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Science as a fundamental framework for shaping policy discussions regarding the use of groundwater in the State of Michigan: a case study

Alan D. Steinman[a], James R. Nicholas[b], Paul W. Seelbach[c], Jon W. Allan[d] and Frank Ruswick[e]

[a]*Corresponding author. Annis Water Resources Institute, Grand Valley State University, 740 West Shoreline Drive, Muskegon, Michigan 49441, USA. Fax: 1-616-331-3864. E-mail: steinmaa@gvsu.edu*

[b]*USGS Michigan Water Science Center, 6520 Mercantile Way, Suite 5, Lansing, Michigan 48911, USA*

[c]*Michigan Department of Natural Resources, Institute for Fisheries Research, Room 212, Museum Annex Building, 1109 North University, Ann Arbor, Michigan 48109, USA*

[d]*Consumers Energy Company, 1945 West Parnall Road, Jackson, Michigan 49201, USA*

[e]*Michigan Department of Environmental Quality, 525 West Allegan Street, Lansing, Michigan 48911, USA*

Abstract

The availability and use of freshwater is a growing concern in the United States and around the globe. Despite apparently abundant water resources, several conflicts over water use have emerged in the Great Lakes region and the State of Michigan. These conflicts resulted in state legislation that both addresses water withdrawal from the Great Lakes Basin and requires the State of Michigan to begin a process to address the sustainability of water resources. The former resulted in Michigan's support of the Great Lakes–St. Lawrence River Water Resources Compact, whereas the latter resulted in the formation of a Groundwater Conservation Advisory Council. This paper focuses primarily on the Council, describing its formation, and the products it generated. In particular, we focus on the development of indicators of sustainable use of water, the creation of a water withdrawal assessment process to determine if a proposed withdrawal will create an adverse resource impact in the state, and how the lessons learned in Michigan may be applied to other units of government addressing similar issues. Attention is also given to the Compact, as it provides important context for the Council's formation.

Keywords: Great Lakes; Groundwater withdrawal; Michigan; Science policy; Sustainability

Introduction

Conflicts and inequities over access to freshwater have received considerable attention in regions that have limited water supplies (Gleick, 1993). However, these conflicts can exist even in regions with

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seemingly ample amounts of water (Hunt, 2003). While there is a general acknowledgment that society needs to use its freshwater resources in a sustainable fashion, it is less clear what is specifically meant by sustainable use or how it is achieved (cf. Clark & Dickson, 2003; Marshall & Toffel, 2005). In addition, there is a growing call for using science to help inform water management recommendations. However, societal values weigh heavily in the degree to which science-based recommendations will be modified once they enter the political arena (Steinman *et al.*, 2004; Rosenberg, 2007).

Michigan is a state that, overall, has an abundant quantity of fresh water. In addition to bordering four of the five Laurentian Great Lakes (over 5,150 km of Great Lakes shoreline), Michigan has more than 35,000 mapped lakes and ponds and over 58,500 km of streams. This surface water is sustained both by precipitation, which averages c. 81 cm/yr (c. 310×10^9 L/d), and by groundwater. In 2000, the pumpage of fresh groundwater in Michigan was estimated to be c. $2{,}763 \times 10^6$ L/d, which is c. 2.6% of the estimated 102×10^9 L/d of natural recharge to Michigan's groundwater systems. Based on these data, there is an understandable perception that Michigan's groundwater is abundant and its uses can be sustainable.

Despite the large volume of fresh water in Michigan, there are significant concerns over diversion (i.e. the physical removal and transport of water out of the basin). There is a strong public view that the water (both surface water and groundwater) in the Great Lakes Basin should not be diverted outside the basin (cf. Annin, 2006); this position has significant political importance. In 2001, the Great Lakes governors and Canadian premiers reaffirmed their commitment to protecting the health of the Great Lakes by signing the Great Lakes Charter Annex (CGLG, 2001) and the Great Lakes–St. Lawrence River Water Resources Compact (hereafter the Compact) in 2008 (CGLG, 2008). This document, and its relationship to the process by which Michigan is evaluating water withdrawal, is discussed in more detail below.

Relative to surface water, less attention has been paid to the withdrawal of groundwater in the Great Lakes Basin, despite the fact that groundwater supplies up to 67% of the flow in tributaries feeding the Great Lakes (Holtschlag & Nicholas, 1998). This oversight is perhaps not surprising given the volume of surface water in the region but it does reflect a lack of understanding of system hydrology. Because surface water and ground water are one connected hydrologic system (Holtschlag & Nicholas, 1998; Winter *et al.*, 1998), groundwater withdrawal can strongly influence stream flows, and alter temperature regimes for cold water and cool water streams in the basin (Grannemann *et al.*, 2000; Baker *et al.*, 2003, Wehrly *et al.*, 2006). This has implications for both water quantity and quality; groundwater withdrawals can result in reduced flows to streams and alter wetland hydrology, potentially impacting biotic resources and ecological processes (Poff *et al.*, 1997; Zorn *et al.*, 2002; Baker *et al.*, 2003; Richter *et al.*, 2003; Cott *et al.*, 2008). Alternatively, groundwater quality can be affected if withdrawals induce water of poorer quality into an aquifer (Grannemann *et al.*, 2000; Polizzotto *et al.*, 2008).

Sustainable management of natural resources, including water, requires the balancing of needs and values from the natural, social, and economic sectors of our society (Gleick, 1998; Baron *et al.*, 2002; Holdren, 2008). Science can play an important role in framing the debate regarding the prioritization of the competing demands for water resources (Johnson *et al.*, 2001; Holdren, 2008), although science-backed policy positions do not directly translate into implementation (Steinman *et al.*, 2002; Rosenberg, 2007).

This paper discusses: (1) the ensuing developments, including the formation, recommendations, products, and current status of the Groundwater Conservation Advisory Council; (2) a pragmatic approach for addressing sustainable groundwater use; and (3) the bidirectional relationship between science and policy, especially as it relates to a vision for sustainable and environmentally sound water use in Michigan.

Formation of the state council: phase I

Overview

Groundwater sustainability is an issue of growing concern in Michigan and the Great Lakes Basin. Concerns over water withdrawal from the Great Lakes, conflicts between owners of large-capacity wells and owners of small-capacity domestic wells, and the public attention and litigation associated with the building of a bottled water facility in the state (Steinman *et al.*, 2004) all contributed to help motivate the Michigan legislature to address water use in the state. This took the form of Public Act 148, which became law in August 2003. The law's language formed the Groundwater Conservation Advisory Council (hereafter, the 'Council'), placed it within the Department of Environmental Quality (MDEQ), and explicitly denoted that its membership would consist of ten voting members and three non-voting (state agency) members. Council members were selected and appointed to provide a relatively broad representation of perspectives with respect to the uses and social values of water in Michigan (Table 1). This initial period of the Council's existence is referred to as Phase I.

The Council was charged to: (1) study sustainability of the state's groundwater use and whether the state should provide additional oversight of groundwater withdrawals; (2) monitor Annex 2001 implementation efforts and make recommendations on Michigan's statutory conformance with Annex 2001, including (a) whether groundwater withdrawals should be subject to best management practices or certification requirements, and (b) whether groundwater withdrawals impact water-dependent natural features; and (3) study the implementation of and the results from the groundwater dispute resolution program (see below for description).

The Council spent its first 6 months learning the key principles and characteristics of Michigan's water resources and uses. This was accomplished through a series of presentations, discussions, and reading of relevant reports. This process was time-intensive, and resulted in frustration among some Council members who were already well informed about water resource issues in Michigan. However, Council leadership felt this investment in joint learning was important to ensure that there was a common knowledge base among Council members, who represented a diverse array of interests (Table 1). This, in turn, was critical in facilitating a constructive and respectful dialogue during discussions over final recommendations to the legislature. The Council was given $2\frac{1}{2}$ years to submit a final report of their findings to the Michigan legislature. Concurrent with the work of the Council, a groundwater inventory and mapping project was initiated, as mandated by Public Act 148, Section 32802. A multi-agency team comprising of scientists from MDEQ, United States Geological Survey (USGS), and Michigan State University finished this project in August 2005; the results from this project are available on-line (http://gwmap.rsgis.msu.edu/).

Sustainability

In their 2006 report to the legislature, the Council recognized that the sustainable use of groundwater resources involved the following hydrologic principles: (1) connectivity between surface water and

Table 1. Members of Michigan's Groundwater Conservation Advisory Council when formed in 2003, including their affiliations, group(s) they represent, and responsible party for their appointment.

Name	Voting or non-voting member	Affiliation	Representing	Appointed by
Jon Allan	Voting	Consumers Energy	Utilities	Senate Majority Leader
Jim Cleland	Non-voting	MDEQ	MDEQ	Director, MDEQ
James Clift	Voting	Michigan Environmental Council	Environmental organizations	Director, MDEQ
Jon Coleman	Voting	Tri-County Planning Commission	General public	Director, MDEQ
Michael Gregg	Non-voting	MDA	MDA	Director, MDA
Kurt Heise	Voting	Wayne Co. Department of Environment	Local units of government	Speaker of the House
Fred Henningsen	Voting	District Agriculture and Irrigation Agent, Emeritus, MSU	Agricultural irrigators	Speaker of the House
Craig Hoffmann	Voting	The Rock on Drummond Island	Nonagricultural irrigators	Director, MDEQ
Rod Mersino	Voting	Mersino Dewatering, Inc.	Well drilling contractors	Speaker of the House
Tom Newhof	Voting	Prein & Newhof	Business and manufacturers	Senate Majority Leader
Mike Newman	Voting	Michigan Aggregates Association	Aggregate industry	Director, MDEQ
Paul Seelbach	Non-voting	MDNR	MDNR	Director, MDNR
Alan Steinman	Voting	Annis Water Resources Institute	Conservation organizations	Senate Majority Leader

MDEQ: Michigan Department of Environmental Quality; MDA: Michigan Department of Agriculture; MDNR: Michigan Department of Natural Resources.

groundwater systems; (2) maintaining a long-term perspective toward management of water resources; and (3) acknowledging that management of water resources can vary based on the spatial scale of interest. The Council emphasized the notion that groundwater and surface water form a complex and interconnected system, with groundwater withdrawals potentially resulting in lower quantity of water in streams, lakes, wetlands, and springs. A long-term perspective is essential because impacts from withdrawals may take years or decades to become manifest (Alley *et al.*, 1999). In addition, changes in climatic conditions can take many years to have a demonstrable influence on water resources. As a consequence, the Council affirmed that the science being conducted to help inform water resource management must also adopt a long-term, adaptive perspective; this adaptive approach to studying, understanding, and managing the regional water supply is also emphasized in the Great Lakes Compact. Finally, the Great Lakes Basin presents a graphic example of why it is important to view groundwater sustainability at multiple scales. A regional abundance of groundwater does not preclude local shortages and conflicts; indeed, Michigan is experiencing groundwater conflicts in certain areas of the state that have limited glacial aquifers. The Council recommended that the State of Michigan develop a set of indicators, coupled to a program that measures and tracks future changes in these indicators, to determine whether or not Michigan's groundwater use is sustainable.

Monitor Annex 2001

On 13 December 2005, the governors and premiers of the Great Lakes states and provinces signed the Annex 2001 Implementing Agreements, which included a ban on new diversions of water outside the Great Lakes Basin (with limited exceptions). The Agreements consisted of two elements: the Great Lakes–St. Lawrence River Basin Sustainable Water Resources Agreement, which is a good faith agreement among the eight Great Lakes states, Ontario, and Quebec; and the Great Lakes–St. Lawrence River Basin Water Resources Compact, which is a binding agreement among just the eight Great Lakes states.

The Council, with the assistance of MDEQ staff, evaluated Michigan's statutory conformance (as of 2006) with the requirements identified in the Agreements. The Council, both in the formal recommendations contained in their report to the legislature (GWCAC, 2006) and in public comments on pending legislation, supported the following principles stemming from Annex 2001: (1) protection and conservation of the levels of, and flows to, the Great Lakes; (2) protection and conservation of the environmental balance of the Great Lakes ecosystem; (3) provision of cooperative programs and management of the water resources of the Great Lakes Basin; and (4) protection of present developments and provision of a secure foundation for future investment and development within the region.

Groundwater dispute resolution program

This regulatory program guides the evaluation of disputes between users of high capacity wells (> 70 gallons per minute (GPM) or 265 l/min) and small quantity wells (< 70 GPM), and is administered jointly by the MDEQ and the Michigan Department of Agriculture. The Council recommended that this program should be periodically reviewed by a representative group of stakeholders, and be open to public access and input. Since this program has been in effect (August, 2003), 101 groundwater dispute complaints have been investigated; 53 complaints have been resolved by the high-capacity well owners reimbursing expenses incurred by the small-quantity well owners. Only four complaints remain unresolved to date and 44 have been closed, either because the claims were invalid or the provisions within the regulation were not satisfied.

This first phase of the Council came to a conclusion in 2006 with the submission of their report to the Michigan legislature (GWCAC, 2006). This report from a societally representative, collaborative body: (1) established fundamental principles and aspects of Michigan's water resources; and (2) proposed a set of recommendations for a science-based state-wide water management program. Enabling legislation in 2006 resulted in the reauthorization of the Council.

Reauthorization of the state council: phase II

Overview

In February 2006, the Michigan legislature enacted legislation, which for the first time established regulation of water withdrawals in the state, and consistent with the language of the Compact, explicitly noted that science should be used as the basis for decision making. Based on the recommendations of the Council in their final report (GWCAC, 2006), as well as on the input of Council members during the drafting of the new legislation, the laws required the reconstituted Council to address three major tasks. The first was to develop criteria and indicators to evaluate the sustainability of the state's groundwater use. The importance of sustainable groundwater use was implicitly recognized as part of the Council's final report (GWCAC, 2006), but the report did not include specific recommendations on how sustainable use could be evaluated. The second major task was to design and make recommendations regarding a water withdrawal assessment tool; the purpose of the tool was to assist in determining whether a withdrawal would create an adverse resource impact. In order to ensure the water withdrawal process was grounded in science, the Council was required by legislation to consult with a technical advisory group to design a water withdrawal assessment tool. The Council was also mandated to make factually-based recommendations to the legislature for the 'policy-based parameters and variables' of the water withdrawal assessment tool, and to recommend an appropriate timetable for periodic updates or changes to the water withdrawal assessment tool and its components. The final major task was to study and make recommendations as to whether the state should consider, as part of its groundwater conservation programs, proposals to mitigate adverse impacts to the waters of the state or to the water-dependent natural resources of the state that may result from groundwater withdrawals.

Criteria and indicators for sustainable use of groundwater

A one-day workshop was held in March 2007 that brought together recognized experts in the sectors of environmental science, economic development and social equity. The workshop had three principal objectives: (1) to gather experts to address the issue of groundwater sustainability in Michigan; (2) to identify a short (3–5) working list of indicators and criteria for each sector; and (3) to review and vet these shortlists among all workshop participants.

The Council, in their 2006 report to the Michigan legislature, noted that sustainable use of Michigan's groundwater resources means meeting the needs of the present while not compromising the ability of future generations to meet their needs, and recognizing that sustainable use encompasses environmental, economic, and social systems and their contribution to meeting human needs (GWCAC, 2006).

Workshop leaders made a conscious decision not to devote time redefining sustainability, as the definition can be elusive (Marshall & Toffel, 2005) and time-consuming. Instead, the workshop focused on the development of criteria and indicators.

Criteria and indicators can be useful tools to evaluate and measure the sustainability of natural resources. Criteria were defined as standards or points of reference that help in choosing indicators; they are more general and less detailed than indicators (Kranz *et al.*, 2004; Steinman *et al.*, 2004). Indicators were defined as measures that present relevant information on trends in a readily understandable way. Good indicators should adequately represent the societal concern, be measurable, consistent, based on readily available or obtainable information, and comparable among various geographic regions. Based on their expertise, workshop participants were divided into environmental, social and economic work groups, and instructed to identify those indicators they believed were most appropriate, irrespective of whether or not relevant data were currently available.

Eleven indicators were identified (Table 2). Five environmental indicators were developed that focused on both water quantity and quality. An indicator of the impacts of water withdrawal on groundwater-dependent biota was not developed. Although workshop participants agreed that this indicator is very important, there were concerns that withdrawal-related impacts on biota could not be clearly or empirically associated with a change in groundwater resources, given the state of the science. Consensus was reached on three general economic indicators (Table 2), but there was considerable debate within this group. Areas not originally identified by the economic breakout group but specified later in the group discussion included: (1) the tourist economy reliant upon Michigan's renowned groundwater-fed rivers and lakes; and (2) the sustainable use of Michigan's abundant groundwater resources as a focal point in the vision for Michigan's future economic health. In addition, three social sector indicators were identified (Table 2) that focused on public education, conservation and restricted groundwater access.

The Council, in their final report to the legislature (GWCAC, 2007), recommended that the state adopt and utilize these indicators in conjunction with an implementation program to determine their current status. In addition, the Council recommended the creation of a working group to review and refine the indicators, as needed.

Water withdrawal assessment tool

The purpose of the water withdrawal assessment tool is to assist a large quantity user (defined as greater than 100,000 gal/d (78,541 l/d) in any 30-day period), or the state, in determining if a withdrawal is likely to cause an Adverse Resource Impact (ARI). In this case, the ARI is characterized in terms of an ecological functional impairment and defined by whether or not a water withdrawal impairs the ability of a surface water body to support 'characteristic fish populations' (see below for definition). Thus, characteristic fish populations were used as a biological proxy for overall stream functional integrity.

The Council was charged with developing a water withdrawal assessment tool that would allow proposed users of water to determine if their withdrawals were likely to cause an ARI. The Council instead developed a water withdrawal assessment *process*, with two levels: (1) a screening tool, that is designed to 'screen in' (i.e. say yes to) those proposed withdrawals that are highly certain not to cause an ARI; and (2) for those withdrawals not initially 'screened in', the applicant has a choice: they may either change the characteristics (e.g. size, location, or depth) of the proposed withdrawal in the hope this will result in a different decision or, if their application cannot pass the tool and they choose to pursue

Table 2. Recommended groundwater sustainability indicators and their associated measurements and criteria for the environmental, economic, and social sectors.

Indicator	Measurement	Criteria
Environmental Sector		
1. Groundwater contribution to stream baseflow	1-1. Change in groundwater contribution over time	1-1. Adequate groundwater discharge to maintain natural flow and temperature regimes
2. Groundwater withdrawals	2-1. Volume of water use by sector	2-1. Efficient use to maintain adequate supply for public and private needs
3. Land use/land cover	3-1. Percentage natural land use/land cover	3-1. Increase
	3-2. Percentage impervious surface	3-2. Decrease below reference impairment thresholds
4. Groundwater contamination	4-1. Number of at-risk sites	4-1. Decrease
5. Groundwater-dependent natural communities	*Not developed*	*Not developed*
Economic Sector		
6. Cost of groundwater by relevant economic sector	*Not developed*	*Not developed*
7. Groundwater Dependent Commerce	7-1. Product-revenue per unit groundwater per sector	7-1. Increase
	7-2. Efficiency of groundwater use per sector	7-2. Increase
8. Water usage from alternative sources	8-1. Gallons of water recycled	8-1. Increase
	8-2. Gallons of water used from collection of stormwater	8-2. Increase
Social Sector		
9. Public education	9-1. Public knowledge of groundwater resources	9-1. Increase
	9-2. Water resource education	9-2. Increase
	9-3. Local government training	9-3. Increase
10. Conservation	10-1. Public water systems using groundwater	10-1. Efficient use to maintain adequate supply for public and private needs
	10-2. Water utilization by sector	10-2. Unspecified
11. Restricted groundwater access	11-1. Use restrictions due to contamination	11-1. Decrease
	11-2. Adverse Resource Impacts (ARIs)	11-2. Decrease
	11-3. Water Use conflicts	11-3. Decrease

the withdrawal, then they may request the MDEQ to undertake a site-specific review. The applicant may provide site-specific measurements to assist with this review, but it is anticipated that in most cases the MDEQ will use readily available information to conduct the site-specific review.

The water withdrawal assessment tool includes three models that are linked through a GIS to associate information about streamflow, groundwater withdrawal and extant fish communities with specific stream segments across Michigan (Figure 1). In aggregate, these linked models help determine the impact potential of the proposed withdrawal on fish populations.

The streamflow model is a regression model that describes how much flow is in Michigan streams and is based on data from 147 gages in Michigan or adjacent states (Hamilton *et al.*, 2008). An index flow was calculated for each gage; index flow is defined as the median flow for the summer month with lowest flow at a site. Summer months (usually August or September) were used in this analysis because this is when the lowest flows and warmest temperatures result in the greatest stress to fish.

The withdrawal model describes how much a groundwater withdrawal will reduce streamflow in nearby streams. This model takes into account the amount and continuity of withdrawal, plus depth of well, distance of well from stream, and aquifer properties (Reeves *et al.*, 2009). The water withdrawal assessment tool accounts for direct surface water withdrawal by subtracting it from the amount of available water.

The fish community model is a statistical model that describes how reduced streamflow will affect characteristic fish populations. This model takes advantage of Michigan Department of Natural Resource's dataset of fish abundance at c.1700 stream locations in Michigan. It relates fish abundance to 11 river classes in Michigan, based on temperature type (cold, cold-transitional, cool, and warm; Lyons *et al.*, 2009) and size (large rivers, small rivers, and streams). This model describes, for each of the 11 stream classes, the change in characteristic fish populations caused by reducing streamflow.

Based on available data from the Michigan Department of Natural Resources, two curves were generated for each of the 11 stream classes in Michigan; these curves show how fish population responds as flow is incrementally reduced (Figure 2). Curve A shows the response of *thriving* species

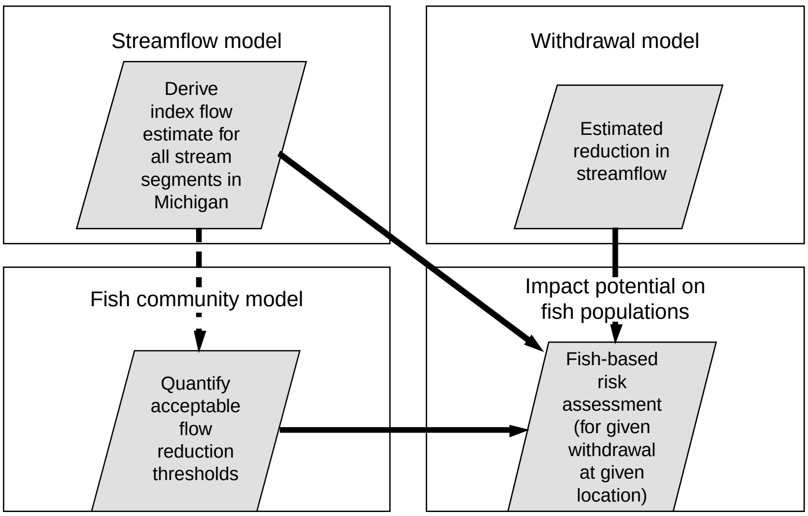

Fig. 1. Schematic showing the three linked models (streamflow, water withdrawal, and fish community) that together determine potential impacts to fish populations in Michigan streams.

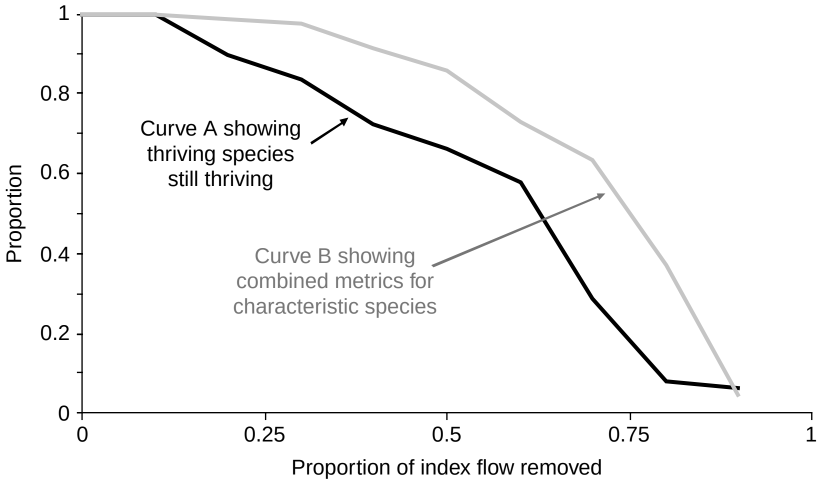

Fig. 2. The two curves showing different aspects of the functional responses of fish populations (proportion of population) to increasing water withdrawals from Michigan streams. Curve A refers to *thriving* fish species; curve B refers to *characteristic* fish species.

(i.e. those fish whose needs are best matched to the temperature and flows of the given stream class). Curve B indicates the impact on abundance of *characteristic* species (i.e. those fish whose needs are still matched to the temperature and flows of the given stream class, but not as well matched as *thriving* species). More details on the explicit definitions of thriving and characteristic fish species, and methods for generating curves, can be found in Zorn *et al.* (2008).

Both the *thriving* and *characteristic* fish curves show a decline as flow is removed, although the thriving species clearly decline at a faster rate (Figure 2). The anticipated order of change will be: (1) an initial decline in abundance of sensitive species; (2) some replacement of sensitive species; followed by (3) a more notable replacement of sensitive species (following the biological condition gradient concept of Davies & Jackson (2006)).

As flow continues to decline with continued extraction, tolerant species will become dominant, and then finally there will be severe alteration of ecological structure and function. The points on the curves at which these changes take place vary depending on the stream class. For example, fish associated with cold water streams can withstand a significant amount of water withdrawal, as in many areas of Michigan abundant groundwater inflow provides a buffering capacity to withdrawal (Zorn *et al.*, 2008). In contrast, fish associated with cold/transitional rivers and streams, which are very near the thermal tolerance of thriving species, are far more sensitive to water withdrawals.

The inclusion of the two different curves assisted in framing the biological uncertainty inherent in the Council's understanding of how fish populations change in response to water withdrawals. These curves focused the ensuing social debate, both within the Council and the legislature, by visually displaying one boundary as an early warning region where the density of thriving fish species is reduced and the other boundary as a region of Adverse Resource Impact where the abundance of characteristic fish is reduced. As a consequence, the debate over water withdrawal and ARI rarely ventured beyond the area bounded by these two curves. This explicit recognition of uncertainty in describing how fish populations change in response to water withdrawals was a critical component in our approach, as details that influence and shape scientifically-derived recommendations are often ignored or poorly understood by policy makers.

As a result, preference may be given to more simplistic answers, and there can be a failure to recognize that these issues are often multidimensional and laden with scientific uncertainty (Dietz & Stern, 1998).

The Council recognized that the determination of ARI might be improved with more scientific information, given broad variability of streams within each stream classification, but also realized that the determination of ARI thresholds is based on societal values, as well as on science. To that end, it was suggested to use both 10% and 20% reductions on the two fish response curves as the starting point for setting thresholds for ecological risk. Horizontal lines were extended from the y-axis, at the 90% (i.e. 10% reduction) and 80% (i.e. 20% reduction) values, to the points where they intersected the fish response curves (Figure 3). At those two points, vertical lines were extended down to the x-axis, which indicated the proportional flow removals associated with each threshold risk. This process ensured that ecological risks were kept relatively low and stayed clear of the portions of the curves that corresponded to notable replacements of sensitive species. The Council also recognized that some stakeholders would find any reduction in streamflow (and associated loss of fish) unacceptable regardless of the predicted or actual impacts.

The Council's approach resulted in three vertical lines and four corresponding zones (A–D): the far left vertical line (demarcating zones A and B) showed the theoretical edge of minor impact, whereas the far right vertical line showed the theoretical start of an ARI (Figure 3). Hence, Zone A represents minimal measurable impact on fish populations, but as more flow is removed, there is a gradient of increasing risk to the point where notable replacement of fish species occurs, thereby constituting an ARI (Figure 3).

The Council recognized that applying the water withdrawal assessment tool would not be done without difficulty. Effective water resources management involves a number of critical elements: (1) use of science to help frame management decisions; (2) broad stakeholder participation to find social balance points and to encourage public buy-in and eventual implementation; (3) development of a process by which the science can be applied effectively and transparently; and (4) establishment of structures or processes that allow for a continued evaluation or adaptation of the model and science over time.

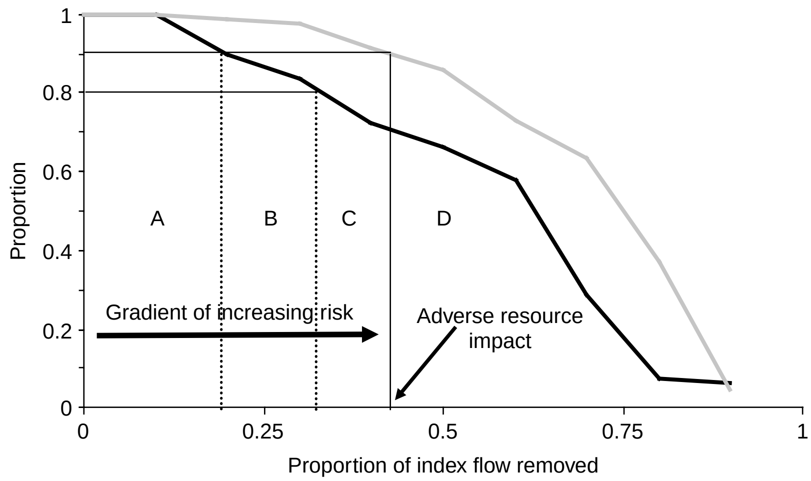

Fig. 3. Hypothetical example showing the four policy zones (A–D), demarcated by increasing levels of index flow removal and the functional responses of fish populations (proportion of population). Curves for thriving (dark line) and characteristic (light line) fish species correspond to Figure 2.

The Council developed a decision-making process that addressed both the science and enabling legislation behind the Council (Figure 4). According to 2006 Public Act 33, a person considering a new or increased large quantity withdrawal is not allowed to cause an ARI. A proposed user may either start the application process on-line by using the screening tool or they may work directly with MDEQ staff to conduct a site-specific analysis (Figure 4). The screening tool calculates the amount of flow reduction for the appropriate stream segment and makes one of two determinations for the proposed withdrawal: (1) that it is not likely to cause an ARI and is authorized; or (2) that there is too much uncertainty in the outcome to determine whether or not the withdrawal would be likely to cause an ARI, and therefore the withdrawal may not proceed without a site-specific review.

For a Zone A determination (ARI not likely; Figures 3 and 4), the user would simply register the proposed withdrawal with MDEQ and receive authorization to proceed. For Zones C and D determination (ARI possible; Figures 3 and 4), the applicant can modify the proposal and try the screening tool again or they can request the MDEQ to conduct a site-specific analysis of the withdrawal. Retrying the screening tool may include reconfiguring the withdrawal (e.g. from a different depth or location). A site-specific analysis will have less uncertainty associated with the withdrawal estimate than the screening tool. As of 9 July 2009, use of the screening tool is required by individuals proposing a large quantity withdrawal from the waters of Michigan.

The Council was not able to resolve all outstanding issues before its report was due to the Legislature in July 2007. This date also corresponded with the Council being dissolved by executive order

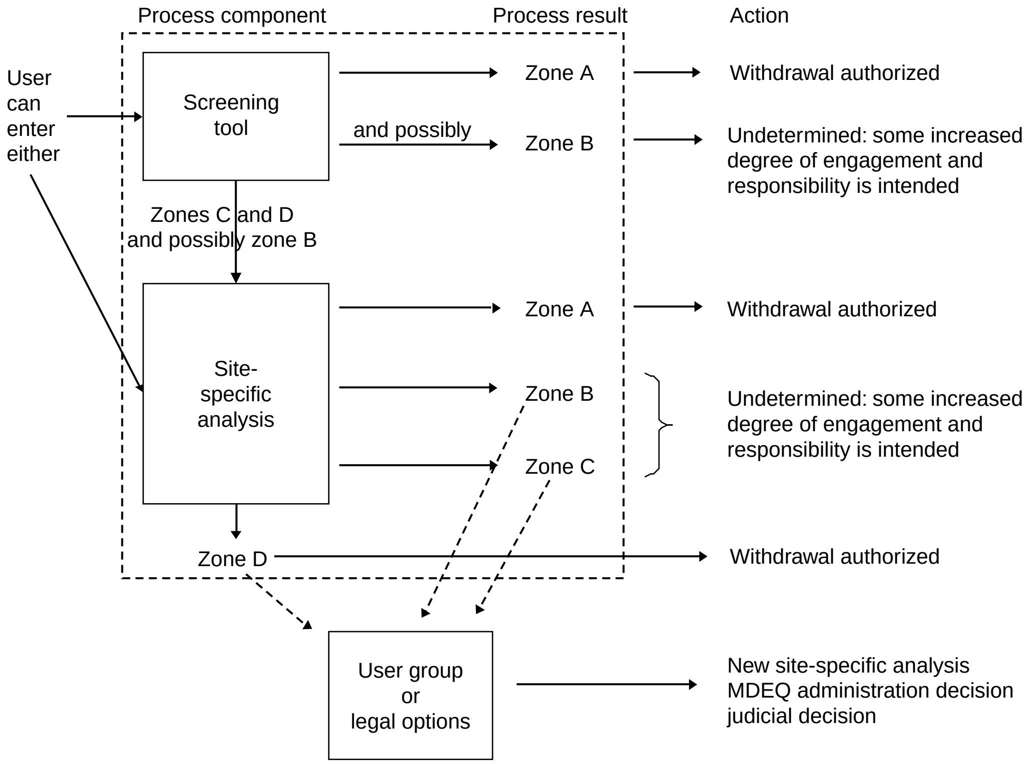

Fig. 4. Decision-making system associated with the water withdrawal assessment process. Zones listed under Process Result correspond to Figure 3.

(along with many other state advisory councils, because of economic distress). There was recognition that the water withdrawal assessment tool is a work in progress. The Council proposed the boundaries of Zones A and D (Figure 3), agreeing that these were the starting points for further policy discussion, and recognizing that the social values of affected constituencies ultimately would influence the location of the boundaries. Indeed, the 2008 implementing legislation contained significant negotiated changes in the location of the Zone A and D lines for most of the 11 stream classifications.

As new users establish themselves in a watershed, the cumulative impact from all users may bring the watershed to the brink of an ARI. Hence, collective actions may be needed, involving both the proposed new user and existing users; this approach is consistent with riparian rights (reasonable-use doctrine). It is critical that water use programs not favor one user over another based on the temporal sequence of authorization of withdrawals.

The Council was unable to reach consensus on whether mitigation should be allowed, or under what circumstances. However, the Council did agree on some general principles regarding mitigation, including that there are stream segments in Michigan that deserve protection because of ecological value, and therefore should be protected and not considered for mitigation. There was an explicit consideration of uncertainty in the Council's deliberations. The Council recognized that scientific understanding of the water withdrawal process could never be complete given the inherent variability in ecosystems and that any prediction could be improved with additional scientific information (cf. Dietz *et al.*, 2003). Given the heavy reliance on models in the assessment process, and the appreciation that these models include multiple sources of error, the Council debated what constitutes an acceptable safety factor, which would avoid causing an ARI. The assessment process incorporates uncertainty in various ways (e.g. the sizing of stream segments, use of a safety factor for index flows in the screening tool, the use of four zones instead of two) but the overall process can still result in underestimating resource impacts. Particular concerns include the exclusive use of fish to assess aquatic ecosystem health, our limited understanding of the impacts of flow reduction on stream temperature, ARI determination in lakes and wetlands, and how future conditions (e.g. climate change) may alter model results.

A new group, the Michigan Water Resources Conservation Advisory Council, was constituted as part of legislation passed in 2008. This group extends the work of the earlier Groundwater Conservation Advisory Council (Phases I and II: January 2004–July 2007) but also differs from the prior council in having a broader membership (21 members) and being charged with evaluating all water resources in the state, not just groundwater. The new council is charged with: (1) evaluation of the water withdrawal assessment tool; (2) evaluation of the overall water withdrawal assessment process; (3) recommendations for inclusion of Great Lakes, inland lakes, and other waters in the process; (4) examining any potential legal conflicts within the process; and (5) recommendations for a new state water conservation and efficiency program.

The science–policy relationship

The call for science to be incorporated into natural resource management policy is common. Indeed, science is often viewed as a neutral arbiter of natural resource debates. However, the role of science is to provide credible information that can be used to inform management decisions; science should not be expected to, and indeed cannot, do the job of determining socially-balanced values and goals. Unfortunately, there are no guarantees that scientific findings or principles will not be modified or re-interpreted for political expediency (UCS, 2004). The investment in a collaborative process among Council members helped build a strong foundation of agreement on the science that underpinned the Council's recommendations and the water withdrawal assessment process. This collaborative environment built trust (cf. Wondolleck & Yaffee, 2000), which allowed divergent opinions to be expressed openly and productively during the ensuing social values debates. In addition, the Council strove continuously to keep the science and the values debates separate and distinct.

The role of science has been emphasized in the debate over water withdrawal in Michigan. A press release from Michigan State Senator Patricia Birkholz, who introduced the original enabling legislation that formed the Council, included the following statement in regard to the 2008 signing of the water withdrawal assessment legislation: '…Michigan will have done what no other state has accomplished by passing the compact along with a water withdrawal tool based on sound science' (Michigan Senate Republicans, 2008). However, not everyone felt the legislation was in the best interest of the Michigan citizenry; the Great Lakes policy director for Clean Water Action said, 'We are extremely disappointed that the legislature failed to strengthen our important public trust protections, which affirms that water is a public resource that belongs to Michiganders and not to corporations or profit-takers' (WIMS, 2008). Several environmental groups were also concerned that the final lines demarcating zones might allow too much water to be removed before an ARI could be determined. Importantly, these groups were not attacking the basic scientific framework, but instead were dissatisfied with policy outcomes that were chosen from among a range of regulatory alternatives resulting from the science. Even in negotiated processes (Wondolleck & Yaffee, 2000), where diverse stakeholders work together collaboratively to resolve natural resource management challenges, not all social value positions will be satisfied.

The Council recognized that the determination of societal values vis-à-vis groundwater withdrawal was outside the mandate of their charge. However, the Council did provide a science-based framework within which an informed discussion of societal values could occur. The Council made a concerted effort to ensure the scientific basis for the water withdrawal assessment process was as defensible as possible, and worked to keep the science separate from the social values debate. Several factors accounted for a successful process:

- inclusion of scientists on the Council itself (Table 1) and the use of agency scientists in the development of the models; there was also an explicit expectation that the science-based components would undergo rigorous peer-review (Hamilton *et al.*, 2008; Reeves, 2008; Reeves *et al.*, 2009; Zorn *et al.*, 2008);
- public unanimity of the scientists; although there was debate within the scientific working groups on technical issues, the scientists were in agreement on the major principles. This was reflected in their presentations to the Council, public, and legislature. This resulted in greater buy-in from these groups;
- the formation of an external Science Review Panel to critique the Water Assessment Tool. This four-member panel consisted of an expert in instream flow standards (Hal Beecher), an ecohydrologist (LeRoy Poff), an aquatic ecosystem modeler (Joe DePinto), and a hydrogeologist (Bill Woessner). Their report states: 'The Science Review Panel views the overall goals and approach used by the Groundwater Conservation Advisory Council to develop a science based screening tool as progressive…We are impressed with the conceptual approach and scientific rigor used to develop linked groundwater-surface water-ecological models that form the basis of the assessment tool' (Science Review Panel, 2006);

- repeated briefings to the state legislature. This not only allowed members to be updated on the progress of the Council, but also provided regular feedback to the Council members, helping to keep the process grounded in policy needs.

No process is perfect, and in addition to its successes, the formation and operation of the Council could certainly be improved. Areas for improvement include:

- a more inclusive Council membership. The original composition of the Council, while designed to be representative of all state interests, had a limited membership. Stakeholders now represented on the new Water Resources Conservation Advisory Council that were not represented on the original councils, include native tribes, riparian organizations, business and manufacturing, Office of the Attorney General, anglers, and tourism;
- a more inclusive charge. The focus of the enabling legislation was groundwater, largely because of growing pressures associated with water bottling plant activities. In retrospect, a more holistic approach to water resources, including all groundwater and surface water resources, would have made more sense both in terms of water sustainability and potential conflicts;
- information exchange among Council members. Perhaps inevitably, some Council members were more engaged in the technical aspects of the work than others. Considerable effort was expended to avoid jargon and engage all Council members, but there was a clear separation in the degree of involvement between the more and less technically trained members of the Council. This did not hinder the process, and in some respects may have actually assisted it, but limited input from some Council members may have resulted in some interests being less represented than originally intended;
- technical agreement among Council members. Not all Council members were in agreement regarding where ARI occurs or on the role of mitigation. As might be expected, those members representing environmental and conservation interests tended to seek more conservative withdrawal standards than members representing business and agriculture. This did lead to some friction, especially as final recommendations were being developed. Nonetheless, the previous 5 years of working together, exchanging information, and consensus building helped to ease tensions.

Epilogue

The State of Michigan has adopted a progressive approach to deal with existing and future potential water conflicts. Although the Water Withdrawal Assessment Process and the Screening Tool are still works in progress, a science-based framework has been statutorily recognized and enabled, allowing for the process to be both rigorously assessed and enforced. Several critical elements aligned themselves, allowing for Michigan to adopt this proactive approach. Application of these or similar elements may allow other states or units of government to determine the transferability of this approach to their location.

First, there was broad, nearly unanimous regional interest in protecting the water resources in the Great Lakes. Commitment to the Compact required the Great Lakes states to implement various measures to protect and conserve the waters of the region.

Second, increasing media attention to real and potential water conflicts helped raise the visibility and public awareness of the issue. This involved both the perceived threat of water diversions from the

Great Lakes as a whole (Annin, 2006), as well as groundwater withdrawal for bottled water facilities. Without public awareness and interest, it would have been far more difficult to engage the legislature.

Third, this process had a strong champion in the Michigan legislature. Senator Patricia Birkholz had an established reputation as being fair-minded and centrist in her policies; her credibility was advantageous when advocating for this legislation. She also sought out scientific advice when crafting legislation with her colleagues. Many of the members of the Council had substantive input to both pieces of enabling legislation. This helped ground the legislation in scientific principles and language, and supported the perception, to outside interest groups and other legislators, that the process was not being overly influenced by one particular sector.

Fourth, a considerable amount of scientific information was already available, thereby both reducing the state's upfront costs and expediting the development of the tool. Given that most, if not all, states have comprehensive aquatic monitoring programs, the basic approach of this water withdrawal assessment process should be transferable elsewhere.

The process was not perfect. Not all Council members were in complete agreement on the final recommendations, although they reached consensus in the end. In addition, legislative timelines rarely coincided with the timelines that the scientists believed were necessary to complete their analyses. As a consequence, some analyses were hurried, some analyses were not completed at all, and others were partially finished. Nonetheless, the development of this process and its accompanying Screening Tool was accomplished within five years. Though the scientific community hoped for more time to study critical issues and hone the results, the process that was enabled in the legislation also includes a periodic review cycle that is a hallmark of an adaptive, science-based approach to natural resource decision making and management. Science cannot make the final resource decision, but it can inform the debate and establish boundaries by clearly articulating the impacts of proposed actions.

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