policy Zone determination caused by the modeled pumping regimes.

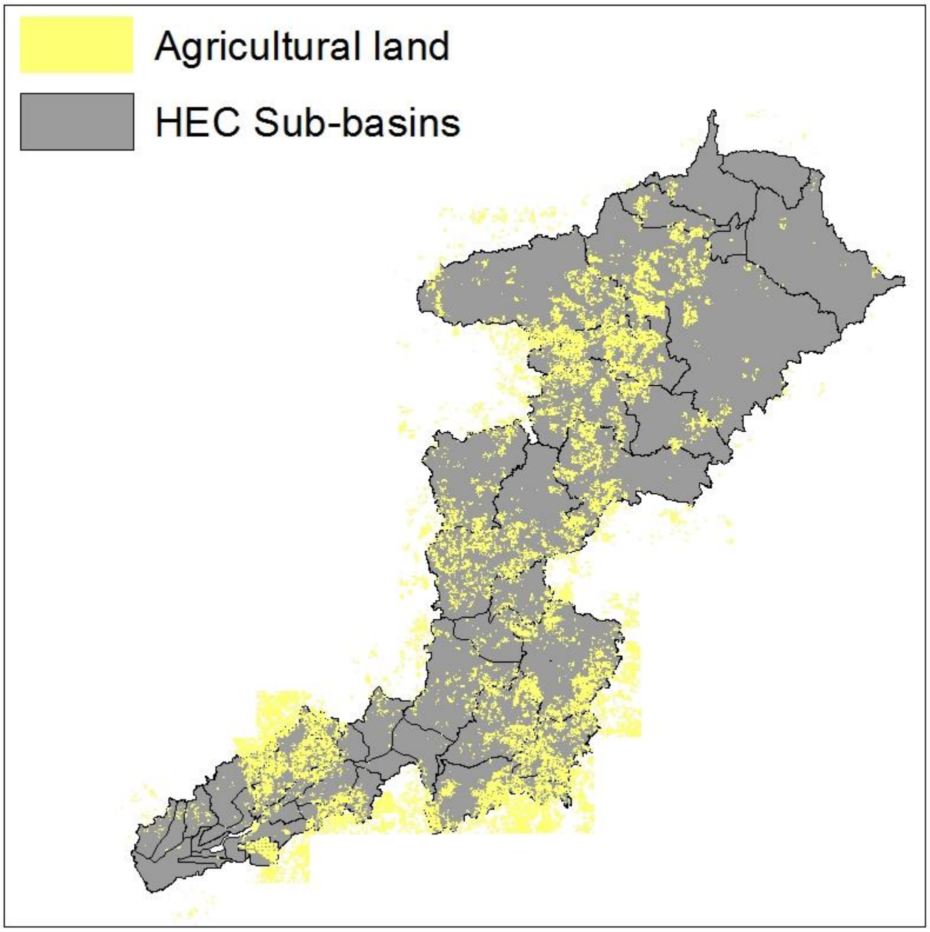


Figure 6.3. Distribution of agricultural land-use in 1998 over the sub-basin units used in the MREMS model.

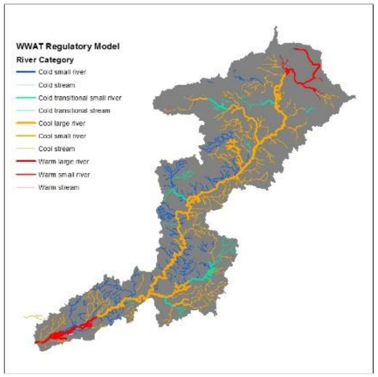
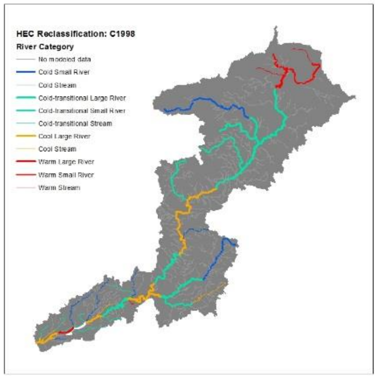
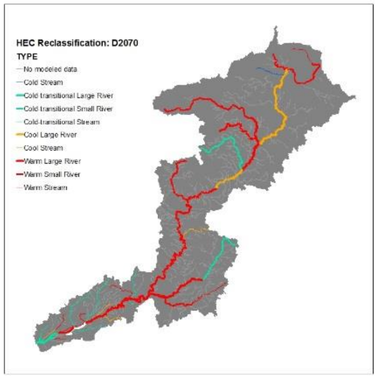
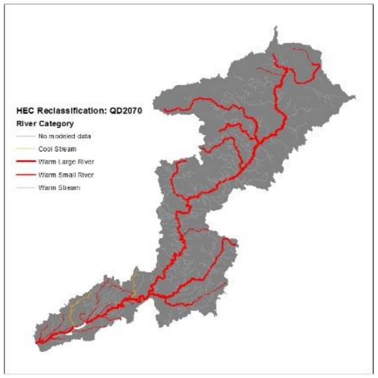
<table>
<tr><td>Hydrologic Model</td><td>WWAT</td><td>MREMS</td><td>MREMS</td><td>MREMS</td></tr>
<tr><td>Physical Scenario</td><td>Present day</td><td>Present day</td><td>Future with land-use change</td><td>Future with land-use and climate change</td></tr>
<tr><td></td><td>
</td><td>
</td><td>
</td><td>
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Figure 6.4. River-type classifications used in the various scenarios. The present-day MREMS model indicates a slightly cooler water system than the present-day WWAT. Water temperatures in future scenarios are warmer than present-day.

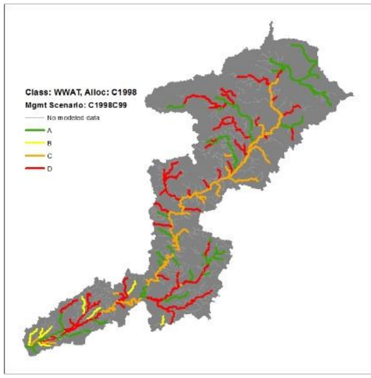
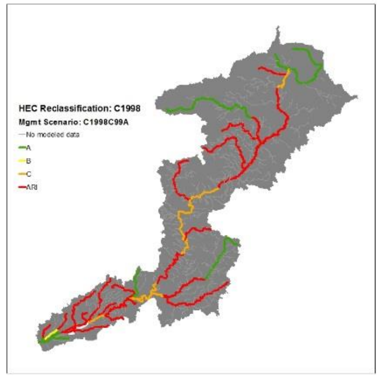
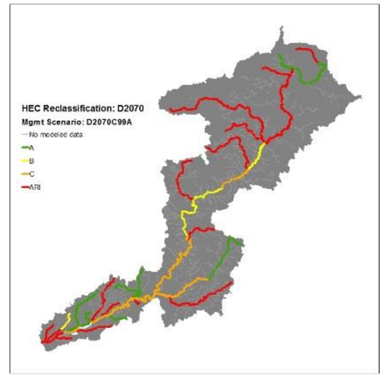
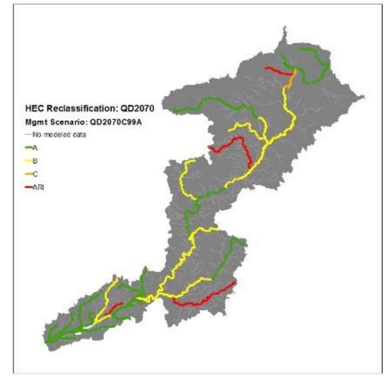
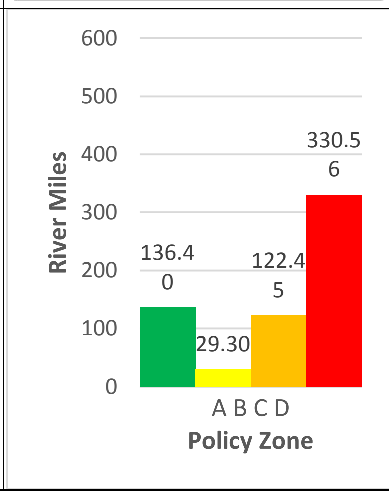
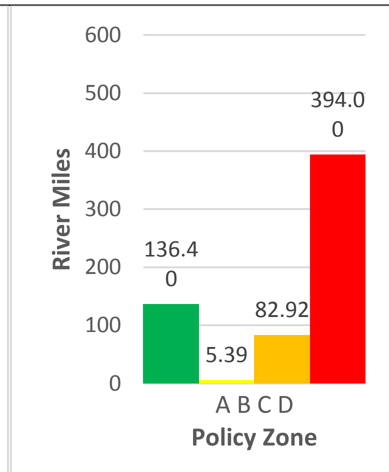
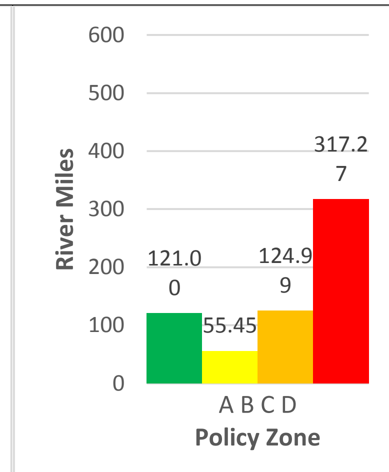
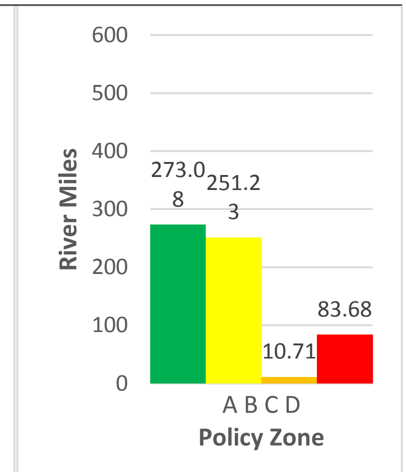
Physical Scenario	Present day	Present day	Future with land-use change	Future with land-use and climate change
	Scenario 1A	Scenario 1B	Scenario 2E	Scenario 3E
				
				

Figure 6.5. Policy-Zone effects of occult pumping in the present day (Scenario 1A, Scenario 1B) and in a future with land-use change (Scenario 2E) and a future with land-use and climate change (Scenario 3E), assuming full regulation adaptation. Michigan Standard.

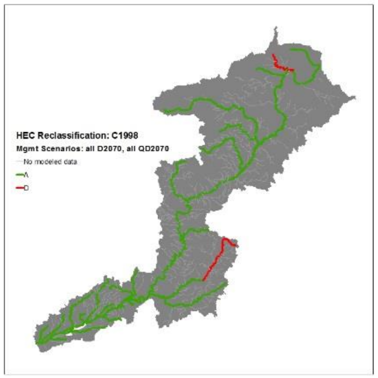
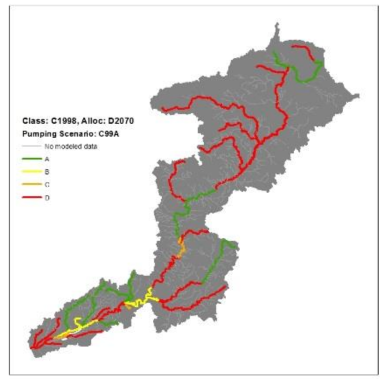
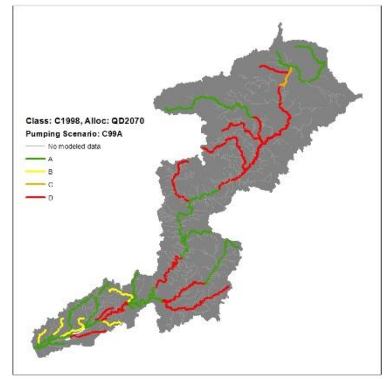
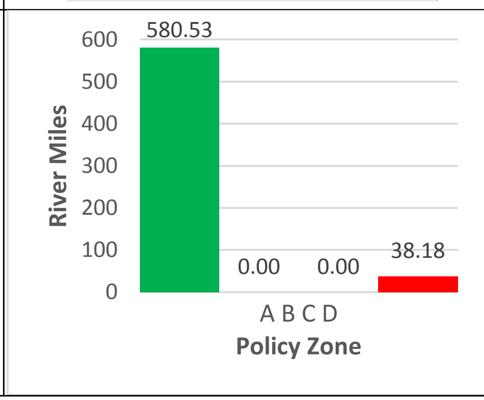
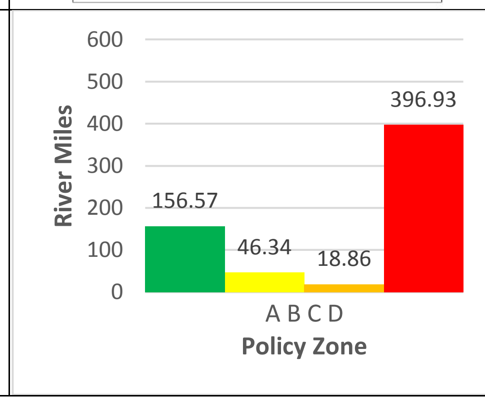
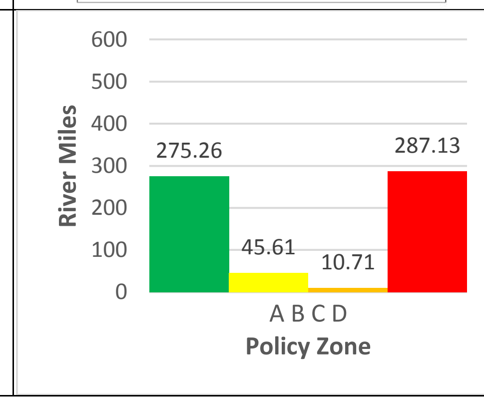
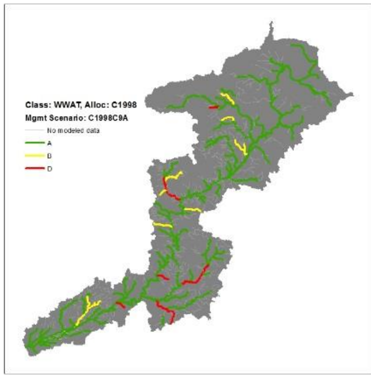
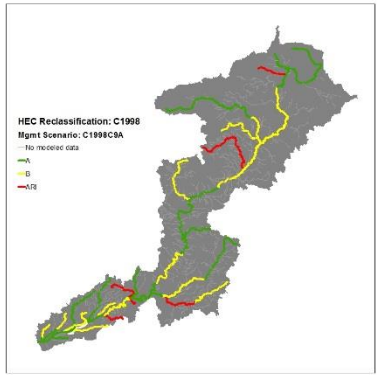
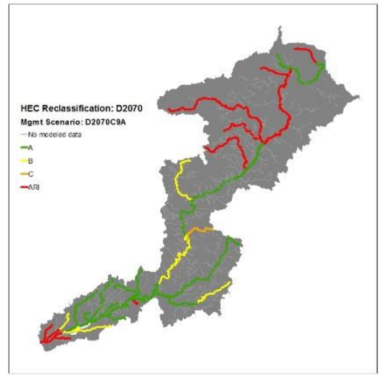
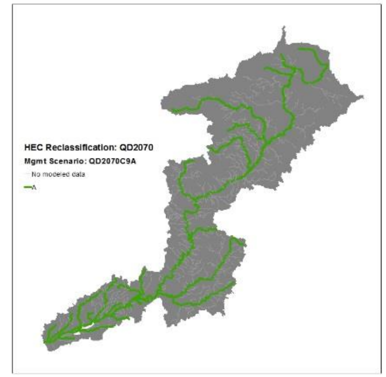
Physical Scenario	*Both future scenarios*	*Future with land-use change*	*Future with land-use and climate change*
Governance Scenario	*No adaptation*	*Adapted water accounting*	*Adapted water accounting*
	Scenario 2A, 2B, 3A, 3B	*Scenario 2D*	*Scenario 3D*
			
			

Figure 6.6. Policy-Zone effects of occult pumping in unadapted regulatory scenarios, with no updates to the regulatory definitions (Scenario 2B, Scenario 3B), and updates to only the water accounting definitions in a future with land-use change (Scenario 2D) and land-use and climate change (Scenario 3D). Michigan Standard

<table>
<tr><td>Physical Scenario</td><td>Present day</td><td>Present day</td><td>Future with land-use change</td><td>Future with land-use and climate change</td></tr>
<tr><td></td><td>Scenario 1A</td><td>Scenario 1B</td><td>Scenario 2E</td><td>Scenario 3E</td></tr>
<tr><td></td><td>
</td><td>
</td><td>
</td><td>
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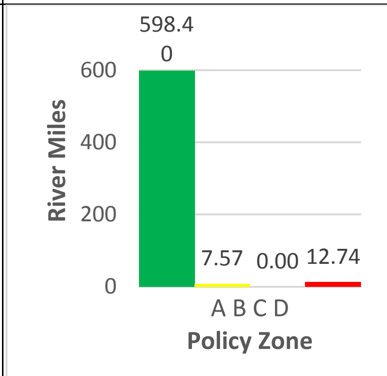
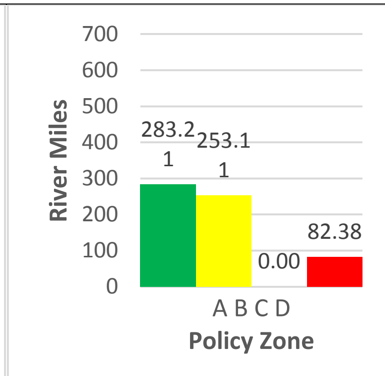
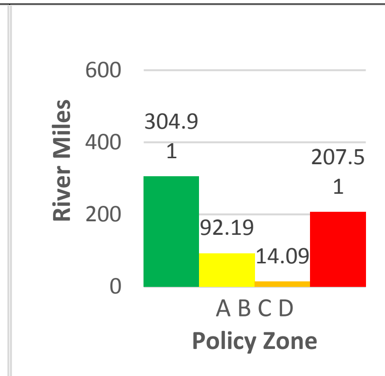
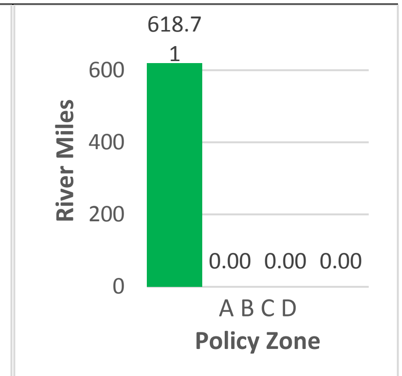
<tr><td></td><td>
</td><td>
</td><td>
</td><td>
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Figure 6.7. Policy-Zone effects of occult pumping in the present day (Scenario 1A, Scenario 1B) and in a future with land-use change (Scenario 2E) and a future with land-use and climate change (Scenario 3E), assuming full regulation adaptation. Minnesota Standard.

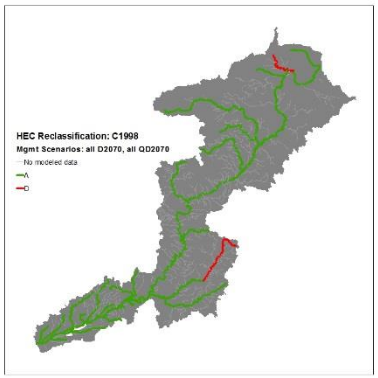
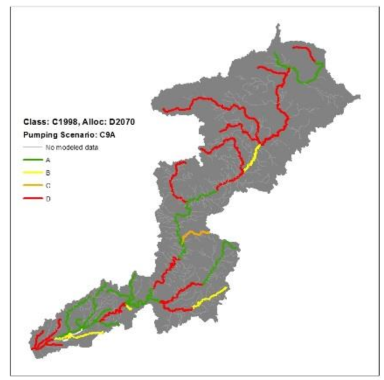
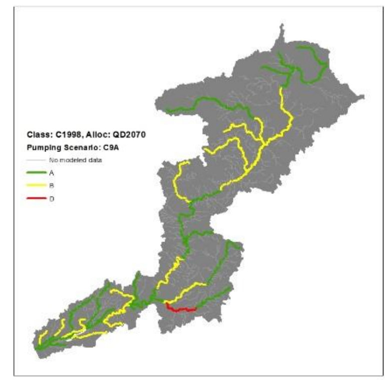
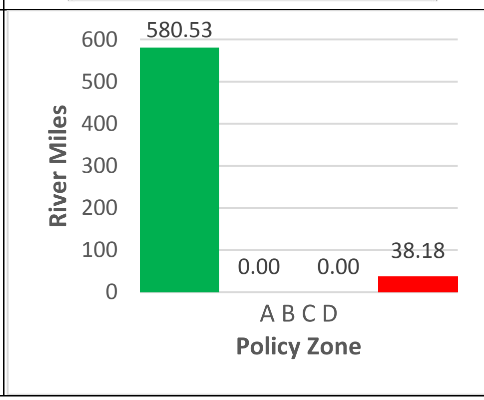
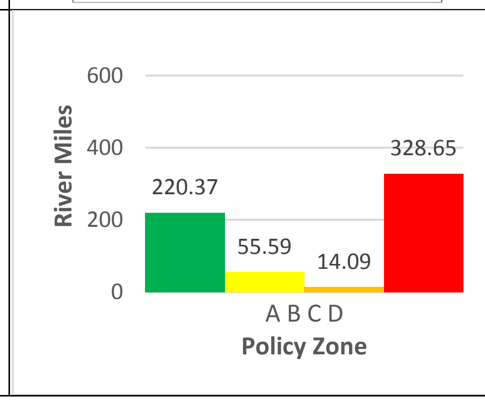
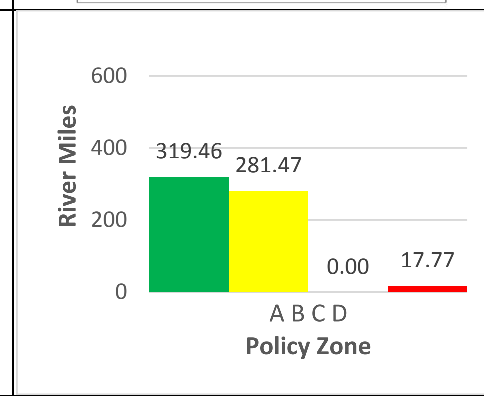
Physical Scenario	Both future scenarios	Future with land-use change	Future with land-use and climate change
Governance Scenario	No adaptation	Adapted water accounting	Adapted water accounting
	Scenario 2A, 2B, 3A, 3B	Scenario 2D	Scenario 3D
			
			

Figure 6.8. Policy-Zone effects of occult pumping in unadapted regulatory scenarios, with no updates to the regulatory definitions (Scenario 2B, Scenario 3B), and updates to only the water accounting definitions in a future with land-use change (Scenario 2D) and land-use and climate change (Scenario 3D). Minnesota Standard.

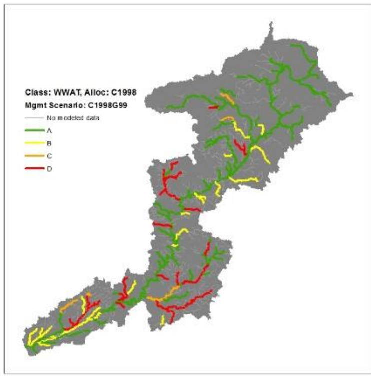
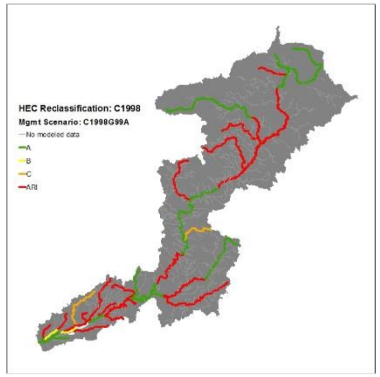
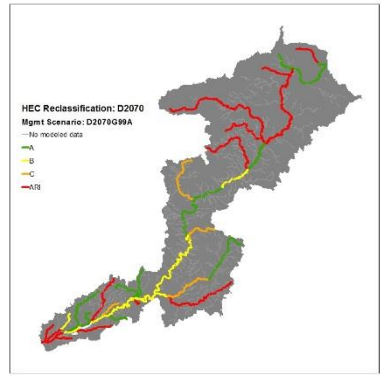
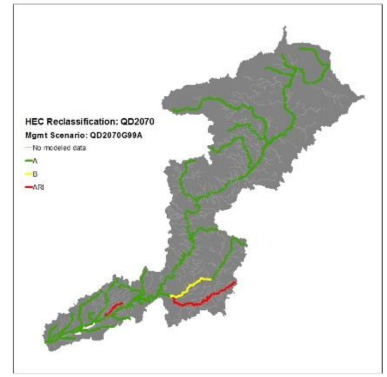
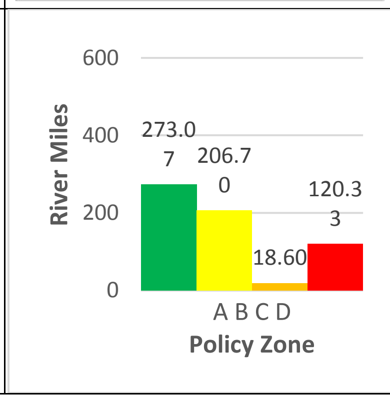
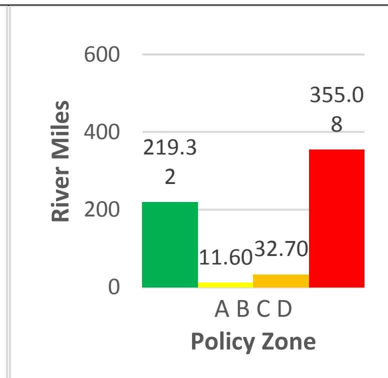
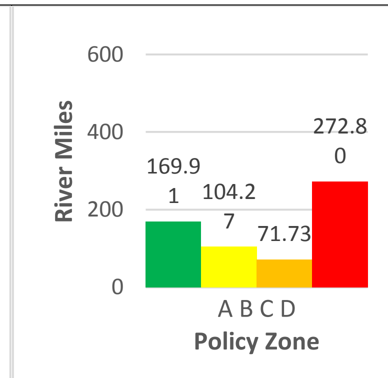
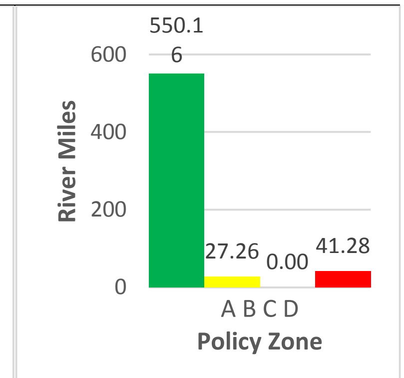
<table>
<tr><td>Physical Scenario</td><td>Present day</td><td>Present day</td><td>Future with land-use change</td><td>Future with land-use and climate change</td></tr>
<tr><td></td><td>Scenario 1A</td><td>Scenario 1B</td><td>Scenario 2E</td><td>Scenario 3E</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td>
</td><td>
</td><td>
</td><td>
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Figure 6.9. Policy-Zone effects of occult pumping in the present day (Scenario 1A, Scenario 1B) and in a future with land-use change (Scenario 2E) and a future with land-use and climate change (Scenario 3E), assuming full regulation adaptation. Graded Michigan Standard.

<table>
<tr><td>Physical Scenario</td><td>Both future scenarios</td><td>Future with land-use change</td><td>Future with land-use and climate change</td></tr>
<tr><td>Governance Scenario</td><td>No adaptation</td><td>Adapted water accounting</td><td>Adapted water accounting</td></tr>
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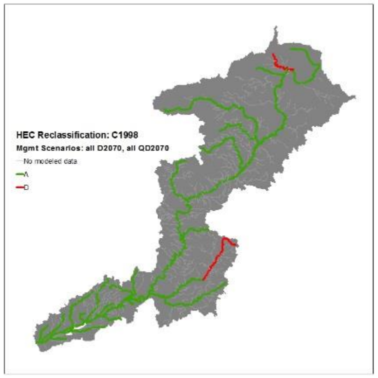
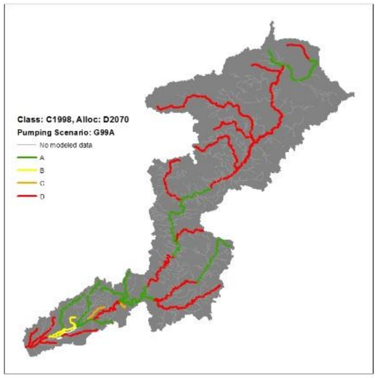
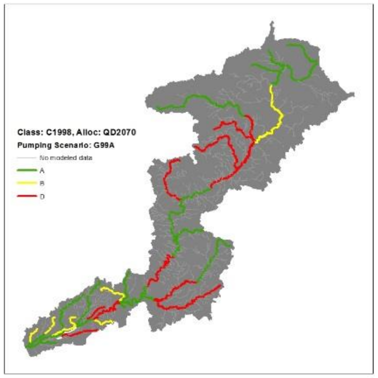
<tr><td></td><td>
</td><td>
</td><td>
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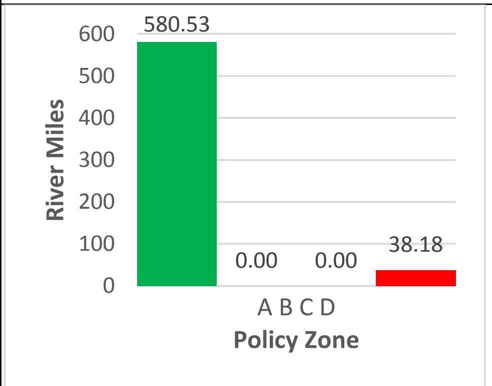
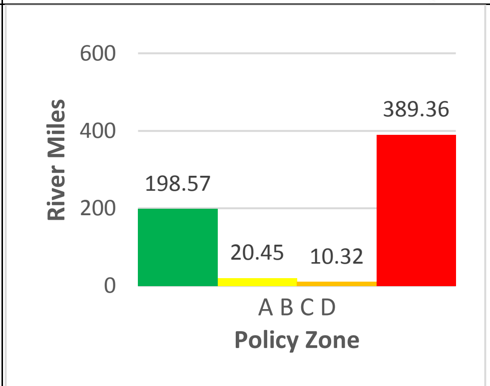
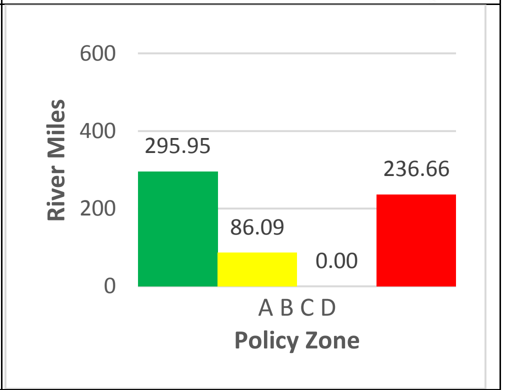
<tr><td></td><td>
</td><td>
</td><td>
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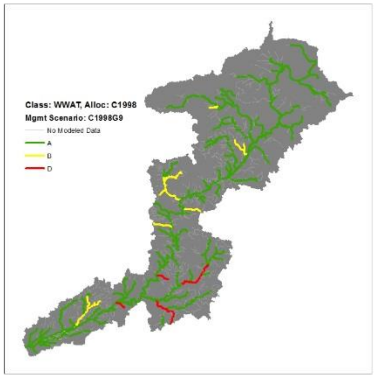
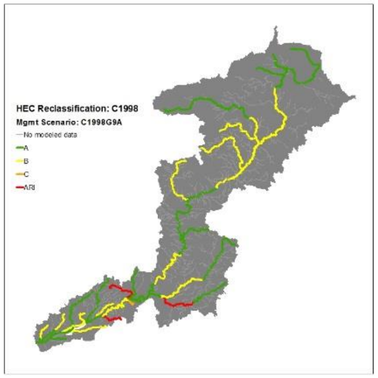
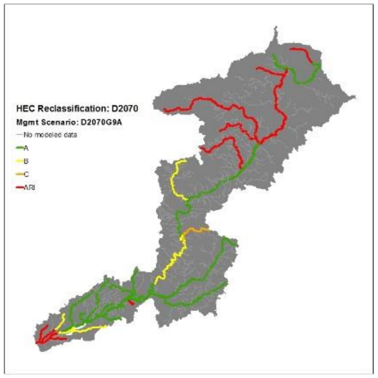
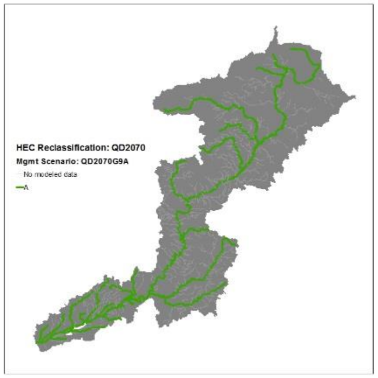
Figure 6.10. Policy-Zone effects of occult pumping in unadapted regulatory scenarios, with no updates to the regulatory definitions (Scenario 2B, Scenario 3B), and updates to only the water accounting definitions in a future with land-use change (Scenario 2D) and land-use and climate change (Scenario 3D). Graded Michigan Standard.

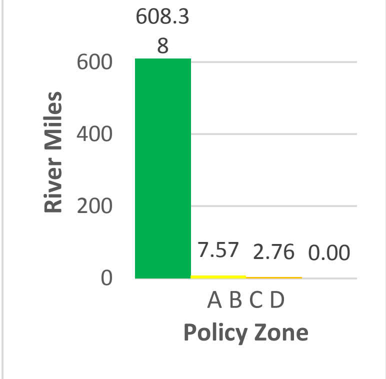
Physical Scenario	Present day	Present day	Future with land-use change	Future with land-use and climate change
	Scenario 1A	Scenario 1B	Scenario 2E	Scenario 3E

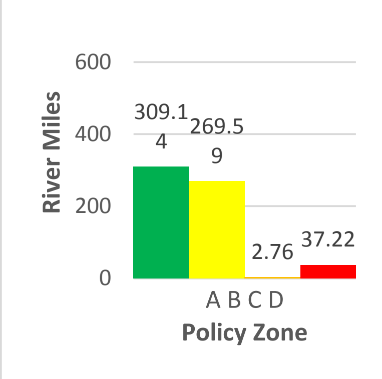


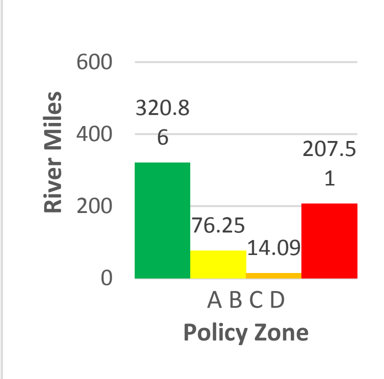












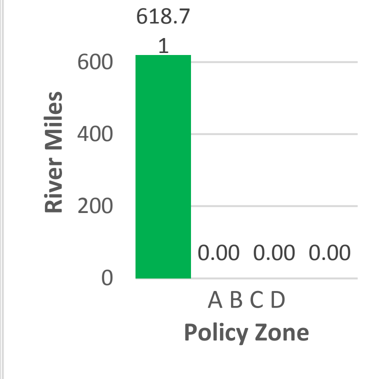


Figure 6.11. Policy-Zone effects of occult pumping in the present day (Scenario 1A, Scenario 1B) and in a future with land-use change (Scenario 2E) and a future with land-use and climate change (Scenario 3E), assuming full regulation adaptation. Graded Minnesota Standard.

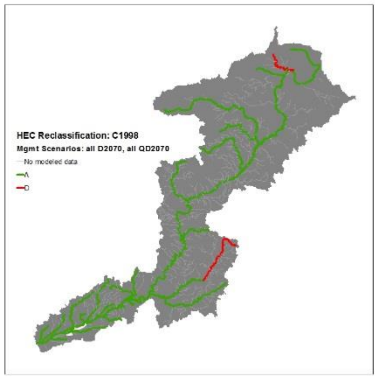
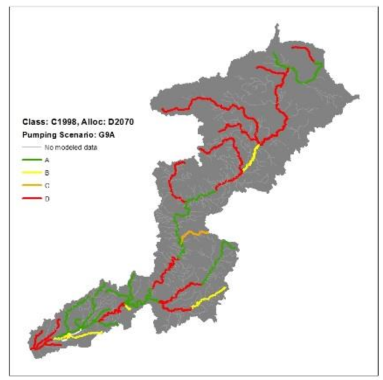
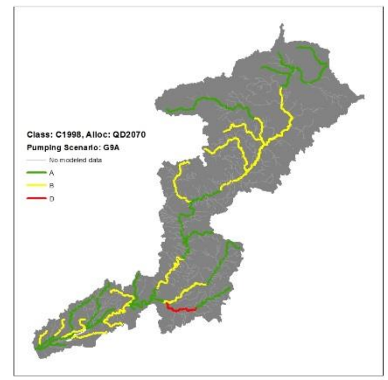
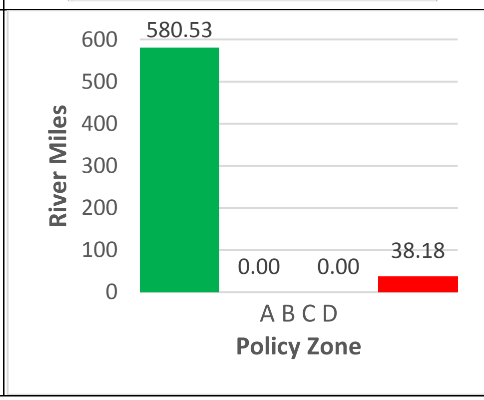
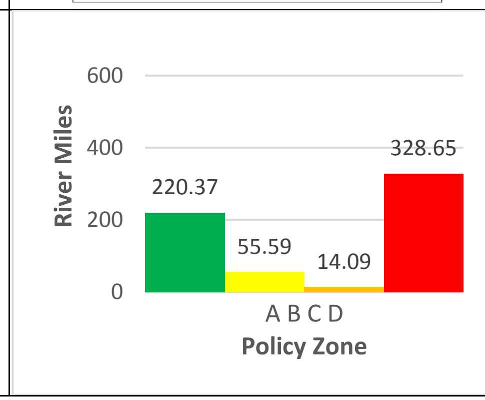
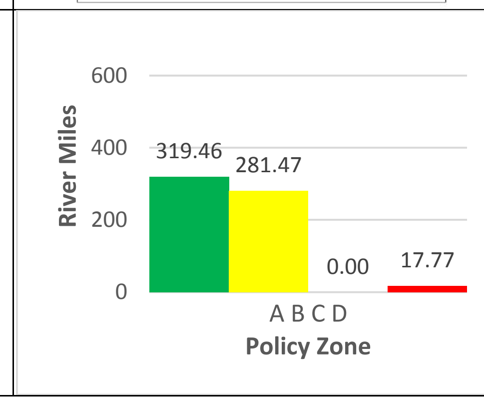
Physical Scenario	Both future scenarios	Future with land-use change	Future with land-use and climate change
Governance Scenario	No adaptation	Adapted water accounting	Adapted water accounting
	Scenario 2A, 2B, 3A, 3B	Scenario 2D	Scenario 3D
			
			

Figure 6.12. Policy-Zone effects of occult pumping in unadapted regulatory scenarios, with no updates to the regulatory definitions (Scenario 2B, Scenario 3B), and updates to only the water accounting definitions in a future with land-use change (Scenario 2D) and land-use and climate change (Scenario 3D). Graded Minnesota Standard.

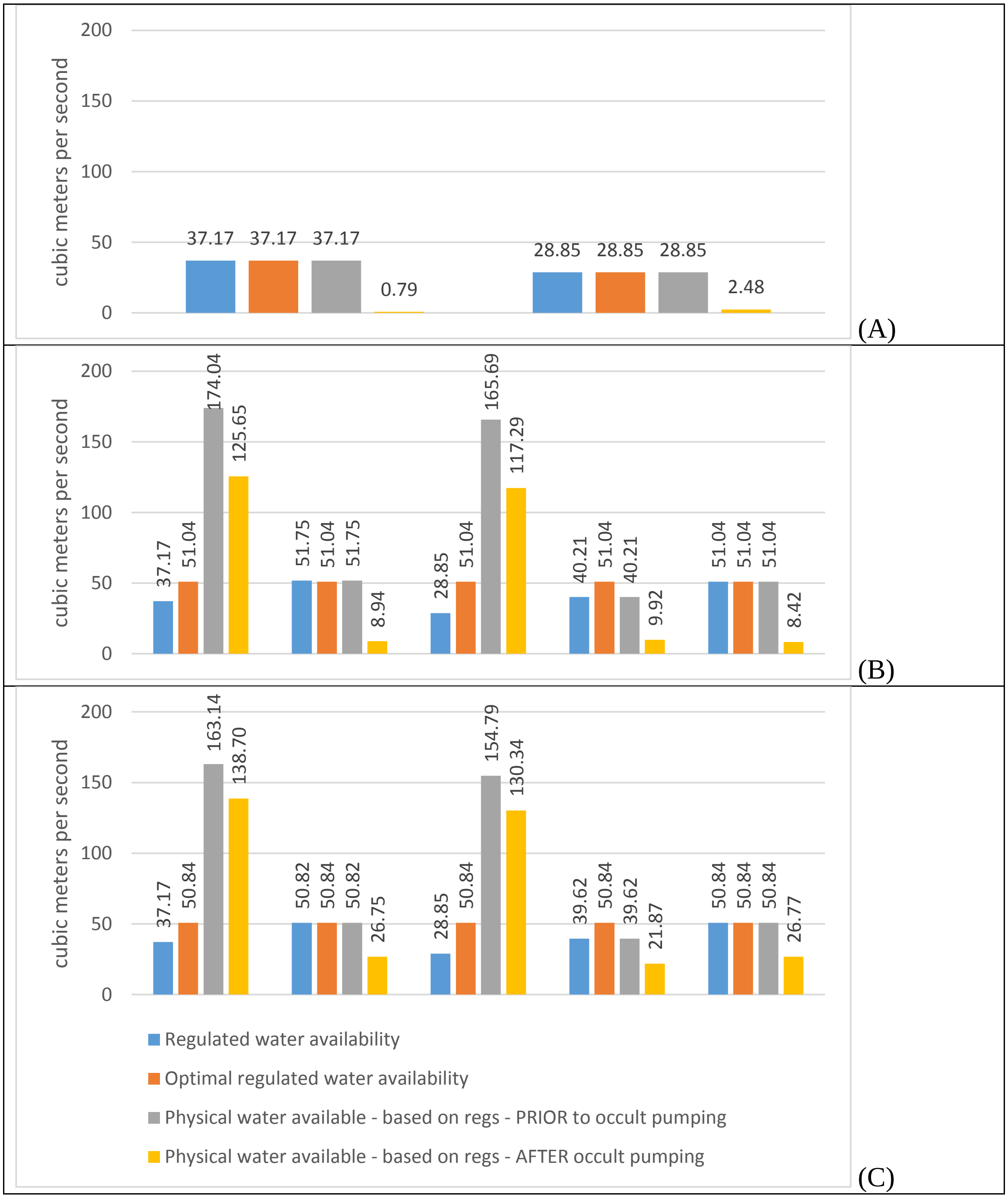


Figure 6.13. Total water availability for (A) Scenario 1A and 1B, (B) Scenario 2A, 2C, 2B, 2D, and 2E, and (C) Scenario 3A, 3C, 3B, 3D, and 3E under the MI Standard pumping regime.

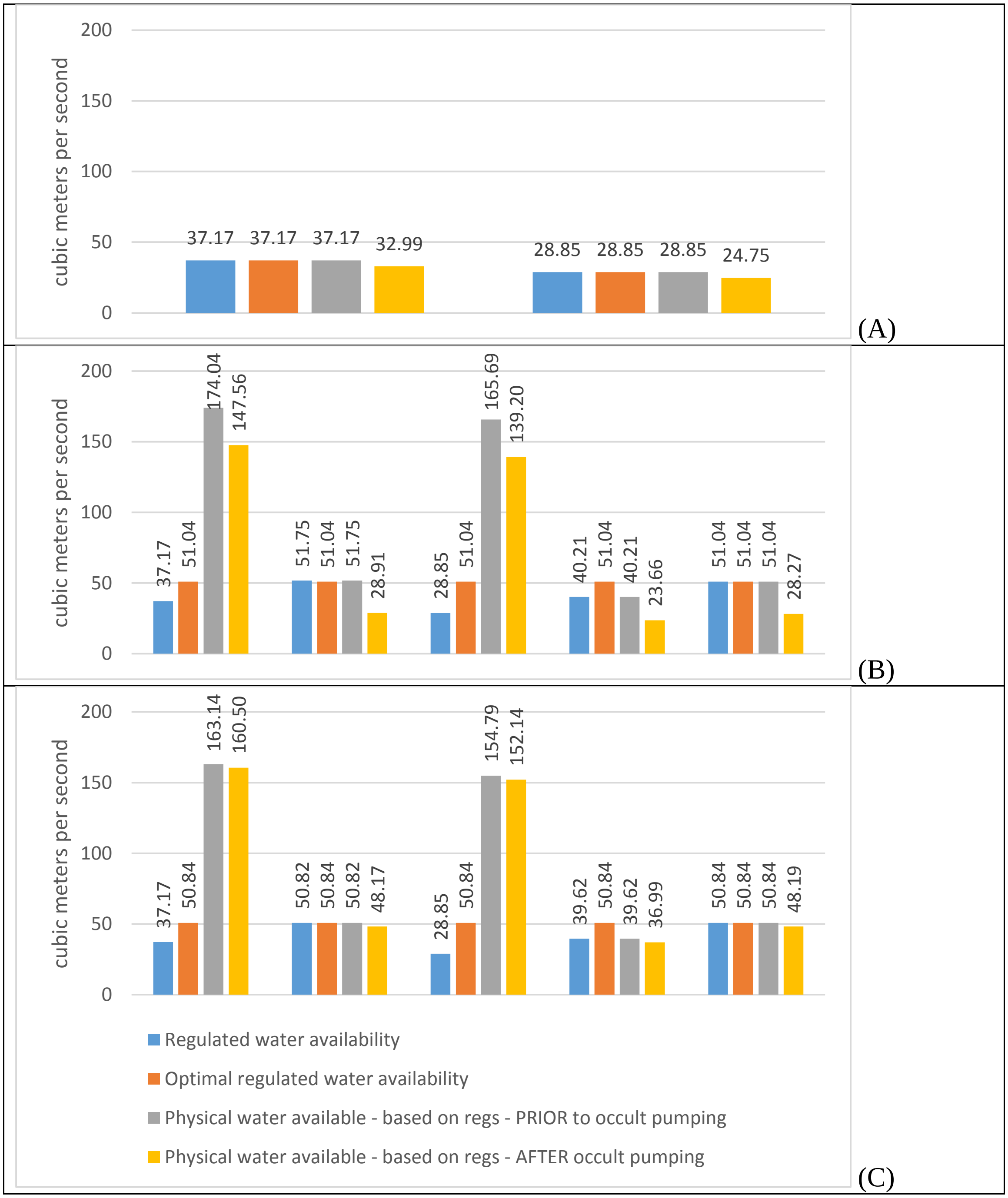


Figure 6.14. Total water availability for (A) Scenario 1A and 1B, (B) (B) Scenario 2A, 2C, 2B, 2D, and 2E, and (C) Scenario 3A, 3C, 3B, 3D, and 3E under the MN Standard pumping regime.

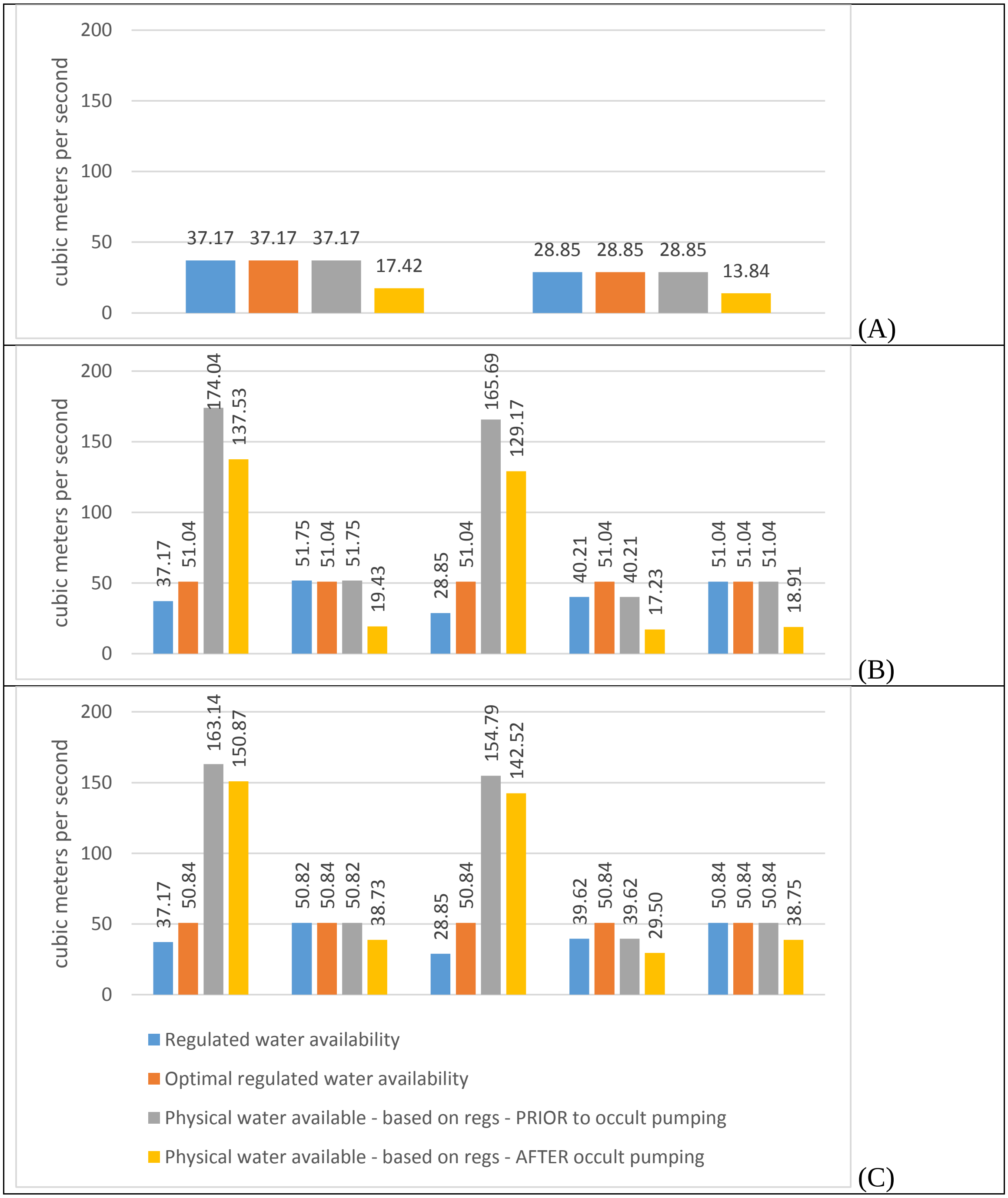


Figure 6.15. Total water availability for (A) Scenario 1A and 1B, (B) (B) Scenario 2A, 2C, 2B, 2D, and 2E, and (C) Scenario 3A, 3C, 3B, 3D, and 3E under the Graded MI Standard pumping regime.

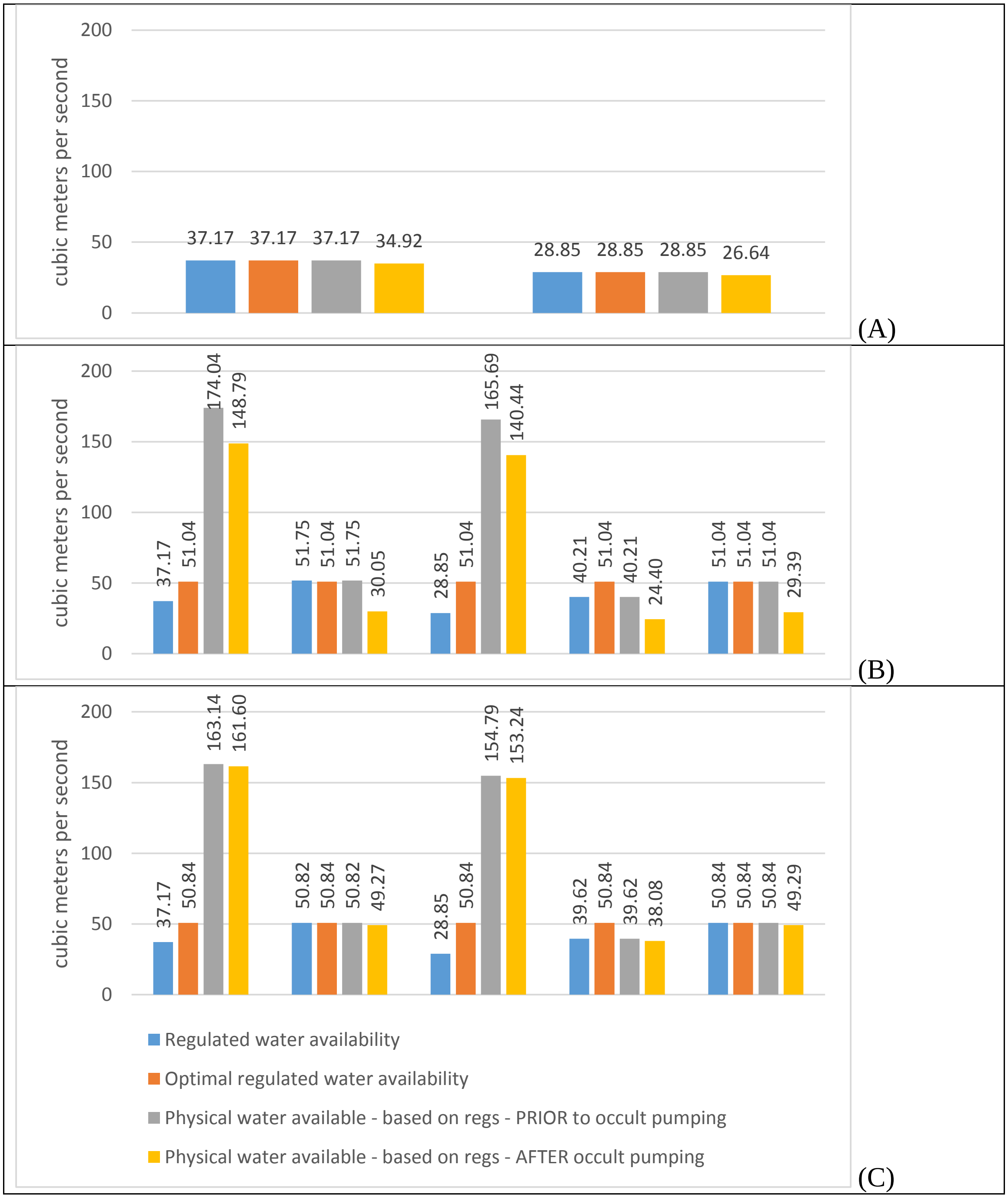


Figure 6.16. Total water availability for (A) Scenario 1A and 1B, (B) (B) Scenario 2A, 2C, 2B, 2D, and 2E, and (C) Scenario 3A, 3C, 3B, 3D, and 3E under the Graded MN Standard pumping regime.

CHAPTER VII:

Conclusions

7.1 Overview

In the previous chapters I have investigated a number of different aspects of the development and consequence of Michigan's 2008 water conservation law. Chapter 2 reviewed the policy context that led up to the passage of the 2008 law. Chapter 3 provided an assessment of the changes in Michigan's water law that led to the implementation of the WWAP (Water-Withdrawal Assessment-Process). Chapter 4 described the development of the WWAP and the development of key scientific and legal terms within the WWAT (Water-Withdrawal Assessment-Tool) within the context of boundary-work. Chapter 4 also provided a retrospective assessment of the WWAP by key actors involved in its production and implementation. Chapter 5 provided a scientific assessment of a legal presumption of the 2006 interim water conservation law, rebutting the presumption that wells further than ¼ mile from trout streams could not have adverse impacts and demonstrating the fragility of marginal trout streams. The implications of these results were ultimately incorporated into the WWAP. Chapter 6 provided a series of model-based assessments of the conservation presumption and adaptive governance presumption of the current (2008) statute. It demonstrated that cumulative water withdrawal at the threshold of regulation can cause massive, widespread adverse resource impacts throughout a watershed and even at a threshold one-tenth the current rate, significant impacts may occur, thus rebutting the presumption that the current regulatory threshold for reporting is necessarily sufficient to achieve stated water conservation goals. Finally, an assessment of different levels of adaptive response to future land-use and climatic changes indicated a potential for major failure of the new WWAP if the models guiding the levels of water conservation are not updated to reflect changes in future physical conditions.

In sum, this dissertation provides a multi-faceted assessment of the development of water governance in the State of Michigan from legal, policy, and scientific frameworks and methodologies. The implications behind these findings, like the topics investigated in this dissertation, are also multi-faceted.

7.2 Impacts of climate change to legal frameworks

Climate change will cause shifts in the historical baselines upon which many environmental regulations are based. For example, in the Colorado River basin, increased periodicity and severity of droughts will require a reassessment of the volume (and perhaps the quality) of water allocated under the Colorado River Compact (Gober & Kirkwood, 2010). In terms of flooding, more intense storm systems will increase the likelihood of severe flooding, requiring the re-drawing of flood zones, re-thinking infrastructure placement in newly created flood zones, and re-assessing the economic impacts of a new potential flooded landscape (Wilby & Keenan, 2012). In terms of ecosystems, changes in the amount and periodicity of water will have major impacts on the types of fish, invertebrate, and plant species that can continue to utilize stretches of river at different times throughout the year, which are likely going to have impacts on the management of hunting and fishing as well as any state or federal endangered species and restoration projects.

Despite these anticipated problems, most water-management regulations are likely flexible enough to allow for changes due to future climate change (De Stefano, et al., 2012), so long as the future climate is similar to that seen in the historical record. The problems caused by non-adaptive governance seen in Chapter 4 suggest that it will be necessary to ensure that further adaptive processes be put in place to allow WWAP to meet policy goals in the future, and not to be ensnared in regulatory standards based on historical conditions that may no longer be valid.

7.3 Role of Science in Policy-Making

In a society that is increasingly driven by science and technology, many have highlighted the need for and potential strengths of incorporating more science into environmental policy-making (Narasimhan, 2008). However, many authors have described the difficulties and pitfalls that often characterize attempts to do so (Jasanoff, 1997; Lackey, 2007; Oreskes, 2004; Pielke Jr., 2007). This is because the science behind environmental conservation is often difficult: problems are complex, poorly documented by existing data, and are often directly related to social questions of social and economic values upon which people have widely divergent opinions.

In addition to the complex nature of many environmental problems, there are also competing public perceptions about what the role of science ought to be in addressing public policy. Perceptions are complicated in part by the public's perception of what science is, what science can do, and who scientists are. Part of the confusion arises from semantic differences in meaning– and therefore in implication and application – of terminology, including terms like "uncertainty," "theory," and "fact" (Firestein, 2012). It also derives from a potential misunderstanding of the motivation of scientists (Firestein, 2012), especially when it comes to why they are making policy (Oreskes, 2004; Pielke Jr., 2007) or acting as an expert witness (Jasanoff, 1997). Sometimes there is an apparent desire (or sometimes merely a cynical statement of desire) for more scientific evidence in order to adjudicate a policy decision, as if the next piece of evidence would provide the linchpin that would finally provide a policy decision. Oreskes (2004) puts this to rest, stating:

> … the idea that science could provide proof upon which to base policy is a misunderstanding (or misrepresentation) of science, and therefore of the role that science could play in policy. In all but the most trivial cases, science does not produce indisputable proofs about the natural world. At best it produces a robust consensus based on a process of inquiry that allows for continued scrutiny, re-examination, and revision. (p. 369)

7.4 The WWAP: A Linkage of Science and Policy

In the end, I believe the new WWAP provides a good example of a merging of environmental science and environmental policy-making through the process of boundary-work. However, although there are general lessons to be learned here, the assumptions of the WWAP itself are heavily based on the peculiarities of Michigan's hydrology and on historical observations of that hydrology. In this way, it could be argued that it is a good example of "governance in place" which is supposed to be a hallmark of good environmental governance (Gasparatos, 2010; Quay, 2010). On the other hand, regulatory tools like the WWAP cannot be immediately applied to the conditions of other states. At the very least, such tools must be reconstructed from analogues of the philosophical bases – both scientific and social – that drove the development of the WWAT in Michigan.

7.5 Implications of a Changing Climate on Hydrology

Significant climatic change could alter a river's hydrology through changes in the amount and timing of precipitation, and through changes in temperature (via evapotranspiration). In the case of the Muskegon River, the projection used presumes that there is an increased amount of precipitation with roughly the same seasonal periodicity of precipitation, meaning that each precipitation event will be more intense, providing more water per minute into the system. This increased intensity is expected to increase the percentage of precipitation converted to overland flow in addition to increasing the specific power of the river. Both of these will increase the amount of sediment transport in the river – conversely it will increase the amount of erosion in the watershed – as the river moves to a new geomorphic equilibrium.

Climate change in the Muskegon River watershed area will also increase the ambient air temperatures. Increasing air temperatures will raise the temperature of all the water in the system, including the groundwater. Groundwater will continue to have a temperature-moderating effect, in that it will minimize the diurnal variability, but the overall water temperature will be higher by upwards of 2 degrees centigrade.

Rises in stream power and water temperatures will mean that fish distributions will become fundamentally altered from historic conditions. Based on the implications of increased water temperatures seen in with the modeling of Augusta Creek in Chapter 2, it is likely that analogous increases in temperature caused by climate change – in addition to those temperature changes caused by groundwater withdrawal – will extirpate cold-water fishes from many of the present-day cold-transitional and cold-water waterways, as can be seen by the changes in river-type mapped out in the Muskegon River in Chapter 4.

As was mentioned in the conclusions in Chapter 3 and Chapter 4, the conservation standards implemented as part of the WWAT were based on the cultural significance ascribed to the eleven river-type classes, with the major conservation weighting based on the four water temperature classes (cold, cold-transitional, cool, and warm) and the types of fish communities associated with each class. The current distribution of cold-, cold-transitional-, cool-, and warm-water fish communities are associated (generally) with gradients in river groundwater-surface-water connectivity, with warm-water rivers generally having the lowest connectivity and cold-water rivers generally having the highest connectivity. Extrapolating the results of Chapter 4 to the rest of the State of Michigan, a future of climate change can shift cool-, cold-transitional, and even cold-water rivers into the temperature range of the July mean water temperature of today's Michigan warm-water rivers. With this, the relatively conservative withdrawal limits of cold- and cold-transitional-rivers will be superseded with the relatively far more generous withdrawal limits of warm-water rivers. In short, under the WWAP a warmer future will be a future that allows greater water withdrawal, due primarily to the lower cultural value that the GWCAC (and subsequently the Michigan Legislature) placed on cool-water and warm-water systems.

Furthermore, the predictive association between the water temperature classes and the expected fish communities is based on state-wide correlations first described in Zorn (2002). However, as indicated in interviews with members of the Technical Advisory Council (TAC) that helped develop the science of the WWAT, if the underlying physical conditions in Michigan's rivers change, then the predictive correlation inherent in the WWAT could well become invalid. This would throw another complication into the regulation of Michigan rivers based not only on river-types that no longer exist, but also on fundamental ecohydrological associations that no longer exist, either.

7.6 Future Associate Research Directions

The new legal and policy landscapes that the 2008 law creates will undoubtedly raise new questions about the boundary items created by the process of their development in Michigan. As is the nature of boundary items, their use in different fields will take on different functions, but the way in which society interacts with them will create new sorts of questions; some of which were likely never intended by the any of the key actors that helped construct and deploy the WWAP and its various products. Research topics that build upon research done in this dissertation include (1) an assessment of the efficacy of the WWAT in accounting for upstream water withdrawal impacts to downstream areas and (2) a comparative assessment of the WWAP with other regional water conservation approaches.

7.6.1 Assessing Longitudinal Pumping Effects under WWAT

The legal doctrine of riparianism is concerned principally with the “reasonable use” of water resources. If the presumption that an ARI is a direct analogue of “reasonable use” under the new structure of the law (see Chapter 3), then it seems necessary to ensure that upstream water uses not cause an ARI locally, but also anywhere downstream (or upstream) since causing an ARI further downstream would also be “unreasonable”. Since each different river type has a different threshold for diminution of the index flow, with some river types having significantly lower thresholds than others (Hamilton & Seelbach, 2011), it seems possible that upstream water withdrawals may cause significant impacts to downstream stretches of the river, thus limiting the ability of those downstream to exercise their riparian rights of reasonable use of water.

Similar to the methodology in Chapter 6, future investigations could utilize basin-wide hydrologic models (e.g. MREMS) to create different types of pumping scenarios in which upstream sub-basins would create pumping pressures on downstream basins. By assessing the legal implications of these pumping pressures as they affect downstream river segments, and determine the extent to which the nested nature of a river system will cause difficulties in applying the existing water conservation standards protecting the principal of reasonable use.

7.6.2 Comparative Assessment of State Water Conservation Mechanisms

The State of Michigan is unique among the Great Lakes states in that effectively all of its territory lies within the Great Lakes watershed. This has meant that the Michigan Legislature was able to pass a single set of water conservation laws that would be in place for the entirety of the

State under the requirements of the Great Lakes Compact. All the other Great Lakes states straddle a watershed divide between the Great Lakes-St. Lawrence River watershed and other watersheds, which means that all of these states had an option to set up a variety of legal mechanisms to deal with the Great Lakes portions of their states versus the non-Great Lakes portions of their states (Annin, 2009). Since the Great Lakes Compact does not require a unified state-based conservation mechanism each state has put in place somewhat unique mechanisms by which to monitor and regulate Great Lakes water withdrawals.

An initial assessment of the various compact-relevant conservation measures around the Great Lakes basin based on legal documentation would provide a starting point for evaluating the differing approaches. Following the general methodology I have developed in Chapter 4, identifying and interviewing the key actors in each state's development process could provide a means by which to determine the recognized strengths, weaknesses, and challenges that each state's system face. An analysis of the degree of similarity in roles of key actors, and of the modes of interaction between science and politics would likewise be informative.

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