WATER USE DECISION-MAKING IN SOUTHWEST MICHIGAN

By

Jennifer Lai

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

Sociology—Master of Arts

2016

ABSTRACT

WATER USE DECISION-MAKING IN SOUTHWEST MICHIGAN

By

Jennifer Lai

Groundwater management has become an increasing concern specifically in terms of global freshwater scarcity. Because most scholarship focuses on groundwater management in arid areas, less is known about groundwater regulation in water-rich areas, which are usually put in place to prevent regional water resources from being transferred elsewhere. This paper will use a hydrosocial cycle analysis to better understand the role of embedded power dynamics within such regulations. In southwest Michigan, where scientists and farmers are engaged in conflict around regulated groundwater use and management, I find that differences in how water is represented within the knowledge systems that these two communities operate by have led to power being exchanged in both overt and covert forms. Specifically, power exerted through knowledge has created conflict at multiple levels, extending beyond epistemological considerations and into social and political realms. As such, understanding how power contributes to conflicts over water, even in water-rich areas like Michigan, can help identify what needs to be addressed before consensus-building strategies around sustainable groundwater use take place.

To my mother Wai Wong-Lai, my father Wing Tak Lai, my beautiful sister Chelsia Lai, my aunts Wai Lin Wong and Wai Wan Wong, my uncle Tak Ming Wong, and my grandparents Shui Shiu Wong Ma, Kui Wong, Swee Yung Poon, and Man Keung Lai.

ACKNOWLEDGEMENTS

Many thanks to my committee, Dr. Stephen P. Gasteyer, Dr. Jennifer S. Carrera, Dr. Thomas M. Dietz, Dr. Aaron M. McCright, my "PhD bestie" Brittany Tucker, and my colleagues at the Institute of Water Research.

PREFACE

"Water scarcity throughout the world – and even in parts of the Great Lakes region – will put mounting pressure on one of the most abundant freshwater ecosystems on earth. One could argue that the era of the Great Lakes water tension has already begun."

Peter Annin, *The Great Lakes Water Wars*

"Michigan's very name is rooted in the Ojibwa (Chippewa) word for "large lake," and its handprint on the earth, the mitten-like Lower Peninsula and jagged-edged Upper Peninsula, is shaped by four of the five Great Lakes....Carved by glaciers more than 12,000 years ago, the Great Lakes regions are the planet's largest bodies of freshwater which are visible from the moon and instantly recognizable on any globe or atlas."

Pure Michigan website, "Land of the Inland Seas"

TABLE OF CONTENTS

INTRODUCTION

Its unique location among the Great Lakes has reinforced Michigan's reputation as a water-rich state. Yet issues related to the management of these waters connect Michigan to a broader story of sustainable water use. Similar issues regarding water allocation and management exist in California and with the Ogallala Aquifer in Nebraska. Likewise, issues engendered by unsustainable water use have also occurred in Arizona and New Mexico, and in Florida and Georgia. Unlike Michigan, these issues are usually framed as conflicts that occur within the context of water scarcity. What is shared across all aforementioned examples is an easy recognition that water is an important resource – perhaps the most important resource – and thus ought to be used wisely and sustainably. At the same time, conflicts still emerge around how to accomplish this.

In southwest Michigan, one form of this conflict specifically involves groundwater use, and how sustainable groundwater use should be achieved. Within this conflict, two major communities represent two different approaches: water scientists and researchers, and agricultural producers. Concerned with protecting water resources for long-term use, water scientists and researchers have attempted to assist local water managers by providing them with scientific modeling tools. Conversely, agricultural producers have argued that continuing the present rate of groundwater use is the only way to ensure that their farm enterprises can continue to operate and expand. Given this, I explore the question, why is there conflict around issues of groundwater use in southwest Michigan? If there is a shared sense of the enormous stakes surrounding the retention of groundwater in the region, why do such conflicts still persist?

My analysis will use political ecology, and in particular, the hydrosocial cycle, to analyze the presence of power within these struggles over water. Water, being necessary for life, is in many ways the ideal venue to form an understanding of how power is imposed and exchanged within society. In other words, struggles over water are struggles over power. After discussing the pattern of conflicts and attempted resolutions over groundwater use in southwest Michigan, I will use a hydrosocial cycle framework to analyze how water scientists and researchers (henceforth, “scientists”) and agricultural producers (henceforth, “farmers”), impose and exchange power through contestations over water management practices, with each side reinforced by certain discourses, conceptualizations, and cultural understandings of water itself. Using project documentation from the most recent water use management tool alongside interviews from farmers, I will show how even when compromise is the intended goal of both parties, struggles over water – and thus, over power – will disrupt the consensus-building process.

Such conflicts over water and power are likely to become exacerbated as uncertainty over water availability increases due to changing conditions under climate change. As such, the question that I explore in this paper may also offer insights into what issues need to be addressed before more successful strategies intended to mitigate the effects of climate change on groundwater availability can be developed.

EFFECTS OF GROUNDWATER AVAILABILITY ON FARMERS

Traditionally, conflicts over natural resources have been approached as an issue of unequal access. It was not until the late 1980s that the effects of environmental factors themselves, including the effect of resource depletion, became more salient within sociological scholarship (Albrecht 1988:145). Albrecht (1988) initially found that in areas with limited and depleted water resources, a decline in the number of irrigated acres in the Great Plains would follow (Albrecht 1988:145). Following theories in environmental sociology and human ecology, Albrecht and Murdock (1986a) used quantitative methods to test the effect of limited or constrained access to resources on social populations, specifically the effect of groundwater availability on the nonmetropolitan areas of the Great Plains (Albrecht and Murdock 1986a:380). The authors found that having enough groundwater to permit extensive development of irrigation practices resulted in major social and economic responses, including increased agricultural production and farm restructuring (Albrecht and Murdock 1986a:392). Specifically, irrigation was revealed to be a technological innovation that not only enabled farmers to use groundwater more efficiently, but also led to an organizational restructuring of traditional farming operations, and also coincided with notable population trends in rural areas (Albrecht and Murdock 1986b:498). And yet, even thirty years ago, unintended effects of these technological modifications were also being foreshadowed (Albrecht and Murdock 1986b:499). For example, after conducting their studies, Albrecht and Murdock (1986a) concluded that "the initial abundance of a natural resource, coupled with the technology needed to make use of it, [would lead] to social changes [that would] gradually deplete the resource" (Albrecht and Murdock 1986a:393).

Albrecht (1990) was particularly sensitive to resource depletion issues due to farmers in northern Texas drawing their irrigation waters primarily from the Ogallala Aquifer (Albrecht 1990:46). Examining how farmers responded to the depletion of groundwater from the Aquifer, Albrecht (1990) found that in general, farmers reduced their irrigation in response to declining water supplies (Albrecht 1990:46). Among the farmers who adopted less expensive forms of water conserving technologies, most represented smaller operations where groundwater supplies were not as bountiful (Albrecht 1990:46). Conversely, farmers who installed more expensive irrigation technologies such as center pivots typically represented larger farming operations and had access to more abundant groundwater supplies (Albrecht 1990:46). In short, farmers varied in their investments on water-efficient technologies depending on how much groundwater was available, and how large their operations were[1].

As such, relationships between resource availability and farming structures are rarely straightforward. Certain perceptions of abundant groundwater resources can lead an increased use of said resources, with the decisions driving the usage being difficult to reverse. While investigating what factors influenced farmers' attitudes on groundwater pollution in Ohio, Napier and Brown (1993) found that farmers were unlikely to adopt new production practices that could protect groundwater from being contaminated if adopting such practices, such as reducing chemical applications, threatened the economic well-being and viability of their farm enterprise (Napier and Brown 1993:438). However, within the same study, environmental concern and worry for family health drove other farmers to adopt the same conservation practices (Napier and Brown 1993:438). Notably, farmers with more environmental concern tended to see themselves as less knowledgeable about groundwater pollution (Napier and Brown 1993:438). This coincides with Lichtenberg and Zimmerman's (1999) findings, in which the farmers in their study were willing to increase farm expenditures in order to prevent the leaching of chemicals into groundwater resources (Lichtenberg and Zimmerman 1999:840). Both concern for environmental quality and the desire to enhance family safety were interpreted as motivating these decisions (Lichtenberg and Zimmerman 1999:840). Ultimately, it is not clear whether social factors or economic realities are more influential on farmers' perceptions of groundwater quality and availability, or whether the "choice" between them is, in fact, a false dichotomy.

---

[1] Such patterns have strong relevance to the farmers in southwest Michigan. Throughout its history, Michigan has had a reputation for being agriculturally productive. Before 1900, indigenous producers, as well as German, Dutch, and Finnish settlers, cultivated numerous crops, including potatoes, celery, and winter wheat. However, after the Industrial Revolution transformed traditional agriculture into a largely mechanized, science-driven industry, specialized crops took hold of Michigan's diverse soils, topography, and climate. Potatoes became concentrated in the sandy soils to the north, while soybeans, seed corn, and other profitable vegetables flourished in the southwest part of the state. In general, increased specialization and the use of scientific technologies such as irrigation to manage inputs and other farm activities have led to there being fewer and larger farms, as smaller farming operations get outcompeted by larger, more profitable operations (Michigan State University 2016). Knowing this context helps with understanding the current distribution of farmers, as well as why they might use the technologies that they do.

What remains clear is how, when left to their own devices, farmers are prone to innovate in response to natural resource challenges, including issues related to the quality and quantity of groundwater (Buechler and Mekala 2005:433). Of course, farmers are rarely left to their own devices. Groundwater use decision-making tends to be a collaborative effort, involving many other stakeholders. For example, while findings from Ward et al.'s (2016) study revealed a strong potential for rural Indian farmers to self-govern well usage, using strategies that could also avoid negatively impacting household wellbeing or local groundwater resources, the deeper implication is that groundwater management requires some form of consensus at a social level. Similarly, in Victoria, Australia, Gill et al. (2014) found that high levels of trust between irrigators and water management agencies had a positive effect on the farmers' amenability to sustainable groundwater management strategies. With the agencies' facilitation, farmers were able to identify the need for clear, technical explanations for management decisions, including a specific need for comprehensible, "good" data on groundwater usage and aquifer levels (Gill et al. 2014:83). Past exposure to usage restrictions, recent experiences of drought, and the ability to individually refine conservation strategies also influenced the viability of sustainable groundwater management for the farmers (Gill et al. 2014:83). Indeed, Gill et al. (2014) speculated that the irrigators' responses in their study would be difficult to replicate in other areas of the world, given the specific social, cultural, and historical positions occupied by groundwater irrigators and managers in northern Victoria (Gill et al. 2014:83).

Farmers will therefore not only respond to adversity in groundwater quality and availability (Buechler and Mekala 2005:433), but also to actions put forth by other water managers and state actors (Birkenholtz 2007:466). For policymakers interested in extending the life of available water resources, conservation techniques are often embedded in or become the primary focus of revised or new policies (Wang et al. 2015:27). Yet policymakers are often not exposed to the same social or economic factors that influence farmers' perceptions about groundwater availability, nor their decisions about groundwater use. Instead, from the state's perspective, farmers often seem to be acting against their own interests, in addition to broader social interests (Loch et al. 2014:5). For example, Janakarajan and Moench (2006) show how the expansion of groundwater-fed irrigation in Tamil Nadu, India has led to increased degradation of the water source, yet the high demand for groundwater has not even begun to cease (Janakarajan and Moench 2006:3977). Even the use of water conservation technologies, when coupled with certain farm conditions, does not always produce the intended effects (Batchelor et al. 2014:140). Batchelor et al. (2014) argue that adopting water conservation practices to improve efficiency, productivity, and profitability on the farm can actually encourage farmers to increase irrigated areas. While this may lead to increased crop yields, paradoxically, it also leads to more consumptive water use (Batchelor et al. 2014:140). Likewise, Wang et al. (2015) suggest that regions that require high pumping costs from the water source do not save water insofar as they actually encourage farmers to take advantage of new, more efficient technologies in order to pursue increased profits (Wang et al. 2015:38). Though the state may try to reach out to farmers in the spirit of collaborative conservation, confusion where water is "saved" at the farm-level or watershed scales (Batchelor et al. 2014:140) may also contribute to a misunderstanding of where conservation interventions from groundwater management agencies ought to take place.

Coinciding with these studies, issues surrounding at what scale groundwater conservation should occur, in addition to whether or not conservation measures even need to take place due to perceptions of technology preserving the abundance of groundwater resources, are likewise present in southwest Michigan. It should also be noted that many of these studies, while being able to convey important findings, were also conducted quantitatively, which meant that the nuance in the positions taken by the farmers and other stakeholders were often left unexplored. Likewise, the role of power and knowledge in shaping the circumstances of each study, with the exception of Birkenholtz (2007), also remained unexamined. As such, in this study, I applied the hydrosocial cycle in combination with qualitative methods to better understand how farmers' and scientists' knowledge of groundwater availability and management are constructed and reinforced, and how they interact to shape the perception and status of groundwater conservation in Michigan today.

THE HYDROSOCIAL CYCLE

The hydrosocial cycle is grounded in the idea that a society/nature dualism does not exist (Schmidt 2014:221). Indeed, without water, society would cease to exist. Thus water flows throughout society so that both become woven together into a mutually-determining, dialectical relationship, or what Swyngedouw (2015) calls a "hybrid" existence (Swyngedouw 2015:19). Viewing relations between water and society as a dialectic is different from adding "social dimensions" to the management of water use (Budds and Linton 2014:167) – a technique that is often popular within modern hydrology. Instead, a hybrid depiction of water and society requires acknowledging the constructed nature of water (Swyngedouw 2015:21). As people struggle to maintain their access to water, usually in reaction to others who are trying to do the same thing, power is imposed and exchanged. That is, power is inherent within their struggle, as meanings and definitions associated with water are produced and reproduced anew. Consequently, water has the ability to organize society, and also be acted upon by society in turn.

The hydrosocial cycle thus provides a framework for analyzing how power exists in daily life, specifically through the investigation of interactions between water and society. Using water, which is vital for life, as a venue to examine where power flows throughout society also generates a profound statement on how society can be governed by diffuse, as opposed to consolidated, forms of power (Swyngedouw 2015:23). Such diffuse forms can be so ubiquitous and integral to our lives that the imposition of power itself can often be unintended and unexamined. Power discussed within the hydrosocial cycle is therefore not only the ability to impose one's will in order to influence the action of others using overt and obvious forms of power, but is also understood to be something that can operate in hidden, taken for granted ways.

It is therefore when conflicts emerge in society that an opportunity presents itself to study power in more distinguishable and oppositional forms. Yet power should not only be discussed in the context of interactions between powerful and disenfranchised actors who struggle over material forms of water. Under the hydrosocial cycle, power also has the potential to incite conflict by challenging the way we think and act. It exists in the ways we define and talk about water, in the cultural meanings we associate with water, and in the dominant discourses and systems of knowledge that ultimately form certain conceptualizations of water. Over time, power consolidates behind specific definitions of what water is, how it is known, and why it is important (Budds and Linton 2014:179), forming a "hydrosocial territory" (Boelens et al. 2016:3). Such territories connect individuals to broader networks of water and power, which individuals can then contribute towards or resist (Loftus 2009:959). The hydrological cycle can be seen as one example of a hydrosocial territory, in which water is known by a discrete, apolitical, and asocial definition of H_2O (Schmidt 2014:221). Throughout history, hydrological discourses that have depended on mathematical and chemical reductions of water have been paired with state and scientific rationalities in order to displace and dispossess other claims and articulations of water (Schmidt 2014:221).

The story of southwest Michigan is not quite one of dispossession and displacement, but elements of the hydrosocial cycle still lie at the heart of the conflict between scientists and farmers. In short, two knowledge systems are coming into contact, and imposing and resisting each other's ideas about groundwater use and management. Their conflict thus goes beyond a hydrological struggle over water, and instead, ought to be analyzed as a hydrosocial and sociological struggle over power. Indeed, using the hydrosocial cycle to better understand conflicts that occur over water taps into the unique tension that occurs as a consequence of water moving life forward, in countless ways, for everyone.

GROUNDWATER MANAGEMENT IN MICHIGAN

Prior to 2003, groundwater use in the state of Michigan was more or less unaccounted for. Yet concerns over groundwater became a priority when disputes between high-capacity, agricultural users and domestic, small-capacity well owners began to accumulate. Steinman (2007) argues that it was the absence of a science-based policy that forced water stakeholders to use litigation as a way to resolve these disputes (Steinman 2007:2). However, litigation was not only costly, but actually led to further polarization between large- and small-capacity users (Steinman 2007:2). In 2008, the governor of Michigan signed the Great Lakes-St. Lawrence River Basin Water Resources Compact, which introduced new standards to account for both surface water and groundwater use within the state. Because the Compact was devised with the intention to prevent the waters of the Great Lakes from being diverted to other, drier parts of the country, Michigan water users now had to take stock of their contributions to the Great Lakes by regulating the flows of their inland streams and lakes, the baseflow of which came from Michigan's groundwater resources (Hamilton and Seelbach 2010:535). It was against this backdrop that the Groundwater Conservation Advisory Council (GWCAC) generated an alternative set of priority groundwater indicators, in which the indicators themselves would be science-based[2], comprehensive, and comparable across various geographic regions of Michigan (Steinman 2007:4).

Framing science-based indicators as a solution to the problems that occurred through litigation, what remained unstated was the assumption that the application of science would be apolitical and conflict-free. Regardless, the GWCAC had also suggested that numerous shortcomings existed with the use of science-based policy tools. It was implied that some indicators, such as the financial cost of groundwater use, or even the health of groundwater-dependent natural communities, could not be easily measured (Steinman 2007:6), and thus, could not meet scientific standards. As such, evoking scientific terms and strategies to instruct groundwater management did not necessarily protect such efforts from the uncertainties that could build to more widespread contention. Indeed, many of the indicators generated by the GWCAC seemed to illuminate sites of conflict to come.

[2] In other words, the indicators were explicitly quantitative (Steinman 2007:4).

With science-based policy tools, climate change also produced another layer of uncertainty. While managing water under variable climate conditions was nothing new to the average water manager (de Loe et al. 2000:164), it was anticipated that increased variability under climate change would exacerbate the "normal variability" that water managers currently operated under (de Loe et al. 2000:165). This uncertainty in the timing and magnitude of impacts on weather forced water managers to consider water management strategies and techniques that could garner benefits for both the present and future (de Loe et al. 2000:177). Such "no regrets" strategies necessitated capturing patterns of water availability and movement in the long-term, and thus produced a desire for tools that could incorporate wide-ranging spatial and temporal scales. For some scientists in Michigan, these tools took the form of science-based digital models, namely the Water Withdrawal Assessment Tool (WWAT) and the Decision Support System (DSS).

Water Withdrawal Assessment Tool

Seen as a science-based and therefore politically neutral management technique, the WWAT laid out a scientific framework to address growing concerns around unsustainable groundwater use in Michigan by defining an indicator called an adverse resource impact (ARI). Development of the ARI was informed by both streamflow standards from the Great Lakes-St. Lawrence River Basin Water Resources Compact, and recommendations made by the GWCAC to use science-based measures to monitor groundwater use (Hamilton and Seelbach 2010:534). ARIs were conceptualized on the basis of "unacceptable" impacts to stream ecosystems, with the cause of the impacts assumed to be cumulative groundwater withdrawals[3] from human activities (Hamilton and Seelbach 2010:534). These "unacceptable" impacts occurred when water withdrawals within a certain area exceeded the maximum amount of water that could be withdrawn before fish populations began to be negatively impacted (Hamilton and Seelbach 2010:535).

Thus the response of fish populations to reductions in streamflow, seen as a science-based indicator, acted as the major computational unit of the WWAT, which ultimately took the form of an online screening tool built using Geographic Information Systems (GIS) software (Hamilton

[3] Using reductions in streamflow to measure groundwater withdrawals were considered appropriate because the two systems were seen as hydrologically linked.

and Seelbach 2010:537). Individual water users could use the WWAT screening tool to evaluate whether or not their proposed large-scale water withdrawals[4] would generate an ARI. If a proposed withdrawal did not generate an ARI, then a permit was issued for the water user to proceed with his or her project. However, if a proposed withdrawal did generate an ARI, then the project was halted, and a more detailed evaluation process in the form of a site-specific review would need to be completed before the project could resume.

In short, the WWAT was seen as a way to neutrally identify groundwater withdrawals that were considered unsustainable by taking into account the streamflow standards from the Great Lakes-St. Lawrence River Basin Water Resources Compact. The WWAT also adhered to recommendations made by GWCAC to define scientific measures of groundwater use as a way to monitor groundwater availability in the state. While the WWAT tool met the standards of the Compact and the GWCAC and therefore seemed to solve one set of problems, the widespread use of the WWAT soon introduced another.

Decision Support System

Not long after the WWAT was implemented, major areas in southwest Michigan were identified as being in excess of their water withdrawal budgets. A historic drought had occurred in 2012, and well applications were increasing in response to unpredictable weather patterns. Local Department of Environmental Quality offices soon found themselves as a bottleneck for site specific reviews, and thus, a source of ire for farmers, who wished to expedite well installation in order to implement irrigation on their fields and protect their crops from being dried out[5]. Rather than settling the issue of unsustainable groundwater use in Michigan once and for all, the WWAT tool had exposed a new problem; in short, a solution to the solution was needed. The DSS, which

---

[4] Large-scale water withdrawals typically existed in the form of digging a new well.
[5] The growth of the seed corn industry had prompted a number of farmers in the southwest region to install irrigation systems. A farmer could only grow seed corn under a contract, and the contract could be renewed or discarded depending on the farmers' performance. His or her performance was measured relative to the output of other farmers growing the same type of seed corn, typically within the same community. From the farmers' perspective, widespread implementation of irrigation was seen as a way to ensure a reliable and consistent water source; it also indicated how farmers had, up until the Compact, enjoyed fairly unregulated use of water resources, both in terms of surface water and groundwater. The role of the seed corn industry and other agricultural industries in driving farmers to use water as they did remained mostly unrepresented in the WWAT and DSS models.

was intended to be a non-regulatory, online informative tool, built in GIS and supported by National Institute of Food and Agriculture and United States Department of Agriculture funding, was proposed as this solution. By containing many layers of hydrological information, the DSS also allowed water users to learn about their individual impacts on current water availability, which would hopefully encourage the implementation of conservation practices as a way to make more water available in the future.

My personal entry into research on sustainable groundwater use in Michigan occurred because of my work on the DSS project. My initial task was to interview farmers and other water users in southwest Michigan to determine whether or not the DSS tool would be useful during their daily water use activities. However, upon hearing their responses, I soon came to understand that farmers conceptualized groundwater management issues quite differently from that of the scientists. In short, it seemed that farmers would not utilize the DSS as originally envisioned by the scientists. Embarking upon what Charmaz (2008) refers to as the "researcher construct[ing] throughout inquiry" (Charmaz 2008:397), I then began gathering data on the discrepancies that I observed in regards to how these two communities were discussing groundwater management as a way to understand why conflict was once again rearing its head under the DSS project. For the remainder of this paper, I will elaborate on how such discrepancies have underlaid the conflict over groundwater use in southwest Michigan under the DSS project, and how management tools like the WWAT and the DSS often perpetuate the drivers of conflict rather than resolve them.

METHODS

A hydrosocial cycle framework informed my understanding of the continuing conflict over groundwater use under the DSS project, which I now saw to be an issue of power. As such, an investigation on how power shapes and maintains discourses and knowledge systems about water, and how contestations between knowledge systems may lead to conflict between scientists and farmers, required that I acknowledge the constructed nature of the data that I was gathering (Charmaz 2008:402). Thus, qualitative techniques, which could engage with such data forms, guided my research process.

In regards to gathering data from farmers, I used in-depth interviews to gather rich data that could inform my understanding of the processes behind the production of knowledge systems within specific communities, and how they interacted to produce conflict. In general, in-depth interviewing allows researchers such as myself to understand the experience and meanings that research participants attribute to certain social situations or circumstances (Hesse-Biber 2014:192). In other words, in-depth interviewing can extract subjective understandings, which the researcher can then piece together in order to interpret and ultimately reconstruct how her research participants make sense of the world (Becker 1998).

I used a semi-structured interview technique with open-ended questions structured through an interview guide; the interviews themselves were conducted conversationally. Using an interview guide ensured that while relevant topics were covered, opportunities remained for research participants to offer more information beyond the interview guide. I chose to use an interview guide due to the structure that it offered, since such a structure allowed responses to be compared and contrasted across interviews during the analysis phase (Hesse-Biber 2014:187). It is also important to note that the interview guide did not contain questions that would prompt interview participants to reveal any personal information. Early on, I had made the decision to secure the participants' comfort with contributing potentially sensitive information on the research topic by excluding such questions.

After completing the interviews, I transcribed them with the help of two research assistants. I then coded and developed concepts that emerged from the transcriptions. New data was collected and incorporated as new ideas and questions emerge throughout the research process (Charmaz 2008:408). As such, I also coded and built concepts from DSS project documentation that, when compared to emergent concepts from the farmers, allowed me to understand the conflict around groundwater use in greater depth.

Data

Taking into account my initial task to investigate the amenability of the DSS in southwest Michigan, I initially conducted interviews with forty water users. These users occupied a diverse range of professions, and included municipal representatives, water conservation non-profit employees, agricultural producers, and commercial business owners. However, the DSS tool was primarily intended for the same group of water users as that of the WWAT, in other words, "large-quantity" users. As such, the findings that come from my interviews and are reported in this paper will feature exclusively large-quantity users, all of whom were white, male farmers who grew primarily seed corn, commercial corn, and/or soybeans. I conducted seventeen interviews with farmers in total.

I initiated contact with farmers through the Farm Bureau. After presenting information on the DSS project at local Farm Bureau board meetings, I would then request a list of potential interview participants from those in attendance. Upon receiving these lists, I would contact potential interview participants no less than two weeks in advance of a proposed interview date. I attended Farm Bureau board meetings for Calhoun, Hillsdale, Jackson, and Van Buren counties. The interviews themselves took place between May and August 2015, across Berrien, Branch, Calhoun, Cass, Kalamazoo, Hillsdale, Jackson, and St. Joseph counties. Each interview lasted approximately 30 to 90 minutes.

Having collected data on how groundwater was discussed and utilized as part of daily life for farmers, I then located data on how knowledge of water was represented by the scientists. I did this by referring to project documents in the form of the original grant proposal for the DSS, along with other reports and presentations that were generated as the project moved forward. This data was later coded alongside the interviews; the concepts that emerged shed further light on the situation in southwest Michigan.

RESULTS

Under a hydrosocial cycle framework, power can shape knowledge systems and likewise, consolidate behind certain conceptualizations of water. When different knowledge systems come into contact, conflicts may emerge, encompassing a struggle not only over material forms of water, but also over power. In southwest Michigan, these knowledge systems can be understood by following the process by which water flows throughout the social settings provided by the scientists and farmers. Detailed descriptions[6] (Becker 1998) of the treatment of groundwater by these two communities are provided below.

Water flowing through scientific communities

According to the original grant proposal, the primary purpose of the DSS is stated as being the integration of a "diverse set of models and processes" into a single tool intended to "aid water managers and agricultural producers in futuristic planning for agricultural water uses" (Bartholic et al. 2013). The presence of water in this description is implicit rather than explicit; likewise, "water use" is presented as a unidirectional, human-driven activity that is enacted upon water; there is no mention of how water may also be reactive to human activities. This representation of water suggests that the scientists do not consider themselves as water users. Instead, the grant states that the scientists' role is to integrate information within the DSS in order to encourage "sustainable water strategies within communities and policy decisions under varying climatic conditions" (Bartholic et al. 2013). The grant further implies that by using the DSS tool, individual water users can better understand the impending uncertainty that climate change represents, and adjust their water strategies accordingly. As such, it is the scientists who will ensure that the DSS can provide enough information to facilitate and transform current water management strategies into more sustainable ones.

This assumption that the individual is the key water actor, and therefore, the scale at which change should occur as a first defense to the risks associated with climate change, is common

[6] Detailed descriptions utilize a presentational form (Taylor 2004:74) that can show, rather than tell, how water moves throughout the scientific and agricultural communities. Such a technique has the advantage of allowing the reader to see for him or herself the discrepancies that exist between them.

throughout DSS project documentation. One example of this individualization of responsibility to mitigate against climate change comes from a script that was written to promote services offered by the institution that employed the scientists. The script described Michigan as being “lucky” to have the largest supply of freshwater in the world. Yet such a supply would not “last forever,” and if individuals were not careful, the waters would “become unusable quickly.” The script then declares, “By making simple changes to your life, you can help improve our water quality and conservation.” Later, the WWAT and DSS are mentioned as tools that are “easy to use” and that can “give you the knowledge to make smarter water decisions.” This section of the script then ends by stating, that “[the scientists are] planning for your water future by supplying these online tools...now it’s your turn to use them.”

In other words, according to these documents, the scientists are designing tools intended for individual users to make changes to their water use practices, which remains consistent with the belief that cumulative changes can effectively mitigate against any severe risk to regional water systems, including those that occur due to climate change. Such a belief parallels the logic behind the WWAT tool, in which cumulative withdrawals within a certain geographic area are predicted to have an impact on streamflow, and subsequently, fish populations. To prevent these impacts (i.e. ARIs) from occurring, DSS documents frame the role of the scientists as being able to provide specific and highly specialized types of water knowledge to individual users so that they can still continue to use water, but do so after being informed of ways to minimize the risk of an ARI.

This is not to say that the creation of these tools occurs within a structure of top-down decision-making. On the contrary, statements from the grant proposal convey a genuine desire to incorporate input from water users who remain their target audience: large-quantity users, and in this case, farmers. Supporting objectives of the DSS are stated as being able to work “interactively” with water users to understand and assess how “future climate change” will affect water management strategies and shed light on possible options for future climate scenarios (Bartholic et al. 2013). As such, the design of DSS is also meant to be ongoing and dynamic in that information on “actual climate conditions and water demands” can be continuously updated and incorporated. Further, the framing of these objectives include asking "farmers, local water users committees, the States' Water Use Council, and other existing water planning efforts" to assist in providing information and updates to the DSS. Indeed, several user groups -- which include drain commissioners, lake associations, producers, watershed groups, and community planners -- have been identified as key contributors of the DSS design process, most notably at the "prioritizing system requirements" and "evaluation" stages (Asher 2016:4).

Even though an interest to incorporate user input was established (Asher 2016:3), descriptions of the data needs of the DSS do not indicate much room for other forms of water knowledge beyond scientific ones. Project documents indicate that the DSS "system requirements" (Asher 2016:3) begin with a process to "digitize," or digitally represent a watershed. As such, generating a watershed requires a number of overlapping data layers, including information on the locations of groundwater inlets and outlets, surface runoff, recharge rates, and baseflow data. Rainfall data is added using measures of intensity, timing, and trends, along with heat units and recent precipitation – the latter of which is also meant to represent the use of irrigation. Land use and land cover is accounted for using pollutant load estimates, quantities of nutrients and sediment, runoff volumes by parcel, and habitat and cropping changes. The information that these layers contain are activated when a user wishes to evaluate a proposed water withdrawal; after drawing a watershed boundary and specifying the "output parameters," "date range" and "land use changes," the DSS will generate a report containing a water budget for the user and other output trends (Asher 2016:6).

How water is represented throughout the many layers and models that make up the DSS thus supports a line of reasoning that in order to achieve sustainable groundwater use within a certain geographic area, a diverse range of information is first needed. The hydrological and technical definitions of water that are utilized, in addition to the technical descriptions of collecting, selecting, and transforming data through digital means in order to update the DSS models, standardize the purpose of the DSS across all users. In other words, due to its ability to contain hydrological information that spans enormous geographic and temporal scales, the DSS can be treated as, more or less, a universal[7] tool to predict groundwater availability. Yet this standardization also comes at a cost; namely, not all water users adhered to strict, hydrological definitions and assumptions about groundwater management, and such differences in water knowledge soon began to appear in DSS project documentation.

The constraints that scientific knowledge of water introduced to true collaboration between scientists and water users, as well as to equal representation of water knowledge within the DSS models, was aptly demonstrated in how feedback on the DSS tool was received from water user groups. Farmers had noted that the inclusion of a field-level recharge calculator, cost impacts from Best Management Practices, and real-time data on where water flows would be particularly useful. Yet documents show how the output options available from the three models that were combined to form the DSS would not be able to accommodate such requests. Other variables were available, including groundwater recharge, groundwater table change, evapotranspiration, streamflow, and corn yield, soybean yield, and irrigation change from a present-day baseline of water quantity, all of which could encompass a wide range of spatial and temporal scales and units, from inches of water, fields, sub-basins, and watersheds, and from months to decades to the next century. However, even this information could not provide field-scale measures on "rain gauge data for fields," "localized data," or "water quality impacts" as desired by the farmers. Indeed, the only major understanding that remained undisputed between both groups was the non-regulatory status of the tool itself (Reinart 2015:1).

In summary, water is represented within scientific communities in ways that allows scientists to maintain an intellectual and occupational distance from the users of the DSS tool. There is more than a little irony at work in how the scientists are intending to design a tool that they themselves will not use. While there were efforts to incorporate the input of user groups into the DSS system, such efforts were unfortunately constrained by what data and modeling capabilities were

[7] The DSS is not universal in the true sense, since it only contains hydrological information for the state of Michigan. However, users across the state are expected to use this tool to evaluate proposed water withdrawals, which brings up questions on how "fine" the resolution of the data is, and whether or not the finest resolution is actually the same scale at which water users operate and make changes to water use practices.

available using hydrological assumptions. In short, strict adherence to hydrological definitions of water, and hydrological-driven assumptions about the scope and major drivers of water use decision-making, diluted the opportunity for scientists and water users to work together to create an effective, consensus-driven groundwater management tool. The hydrosocial cycle highlights the particular challenge that comes with attempting to standardize sustainable water use practices via a statewide tool, and being unable to accommodate the specific needs of all potential users. Furthermore, because of the connection between the DSS and the WWAT, in which the former was proposed as a "solution" to the latter, even though the DSS was intended to be non-regulatory, expectations for its use closely parallel that of the WWAT. This once again replicates a conflict that addresses not only the ability to use groundwater freely, but also reproduces assumptions supported by certain knowledge systems regarding how and why water is used, and what changes water use. The hydrosocial cycle thus describes how such conflict can be an exertion of power through certain types of knowledge, which then manifest into seemingly asocial, apolitical scientific tools.

Water flowing through agricultural communities

Above all, farmers are concerned with producing a good crop. One farmer said bluntly, "If you're going to pay for the land, you have to have a good crop." Another farmer similarly stated, "If you don't have a good crop, you can't sell it, and you can't make money on something you don't have, so you've got to produce a decent crop." The costs required to produce a good crop are often characterized as self-evident; everything, from the land to the soil to the seeds, requires money. Water is perhaps the most important cost because it ensures that all the other investments do not go to waste. Therefore, water has to be carefully managed not only because of the cost required to apply water to the crops, but also the cost at stake to the farmer if he cannot produce a good crop. As such, protecting the crops, and the profits they represent, is of utmost priority.

Farmers thoroughly understand that many environmental conditions contribute to the availability of groundwater. Atmospheric pressure, time of day, crop maturity, temperature, rainfall, and other factors are typically considered before a farmer decides whether or not to apply water to their crops. Time of year was one of the more important factors, as many farmers identified certain months out of the year signaled increased applications of water. As one farmer stated, “From the middle of June until the end of July…typically an inch of rain [is needed] a week, either [from] natural rainfall or irrigation.” How the necessary inches were determined also took into account the soil types that farmers had on their property. According to another farmer, “Our soil does not have the water holding capacity that heavy ground does…On sandy ground, we can hold about an inch…So say you get three inches of rain on June 30th, you still only really have enough water for ten days, because it will not hold long.”

These observations indicate that farmers utilized hydrological and technical definitions of water, but their decisions to water are not based on these definitions alone. They also made their decisions using more practical, empirical considerations. Certainly farmers may rely on hydrological measures of water, such as atmospheric pressure, or static water levels, as part of the calculation behind where and how much water should be applied. Yet their knowledge of water is also built and rebuilt on a daily basis, based on what they encounter on their land, at the farm level. Specifically, their knowledge regarding what and when are the right conditions to water is reshaped according to how they personally experience the current humidity, heat, or wind. This type of knowledge is intimately tied to a specific time and place, and is difficult to capture in comprehensive modeling tools such as the DSS or WWAT.

Much of the southwest region is composed of sandy soils. Because of the sandy ground and its decreased moisture holding capacity, irrigation is used as a form of “crop insurance…[that can] almost [guarantee] a crop.” Irrigation therefore pairs well with the farmer’s goal to produce not only abundantly, but also save on cost, all the while maintaining the high quality of their products. From the farmer’s perspective, irrigation systems may require more wells, and may pull more groundwater at a faster rate, but they actually assist the farmer with using water sparingly; indeed, the use of irrigation is generally seen as a supplement to natural rainfall. Farmers further justify the use of irrigation by citing economic principles as a way to “incentivize” farmers from over-watering; in short, watering more costs more.

Additionally, irrigation is a “requirement to get a contract” from seed corn companies. Many farmers expressed gratitude for the presence of seed corn companies in the area, and for making what were once struggling, “relatively poor” communities into a region associated with high productivity and high agricultural value. Irrigation played a key role in this. “We wouldn’t grow seed corn if we didn’t have irrigation,” stated one farmer. Another farmer attributed the increase in wealth to both his community and the land he owns to the presence of seed corn companies. Still another stated, “We wouldn’t be nowhere without these seed corn companies, and we wouldn’t be able to have afforded the irrigation system we have built up over the years. It has got to drive the farm economy in this area.” He further explained that because the contracts are competitive, farmers must use every advantage they have to produce more high-quality seed corn for the companies. One way to gain more advantages is by digging new wells and installing irrigation systems; it would be difficult to expand production otherwise.

Even though the region has seen a significant influx in irrigation, farmers do not worry that irrigation will deplete their water resources. While they acknowledge that many people are concerned about impacts from irrigation, they believe that Michigan’s surface and groundwater sources are “very renewable.” Indeed, irrigation is often framed as a natural consequence of having a renewable aquifer; many farmers believe that the aquifers “have [not] changed even with the amount of irrigation that’s going on.” While they are certainly pumping out water at faster rates from underground aquifers in order to irrigate their crops, the water that is not taken up by the crop goes back through the soil and replenishes the underground aquifer. As such, rather than depleting the resource, farmers help keep groundwater within a local hydrological system. From the farmers’ perspective, further evidence that irrigation has had minimal impact can be found by measuring the static water levels, which, according to farmers, have remained unchanged for many years. As one farmer stated, “We don’t have a water supply issue…after all of these years of irrigation, nothing. It’s not like the Ogallala Aquifer.” Given this, farmers in southwest Michigan see their use of irrigation as a sustainable groundwater use practice.

For some farmers, it was therefore frustrating that the agricultural community did not receive recognition for their contributions to sustainable environmental practices. As one farmer stated, "Nature has a huge hand in [climate variability][8]...[meanwhile] are we recognized for owning the land and not building it into something other than farmland, where it can collect the rainwater and absorb it? That's always one of my concerns, [that] we're not credited for what we do all the time." They felt that the blame on their community was often misplaced or "misrepresented," and would point out that urban centers often used more water, or produce more contaminants, yet were able to escape the blame. Another farmer argued that "it doesn't make any sense" to willingly contaminate or use too much water, because he and his family lived here too. From the farmers' standpoint, regulations that attempted to control the quality or quantity of water available for use within agricultural communities fundamentally misunderstood what farmers prioritized in regards to their community, and what they valued about living there.

Indeed, most farmers argued that they have maximized their efforts when it comes to using groundwater sustainably. Many have made the switch from "big guns" to pivots with drop nozzles, and have adjusted their irrigation schedules so that water is put on the crops when temperatures are cooler and conditions are less windy, usually early in the morning or late at night. Overall, irrigation[9] and the use of other technologies can compensate for and respond faster to the uncertainty embedded in other factors that farmers have to regularly consider in order to produce a good crop, including weather, soil type, and crop needs. "Technology goes hand in hand with what we're doing," stated one farmer. Other farmers mentioned using technology in the form of water moisture sensors, remote sensors, variable rate applicators, and even infrared technology to better monitor crops that are sometimes spread across multiple properties and miles apart. It is

---

[8] For farmers, Mother Nature represented an unknown that could not factor into their daily water use decision-making. Therefore even when unpredictable weather events, such as drought or flooding occurred – one farmer joked that he wished the weatherman could be right from time to time – they were seen as part of a cycle, which "Mother Nature [would eventually] straighten it out." Indeed, some farmers outright rejected what they perceived to be a hubris that suggested human activities could change the environment.

[9] It should be noted that modifying equipment or irrigation schedules are not only an altruistic move; such changes are also prompted by a desire to lower the costs of production, which can help produce more crops, and likewise secure seed corn contracts. One farmer stated, "Usually when change [to the land] occurs within the agricultural community, it's money motivated." Another farmer commented, "profitability-wise, you're only going to use [water] when you need to, because it's expensive to irrigate...[it's] economics I think that drives it." Therefore a tension exists between farmers not wanting to over-apply water because of the cost of irrigation, but also needing to apply water regularly in order to guarantee a good crop, not lose profit, nor the chance to grow seed corn in the following year.

clear that technology, including irrigation, is absolutely necessary for farmers to improve the overall efficiency of their operations. As such, use of these technologies has been the most visible cultural change in the region.

In summary, water is represented within agricultural communities as a necessary part of achieving the farmers' ultimate goal: to produce a good crop. For farmers in southwest Michigan, water lies somewhere between being a commodity, and being seen as something more essential and sentimental. In general, it is only one out of many calculations that farmers must perform as they simultaneously juggle where to put certain inputs when, and consider how much each input costs. Yet the economic drivers that govern groundwater use have also incentivized farmers to install new technologies – namely, irrigation – that can extract groundwater from underground aquifers at faster rates. Farmers justify the use of irrigation by arguing that it helps them achieve several high priority yet compatible goals. It is by applying a hydrosocial cycle framework that the compatibility between these goals can be more carefully questioned. Indeed, these goals are mainly compatible in that they rely upon the same narrative of farmers somehow being able to use groundwater sustainably as they continue to produce more crops. In short, irrigation coincides with the farmers' approach to sustainable groundwater use; moving forward, farmers can only improve upon this strategy by adopting even more sophisticated water technologies. As such, this is the change to water use practices that farmers will most likely engage in; change that requires large-scale land use change is far less likely. As one farmer stated, "I think land use evolves on its own over time, through economics and use." Given these motivations, farmers are unlikely to use the DSS modeling tool[10] in the way that it was originally intended. Because change occurs for farmers under different circumstances, they are able to resist – that is, exert power against – assumptions of groundwater management as conveyed by the DSS, rendering the tool ineffective, and creating conflict.

[10] The DSS tool is currently not being used by farmers.

DISCUSSION

Analysis of written data from the scientists and interviews with farmers revealed a shared agreement that sustainable groundwater use and management should be a priority for the state of Michigan. Despite this agreement, there were significant differences in how each community viewed the problem of sustainable groundwater use, and how each community saw opportunities to change current water use practices so that more groundwater could be conserved. These differences led to a conflict that occurred not only over issues of water quantity and other material forms of water, but as revealed by a hydrosocial cycle framework, over the knowing of water itself.

The hydrosocial cycle helps us understand how differences in water representations may produce conflict via two knowledge systems that produce different water representations coming into contact. The DSS grant proposal frames the scientists as a group seen as separate from water users; likewise, their knowledge of water relies on objective, hydrological definitions of water that remain distant from any physical interaction with material forms of water. This distant, objective knowledge is useful for the task at hand: creating a groundwater management tool that can be standardized to the degree that any large-quantity water user in the state may use it to evaluate his or her proposed water withdrawal, and thus cast individual water users as agents of change in order to mitigate against future climate change uncertainty. Such a task also necessitates the tool being able to include a wide range of geographic, temporal, and hydrological information, information that can prompt water users to make changes to their water use practices in the present, so that groundwater availability will be less at risk in the decades to come.

Yet these are not the water representations that water users – in this case, farmers – operate by. Instead, farmers portray water as a necessary input used to produce a good crop; from their standpoint, groundwater is also seen as plentiful and renewable. Rather than using too much water, farmers argue that they strive to use water efficiently due to the high cost of applying water to their crops; irrigation is one way to achieve this. Relying on a more embodied form of knowledge that takes into account the environmental conditions they encounter daily on their farms, farmers are able to determine when irrigation should be utilized, as opposed to when natural rainfall should be sufficient for their crops. This embodied sense of knowing when to water extends into how farmers have interpreted static water levels as evidence of irrigation having minimal to zero impact on groundwater resources in the state. As such, farmers do not share the scientists' concern that long-term groundwater availability is at risk, and are able to reinforce their position by pointing to the physical evidence of unchanging static water levels.

What leads to conflict is a power exchange that occurs at the level of two knowledge systems coming into contact. Scientists and farmers impose and resist each other's knowledge systems by conceiving of two different approaches to sustainable groundwater use. The DSS highlights sites of imposition and resistance through its propositions of certain water representations – representations that can be synthesized by scientific models in order to execute the primary purpose of the tool. Yet examining the DSS through a hydrosocial cycle lens also reveals that the tool is mostly devoid of water representations utilized upon by farmers[11] and other water users. By extension, the social relationship that farmers have with water – in other words, what their representations and knowledge systems encompass – are plainly rejected by the underlying principle of the DSS: that changes to current water use practices ought to occur now in order to prepare for greater uncertainty in regards to groundwater availability in the future.

Farmers thus resist the assumption that long-term groundwater availability is at risk by insisting that their groundwater use activities are currently sustainable, evidence of which can be seen by static water levels remaining unchanged even as the region has seen a substantial increase in irrigated agricultural operations. As such, they will likely not use the DSS modeling tool as originally intended. Furthermore, considering how farmers had enjoyed unregulated use of groundwater up until the implementation of the WWAT tool, the DSS tool also signals a more overt expression of power to control water use in the region. Despite its non-regulatory status, DSS project documents indicated an intention to prompt change to current water use practices,

[11] This is not to say that farmers don't have blind spots. They take as given the constraints that go into making a "good crop," reifying not only markets, but the need for and desirability of seed and produce companies with whom they contract who either directly or indirectly require irrigation so that the farmers' crops meet production and distribution standards. Farmers express the belief that without such enterprises, prosperity and agricultural production would simply not be possible. Thus, for farmers, limitations on water use are limitations of the ability to live.

which did not meet scientific standards of long-term sustainability. Inadvertently, the power that was exerted through the suggestion that groundwater use was currently unsustainable forced farmers to resist by condemning tools like the DSS and WWAT as fundamentally flawed, because they would never capture the true scale of water use activities that occur on their land.

In short, the conflict that occurred between scientists and farmers at the onset of the DSS existed on several levels. Power was exchanged and resisted as different representations of water, conceived of and supported by different knowledge systems, came into contact. Power existed in the ability of the scientists to unintentionally utilize the DSS as a platform to impose scientific standards in the form of a message about groundwater conservation onto water users in southwest Michigan. Power also existed in the ability of the farmers to resist this message by relying on gathered evidence that even with an increase in irrigated land, static water levels and other groundwater flow measures have remained unchanged. Power was subsequently exchanged through the scientists' unintentional attempt to control water use in southwest Michigan via the DSS and WWAT tools and the farmers' rebuttal that the measures used to represent water use within the tools were flawed and therefore too unreliable to be connected to regulation. It is through a hydrosocial cycle framework that such power exchanges can be accentuated to understand why this conflict over groundwater has occurred in southwest Michigan, and why such conflicts may keep occurring not only within but also beyond the state.

CONCLUSION

More often than not, scientists and farmers are considered important stakeholders whose cooperation is needed to achieve sustainable use of water resources throughout the world. Indeed, they are regularly consulted with implement such strategies, and in the West, typically enjoy fair representation and recognition of their role as water decision-makers. Yet the events of southwest Michigan provide an example of how conflicts can emerge even between two traditionally important stakeholder groups. It is through the hydrosocial cycle that we understand how this conflict is rooted not only in struggles over water, but over power.

In my paper, I argued that differences in water representations conceived of by scientists and farmers formed a basis for conflict that extended beyond the epistemological realm, and into the social and political realms. On the surface, it seemed as though scientists were inadvertently attempting to control groundwater use through the implementation of tools such as the DSS and the WWAT. Farmers reacted by not using the tools as originally intended, or accusing the tools of being inaccurate and unreliable. However, to identify the roots of this conflict required examining the role of knowledge, and how power gets exerted through knowledge, within the context of groundwater management. This was done by applying a hydrosocial cycle lens. Water, being necessary for life, and therefore ubiquitous throughout society, has a role in shaping knowledge systems for all social groups. Different groups associate different meanings and definitions to water, which are reinforced through their daily encounters with material, cultural, and symbolic forms of water (Swyngedouw 2015:19). The case of southwest Michigan provides an important example of what can happen when two groups, informed by two knowledge systems, come into contact. Examining how knowledge can interact during disputes over water also allows us to bear witness to how power engages with and maintains these conflicts through many iterations. Short of southwest Michigan farmers suddenly adopting a scientific ideology, applying a hydrosocial cycle framework suggests that these conflicts will likely continue.

FUTURE RESEARCH

More investigation is needed on the role of seed corn companies and the contracts they offer; as previously mentioned, the presence of such companies introduced other constraints to farmers regarding the use of water on their land. During interviews, questions about seed corn contracts were not asked, and most farmers did not explicitly mention the contracts as an important driver of their water use decision-making, nor did they mention how contracts may have influenced on their opinion regarding the status of groundwater availability in the state. Neither were the seed corn industries represented within the DSS tool. Future studies should therefore consider how signing one of these contracts influences the short-term and long-term groundwater use decisions of farmers, thus making visible the power they impart on the story introduced here.

Beyond seed corn contracts, many other stakeholders also play a role in shaping the current status of groundwater management in Michigan. These stakeholders include other commodity organizations, including the dairy, livestock, and potato industries, agricultural input suppliers, well drillers, and non-agricultural stakeholders such as conservation organizations and commercial and municipal users. How groundwater is represented and used among these stakeholders, as well as the ways in which they interact with each other in order to influence the circumstances surrounding groundwater management in the state, should likewise be explored in future studies.

REFERENCES

REFERENCES

Albrecht, Donald E. and Steven H. Murdock. 1986a. "Natural Resource Availability and Social Change." *Sociological Inquiry* 56(3):381-395.

--. 1986b. 1986. "Understanding Farm Structure and Demographic Change: An Ecological Analysis of the Impacts of Irrigation." *Sociological Perspectives* 29(4):484-505.

Albrecht, Donald E. 1988. "Resource depletion and agriculture: The case of groundwater in the Great Plains." *Society & Natural Resources* 1(1):145-157.

Albrecht, Donald E. 1990. "The Adaptations of Farmers in an Era of Declining Groundwater Supplies." *Southern Rural Sociology* 7(1):46-62.

Annin, Peter. 2006. *The Great Lakes Water Wars*. Washington, DC: Island Press.

Asher, Jeremiah. 2015. "NIFA Decision Support System." Presented at USDA-NIFA Team Meeting, November 12, East Lansing, Michigan. Retrieved November 16, 2015.

Bartholic, Jon F. et al. 2013. "An Integrative Decision Support System for Managing Water Resources Under Increased Climate Variability." Presented at USDA-NIFA Team Meeting, East Lansing, Michigan.

Batchelor, Charles, V. Ratna Reddy, Conor Linstead, Murli Dhar, Sumit Royo, and Rebecca May. 2014. "Do water-saving technologies improve environmental flows?" *Journal of Hydrology* 518(2014):140-149.

Becker, Howard. 1998. *Tricks of the Trade: How to Think about Your Research While You're Doing It*. Chicago, IL: The University of Chicago Press.

Birkenholtz, Trevor. 2007. "Contesting expertise: The politics of environmental knowledge in northern Indian groundwater practices." *Geoforum* 39(2008):466-482.

Boelens, Rutgerd, Jaime Hoogesteger, Erik Swyngedouw, Jeroen Vos, and Philippus Wester. 2016. "Hydrosocial territories: a political ecology perspective." *Water International* 41(1):1-14.

Bouleau, Gabrielle. 2013. "The co-production of science and waterscapes: The case of the Seine and Rhone Rivers, France." *Geoforum* 57(2014):248-257.

Brown, George E. 1992. "Digital Data and Geographic Information Systems." Retrieved October 20, 2016 (https://www.loc.gov/rr/geogmap/guide/gmilldma.html)

Buechler, Stephanie and Gayathri Devi Mekala. 2005. "Local Responses to Water Resource Degradation in India: Groundwater Farmer Innovations and the Reversal of Knowledge Flows." *The Journal of Environment & Development* 14(4):410-438.

Charmaz, Kathy. 2008. "Constructionism and the Grounded Theory Method." Pp. 397-412 in *Handbook of Constructionist Research*, edited by J. A. Holstein and J. F. Gubrium. New York, NY: The Guilford Press.

de Loe, Rob C. and Reid D. Kreutzwiser. 2000. "Climate Variability, Climate Change and Water Resource Management in the Great Lakes." *Climatic Change* 45:163-179.

Gill, Bruce C., John Webb, Roger Wilkinson, and Don Cherry. 2014. "Irrigator responses to groundwater resource management in northern Victoria, southeastern Australia." *Journal of Hydrology* 518(2014):83-93.

Hamilton, David A. and Paul W. Seelbach. 2010. "Determining Environmental Limits to Streamflow Depletion Across Michigan." Pp. 534-537 in *The Book of the States*. Washington, DC: The Council of State Governments.

Janakarajan, S. and Marcus Moench. 2006. "Are Wells a Potential Threat to Farmers' Well-Being? Case of Deteriorating Groundwater Irrigation in Tamil Nadu." *Economic and Political Weekly* 41(37):3977-3987.

Lichtenberg, Erik and Rae Zimmerman. 1999. "Farmers' willingness to pay for groundwater protection." *Water Resources Research* 35(3):833-841.

Linton, Jamie and Jessica Budds. 2013. "The hydrosocial cycle: Defining and mobilizing a relational-dialectical approach to water." *Geoforum* 57(2014):170-180.

Loch, A. D. Adamson and T. Mallawaarachchi. "Role of hydrology and economics in water management policy under increasing uncertainty." *Journal of Hydrology* 518(2014):5-16.

Loftus, Alex. 2009. "Rethinking Political Ecologies of Water." *Third World Quarterly* 30(5):953-968.

--. 2010. "Thinking relationally about water: review based on Linton's What is water?" *The Geographical Journal* 177(2):186-188.

Michigan State University. 2016. "History of Agriculture in Michigan." Retrieved December 5, 2016(http://geo.msu.edu/extra/geogmich/ag_history.htm)

Napier, Ted L. and Deborah E. Brown. 1993. "Factors affecting attitudes toward groundwater pollution among Ohio farmers." *Journal of Soil and Water Conservation* 48(5):432-439.

Pure Michigan. 2016. "Land of the Inland Seas." Retrieved October 26, 2016 (http://www.michigan.org/michigan-s-great-lakes/land-of-the-inland-seas/).

Reinart, Emily. 2015. "Additional Information for the Allegan County Farm Bureau Board of Directors. Provided by Michigan Farm Bureau and MSU IWR Project Team." Presented at USDA-NIFA Team Meeting, July 2015, East Lansing, Michigan. Retrieved July 2015.

Schmidt, Jeremy J. 2014. "Historicising the Hydrosocial Cycle." *Water Alternatives* 7(1):220-234.

Steinman, Alan. 2007. Report to the Michigan Legislature on: Recommended Criteria and Indicators of Groundwater Sustainability for the State of Michigan. Presented on behalf of the Michigan Groundwater Conservation Advisory Council.

Swyngedouw, Erik. 2015. *Liquid Power: Contested Hydro-Modernities in Twentieth-Century Spain*. Cambridge, Massachusetts: The MIT Press.

Taylor, Steven S. 2004. "Presentational form in first person research: Off-line collaborative reflection using art." *Action Research* 2(1):71-88.

Wang, Tong, Seong C. Park, and Hailong Jin. 2015. "Will farmers save water? A theoretical analysis of groundwater conservation politics." *Water Resources and Economics* 12(2015):27-39.

Ward, J., M.E. Varua, B. Maheshwari, S. Oza, R. Purohit, Hakimuddin, and S. Dave. 2016. "Exploring the relationship between subjective wellbeing and groundwater attitudes and practices of farmers in Rural India." *Journal of Hydrology* 540(2016):1-16.