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Sustainability of Surface and Subsurface Water Resources: Case Studies from Florida and Michigan, U.S.A.

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The United Nations designated 2003 as the International Year of Freshwater, in part to increase human awareness of the declining state of the freshwater resources throughout the world. Projections of freshwater availability from 2000 to 2025 indicate that global water scarcity (<1,000 m^3/person/yr) will increase from 3% to 7% while water stress (1,000 to 1,700 m^3/person/yr) will increase from 5% to 31% (Gleick et al. 2002). Given that freshwater lakes and rivers contain less than 0.01% of all water on earth (Cech 2003), it is imperative that the sustainability of the planet's freshwater resources becomes more deeply ingrained in human culture and actions.

Sustainability of freshwater resources requires both a holistic approach to water and recognition that no matter how rigorous the science available to back up resource management recommendations, the political arena strongly influences what will, and will not, get done. A holistic view of fresh water recognizes both that surface water and ground water are connected and that they should be treated as a single resource (Winter et al. 1998). This has implications for both water supply and water quality. For example, ground water withdrawals can result in reduced flows to streams and alter wetland hydrology, potentially impacting biotic resources and ecological processes (Poff et al. 1997; Richter et al. 2003). In addition, ground water quality can be affected if withdrawals bring water levels below the aquifer's confining layer, or by inducing water of poorer quality into an aquifer (Grannemann et al. 2000).

Sustainable management of freshwater resources requires the balancing of needs from the natural, social, and economic sectors of our society (Gleick 1998; Baron et al. 2002). The political environment can greatly influence the allocation of these resources, and whether the balance is tipped in one direction or another. Science can play an important role in the debate over competing demands for water resources (Johnson et al. 2001; Steinman et al. 2002b), although clearly science too can be co-opted as part of the political process, as is being evidenced in the Klamath basin of Oregon (cf. *Science* 2003 300: 36-39).

In this paper, we present case studies from Florida and Michigan that focus on water resource sustainability. Both of these studies are taking place in politically charged environments, where decisions are being made under media scrutiny. Despite differences in their geographic location, two common themes emerge: 1) surface water–ground water linkages are critical elements for the present and/or future sustainability of these systems; and 2) science is playing a role in the structure and language of state and federal legislation, which in turn, is influencing resource management decisions in these systems.

South Florida

The aquatic landscape of south Florida extends from the headwaters of the Kissimmee River in the north, through Lake Okeechobee in the center, to the Everglades in the south, and empties into Florida Bay at the southern terminus. Although the initial attempts to alter the hydrology of this region began in the late 1800s, it was the Central and South Florida Project for Flood Control and Other Purposes, which began in 1947, that resulted in the greatest changes. This Project, authorized by the U.S. Congress in 1948, provided the U.S. Army Corps of Engineers funding to build levees, pump stations, and flood control structures. When combined with the projects to channelize the Kissimmee River and construct a dike around Lake Okeechobee, the engineering efforts in south Florida were designed to disconnect the natural flow patterns in an effort to enhance both flood control and agricultural production (Advisory Committee 1944; Steinman and Rosen 2000; Steinman et al. 2002a; Sklar et al. 2001).

Today, water resource managers face a dilemma given the competing demands for water in south Florida as well as the recognition that natural systems also have a claim for water quantity (amount and timing) and quality. To meet these demands in light of continued population growth in the region, an overarching, multi-decadal restoration program for the south Florida hydroscape is currently being implemented. This restoration effort, known as the Comprehensive Everglades Restoration Plan (CERP), consists of more than 60 major elements at an estimated cost of $8 billion. The major goal of CERP is to improve the timing and distribution of water throughout the region. Instead of discharging over 1.7 billion gallons of water per day to the oceans, a series of projects will attempt to save the water either above or below ground.

One of the key elements of CERP is the use of aquifer storage and recovery (ASR). The proposed ASR project involves injecting up to 1.6 billion gallons per day of treated surface water into the slightly saline Upper Floridan aquifer, during periods of high rainfall and surface water runoff, and then recovering the water during periods of water deficit. The project calls for up to 333 wells, with approximately 200 wells located around Lake Okeechobee, and depths ranging from 600 to 1000 feet. In theory, the injected fresh water will form a bubble within the aquifer's heavier, saline water, displacing the native groundwater around the well. This fresh water can then be recovered, presumably with minimal impact to water quality. CERP identifies several benefits associated with ASR:

- Large volumes of water can be stored during periods of high rainfall
- Little water is lost to evaporation (unlike surface reservoirs)
- The amount of land removed from current land use that might otherwise be used for above ground storage reservoirs is minimized
- Lake Okeechobee can follow a more normal hydroperiod instead of being used solely as a flood control and water supply reservoir
- Damaging discharges of fresh water from Lake Okeechobee to estuarine ecosystems can be reduced in their frequency, duration, and magnitude

However, there are numerous uncertainties associated with ASR, especially at this scale (Renken et al. 2002). These include: 1) what impact hydraulic head changes may have on other Upper Floridan aquifer users; 2) how much pretreatment of surface water is necessary before injection, and how much would that cost; 3) will water quality within the "bubble" change during storage; 4) will the quality of recovered water pose environmental or health concerns (e.g. potential radionuclide release, increase in methylmercury bioaccumulation, and pathogen dynamics); and 5) will the proposed injection volumes result in pressures sufficient to fracture rock, thereby altering the hydraulic properties of storage zones.

The ASR project is an interesting, albeit reversed, example of the typical surface-ground water connection. Instead of withdrawal from the ground, ASR involves an addition. However, the surface water connection in this region is still critical, as the underground storage helps offset the water that otherwise would be placed into Lake Okeechobee or discharged to the estuaries, potentially creating a salinity imbalance. Altered hydroperiods in Lake Okeechobee have resulted in ecological damage to the lake and became a highly contentious issue during the high water periods in the late 1990s and the severe drought of 2000-2001 (Steinman et al. 2002b). ASR, if effective, would allow excess water to be stored underground during high water periods, thereby minimizing the loss of aquatic plant beds and the associated decline of the recreational and commercial fishery in the lake. Alternatively, recovery of water during dry periods could maintain the minimum levels needed by the lake to sustain its uses by the industrial, agricultural, and environmental sectors.

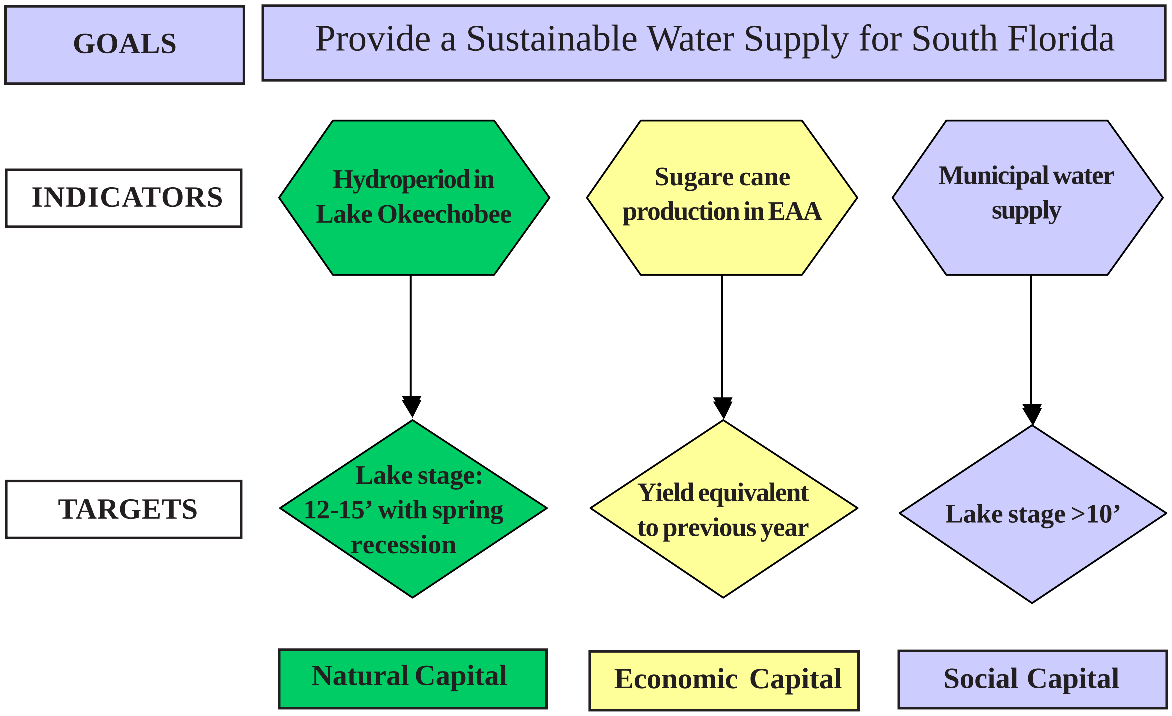

Figure 1. Conceptual diagram showing indicators and associated targets for natural, economic, and social capital based on the goal of using ASR (aquifer storage and recovery) technology to provide a sustainable water supply for the south Florida region.

Any effort to provide a truly sustainable water resource in south Florida must address natural, economic, and social capital (Figure 1). After defining the goal (Figure 1), indicators can be developed for each type of capital—indicators are defined as quantitative measures that are selected to assess progress toward or away from a stated goal (Parris and Kates 2003). Although only one indicator is identified within each type of capital in this case, clearly multiple indicators would be appropriate in a fully developed scheme. For each indicator, specific targets are developed with endpoints and often time frames. In Figure 1, we identify those indicators representing some of the most vital interests in the area. Maintaining a natural hydroperiod in Lake Okeechobee is critical for the ultimate growth of submerged aquatic vegetation, which in turn influences both water quality (reduces nutrients due to biotic uptake) and the recruitment success of littoral fish (provides critical habitat for growth and spawning). Hence, other indicators within natural capital might include abundance of submerged aquatic vegetation, fish health, or water quality in the lake. The Everglades Agricultural Area (EAA), located immediately south of Lake Okeechobee, generates approximately 2 billion dollars per year in farm revenue in this region. The producers are very concerned about having sufficient water supply for irrigation of their crop, and Lake Okeechobee is their primary water source. Five municipalities draw their drinking water from Lake Okeechobee; when water levels become too low, the intakes are unable to draw water. Hence, this is a critical indicator within the social infrastructure of the region. A process very similar to the conceptual approach shown in Figure 1 is currently being used by the South Florida Water Management District and U.S. Army Corps of Engineers to evaluate alternative plans for other components of CERP. In some cases, weighting factors are associated with the indicators (referred to as performance measures in CERP), which adds another level of detail to the process. Specific examples may be found on the CERP website, at www.evergladesplan.org.

Although ASR is a proven technology (Pyne 1995), its use in CERP is at an unprecedented scale. As a consequence, considerable debate has surrounded the ASR proposal, especially with regard to water quality standards. The 1974 Safe Drinking Water Act established an underground injection control program. This program aims to protect aquifer water quality by regulating the disposal of waste materials into wells (i.e. the quality of the recharge water must meet all drinking water standards at the wellhead prior to recharge). ASR proponents claim this standard is too stringent and inappropriate for their program, which is aimed at storing a non-waste water source for recovery and beneficial use. Legislative recourse has been proposed, whereby compliance with water quality standards would apply at the edge of the Zone of Discharge (ZOD) instead of at the wellhead during recharge (Pyne 2002). A ZOD is defined as the radial distance around an ASR well (Pyne 2002). Proponents see this change as a means to allow ASR wells to store water that does not meet all federal primary drinking water standards. However, it is unclear whether this will contravene federal requirements for compliance with drinking water standards at the wellhead during recharge. Opponents feel that there is insufficient information to merit any relaxation of federal standards and that much more information is needed on injection rates, number of wells, monitoring data, recovery rates, and well integrity.

Although these issues will no doubt continue to be debated in the media, court rooms, back rooms, and at public hearings, science can play a critical role in helping to resolve some of the debate. For example, pilot projects are now underway in south Florida to resolve some of the uncertainties identified above, to locate the most suitable sites for the wells near Lake Okeechobee, and to design the optimal configuration of the well network. This pilot phase is estimated to require six years at a cost of $19 million. The pilot projects themselves are subject to controversy, and have been criticized for inadequate water quality sampling, insufficient monitoring, insufficient analyses of microbes, and inappropriate oversight and review, to name but a few of the problems (LEAF correspondence, 2002).

Ultimately, both science and legislation will influence the viability of ASR as a tool to store water in south Florida, and elsewhere. If ASR is found to be not viable, potential alternative strategies for water storage and supply in this region currently include: using desalinization plants, growing the capacity and number of surface storage reservoirs, and increasing the water levels of Lake Okeechobee. Each of these alternatives include separate challenges for the natural, social, and economic capital sectors.

Michigan

The state of Michigan is blessed with an abundant supply of fresh water stored largely in the Great Lakes that it shares with its neighbors. Despite the large volume of surface water, strong concerns over diversion (water use involving the physical removal and transport of water out of the basin from which it was withdrawn) exist. Public perception in the Great Lakes region that “their” water is being taken from them is very strong and has significant political capital. 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 2001*. Water withdrawal is dealt with specifically by outlining the basic principles that state and provincial governments should follow when evaluating proposals to withdraw water. However, both the original charter, signed in 1985, and the Annex are nonbinding, and require statutory authority to be implemented.

Ironically, most of the existing diversions from the Great Lakes have very little consequence on overall water levels, and they are well within the typical annual variations in lake level (DeCooke et al. 1984). A proposal in 1998 to export up to 159 million gallons per year by tanker from Lake Superior to Asia was denied. Although this request represents a significant volume of water, the diversion would be virtually undetectable in terms of the region’s overall water budget.

Far less attention has been paid to the withdrawal of ground water in the Great Lakes basin, despite the fact that ground water supplies up to 67% of the water in tributaries feeding the Great Lakes (Holtschlag and Nicholas 1998). This is perhaps understandable given the volume of surface water in the region. However, ground water is important both to the hydrology of the Great Lakes (Holtschlag and Nicholas 1998) and for the maintainance of minimum flows as well as appropriate temperature regimes for cold water and cool water streams in the basin (Grannemann et al. 2000). The combination of an apparently abundant supply of ground water and the absence of regulatory control of this resource in Michigan has resulted in litigation and an attempt by the state legislature to address the issue of ground water withdrawals through the legislative process.

In Michigan, Great Springs Waters of America, Inc. (GSWA), a subsidiary of The Perrier Group of

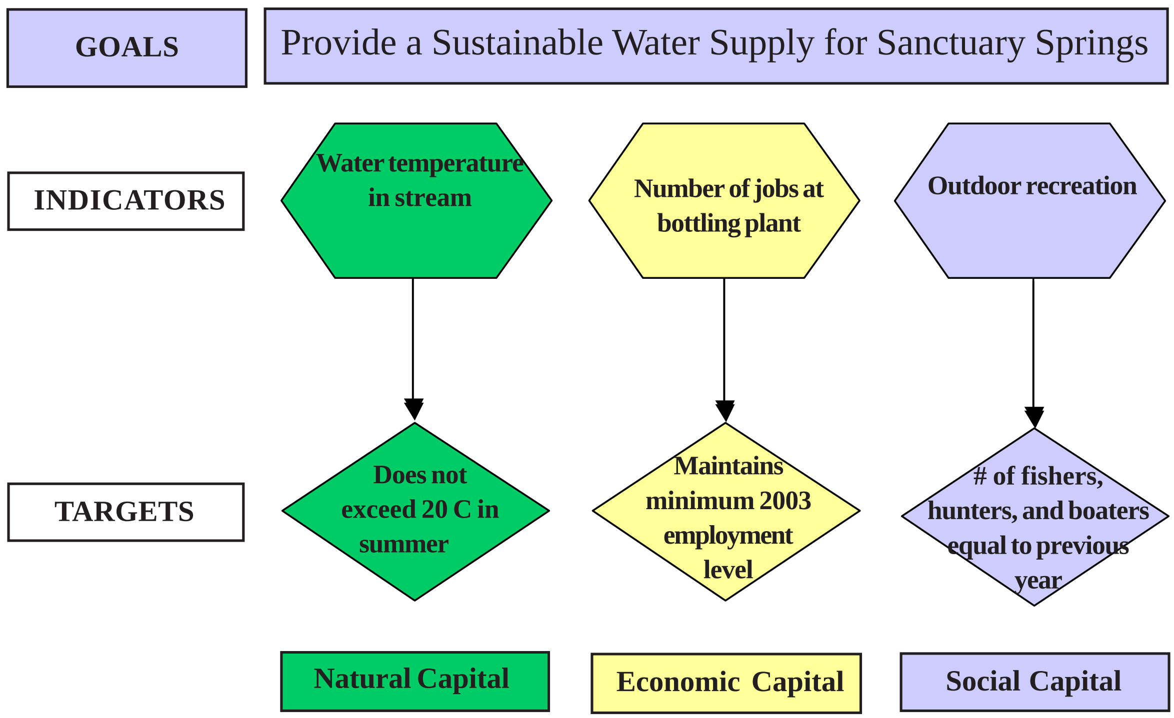

Figure 2. Conceptual diagram showing indicators and associated targets for natural, economic, and social capital based on the goal of establishing a ground water withdrawal rate that balances the needs of a water bottling plant and the natural resources of the region in Mecosta County, Michigan.

America, Inc., identified Sanctuary Springs in Mecosta County, Michigan, as a source for their Midwest water brand, Ice Mountain™. The site is located on a privately owned tract of approximately 850 acres; an 11-mile pipeline connects the wells to the bottling plant. The springs feed the Osprey Lake Impoundment, a man-made water body created in 1953, which, in turn, feeds the 1-mile long Dead Stream and 25-acre Thompson Lake.

GSWA currently has approval from the Michigan Department of Environmental Quality (MDEQ) to withdraw water at a rate of 400 gallons per minute from a total of four wells (total capacity = 210 million gallons per year). A lawsuit was filed in 2002 by the Michigan Citizens for Water Conservation (MCWC) seeking interim relief. At trial in Spring 2003, MCWC requested that both a summer water level minimum and a late winter/early spring water level minimum (with levels 6 to 7 inches higher than in summer) be maintained in Dead Stream in order to sustain spawning of northern pike; MCWC is concerned that increased withdrawal rates would harm the environment by resulting in insufficient flow or water depth to maintain the native fishery. Ultimately, they are seeking permanent relief, which would entail an injunction shutting down the project altogether, claiming that the withdrawals constitute an illegal diversion of water under Michigan law. Conversely, experts for GSWA claim that any decline in stream depth and flow would have little impact and that stream temperatures would decline, benefiting the fish. This case was heard in Mecosta County Circuit Court between May and July of 2003 (19 days total of trial) and on November 25, 2003, the court ruled in favor of MCWC and ordered GWSA to terminate all water withdrawals of spring water within 21 days. On December 12, 2003, the circuit court denied a request by GWSA that the court stay its opinion pending appellate review of the case. GWSA then sought an emergency stay from the Michigan Court of Appeals to prevent the shutdown of the Ice Mountain facility, stating the shutdown would result in the laying off of 120 employees. On December 16, 2003, the Court of Appeals issued a stay of injunctive relief granted by the circuit court. It is of interest that the Michigan Department of Environmental Quality (MDEQ) filed an amicus brief in support of staying the Circuit Court's original ruling. MDEQ's Director, Steven Chester, in his on-line explanation of MDEQ's stance, noted a stay provided his agency the time and opportunity to consider the significant policy implications of the case, and in particular the need for comprehensive groundwater withdrawal and use legislation (http://www.michigan.gov/deq/0,1607,7-135--83319--,00.html). It is unclear when the Michigan Court of Appeals will hear the case.

As with ASR wells in south Florida, a sustainable water supply in Sanctuary Springs requires a balance among the natural, economic, and social capitals of the system (Figure 2). For natural capital, given the ground water–surface water connection, and the potential influence of withdrawal on water temperature, we identify temperature as a critical indicator due to its effect on fish health, although flow and water depth also make useful targets. Employment is a critical concern in Mecosta County, home of the bottled water plant. The county is rural, and according to the U.S. Census, the 1999 per capita income was $16,732 compared to $22,168 in the State of Michigan. People living below the poverty level in Mecosta County in 1999 averaged 16.1% compared to 10.5% for the remainder of the state. The plant currently employs approximately 140 people; it is unclear what affect the court decision would have on future employment, but maintaining this number is an important target within the economic sector (Fig. 2). Much of Mecosta County is within the Muskegon River Watershed, the third largest watershed in Michigan, and an important natural resource in the state. Outdoor recreation, including hunting, fishing, and boating, is important not only for revenue but also for defining the region. It is unclear what impact, if any, media attention associated with this litigation may have on future outdoor recreation in the county (Fig. 2).

The GWSA court case, in particular, has heightened the concern over ground water protection in Michigan. Indeed, the bipartisan Great Lakes Conservation Task Force was formed in the Michigan legislature in 2001 with the charge to recommend policy changes to improve the Great Lakes ecosystem. One of the policy changes recommended by the Task Force is that "the legislature should enact comprehensive water withdrawal laws. This process may require a step-by-step approach, beginning with the enactment of an aquifer protection statute."

In the 2003 Michigan legislative session, Senate Bill 289 was introduced to address ground water withdrawal. This bill would amend the Natural Resources and Environmental Protection Act to do the following:

- Require the Michigan Department of Environmental Quality (MDEQ) to prepare a statewide groundwater inventory and map, within two years after the bill's effective date
- Create an Advisory Council to study the sustainability of the state's groundwater use, monitor implementation of the Great Lakes Charter Annex 2001, and make recommendations on statutory conformance with Annex 2001
- Increase water use reporting fees for industrial, processing, and irrigation facilities with a capacity to pump over 100,000 gallon per day (gpd) from $50 to $100
- Require farms with a capacity to pump over 100,000 gpd either to register with the MDEQ and pay the water use reporting fee, or to submit a water use conservation plan to the Michigan Department of Agriculture (MDA), in which case registration and the fee would not be required
- Require the MDA to use the information in the conservation plan to determine an estimate of water use and consumptive use data for each township in the state, and forward that information to the MDEQ for inclusion in the groundwater inventory
- Require the MDEQ, the MDA, and Michigan State University to validate and use a formula or model to estimate the consumptive use of withdrawals made for agricultural purposes

This bill, as well as a House-sponsored bill dealing with groundwater conflict resolution, were passed by the Michigan legislature in 2003. Science played an instrumental part in the development of the bill. Hydrologists and ecologists were consulted regarding the original content of the bill, testified in front of the Natural Resources and Environmental Affairs Committee in the Michigan Senate, and participated in work sessions with other interested parties in an attempt to craft legislation that was based on sound scientific principles.

Conclusions

There is no shortage of facts identifying the impending, if not already existing, crisis facing the freshwater resource on this planet (cf. Commission on Sustainable Development 1997; Gleick 1998; 2002), and which collectively provide justification for why 2003 is the International Year of Fresh Water. Sustainability of this resource will require enormous efforts from numerous sectors. Certainly one of the critical sectors will be science and technology (Cash et al. 2003), which will be called upon both to provide more efficient ways to deliver water and to develop new technologies to conserve water. In addition, science can play an important role with respect to policy because of the credibility and legitimacy often ascribed to scientific information (Aumen and Havens 1997), especially if the findings have withstood peer review and they were obtained with funding by an impartial source.

Despite the broader regional and societal implications of the previously described case studies on fresh water allocation, the science involved in each study is playing a vital role at the local level. Indeed, there is growing recognition that sustainable development takes place at the local, not global, scale (Clark and Dickson 2003; Kates and Parris 2003). While science can play an important role in helping to sustain our freshwater resources, the political process has the potential to circumvent or use science to its own end. Involvement and engagement of stakeholders in the process of developing solutions to natural resource challenges, thereby engendering a sense of ownership, can influence the political process and provide a tool that prevents water resource projects from becoming endlessly bogged down in conflict.

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