Sustainability & the Management of Water Resources in Florida

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Management of water resources in Florida is governed by a mix of eastern and western water management philosophies under Chapter 373, Florida Statutes. A water use must be reasonable and beneficial and in the public interest. This philosophy is a mixture of appropriative right and vested use. How the current water management methods fit with the sustainable water management concept is open to question.

There are three general aspects to the water management philosophy being administered by Florida's five regional water management districts:

1) The water management planning process
2) Management by regulation (water use permitting)
3) Management by compliance to minimum flows and levels

Each of these components can be evaluated within the context of sustainability, which requires that the resource be managed in a manner consistent with the use of the resource without depleting it, and without creating harm to the resource, the environment, or other users of the resource.

Water management by regulation and minimum flows and levels as practiced in Florida is clearly not consistent with the philosophy of sustainable water management. Individual water-use decisions are often made within the context of groundwater models that have not been assessed adequately to understand the range of errors within the projected water levels.

Regulatory constraints commonly are defined by political, legal, and economic issues, rather than a technical assessment of the facts. For example, a water management district may limit the pumping of an aquifer because of a perceived concept of saline water intrusion based on a model, despite the fact that in some instances the actual monitoring data shows that the saline/freshwater interface is not within several miles of the perceived or modeled location, and the response of the interface to pumping is often just assumed. Minimum water levels can be established to "control" the position of the saline/freshwater interface, but internal aquifer upconing of saline water can still occur inside the set minimum water level.

Water planning and regulatory decisions are relying more upon modeling each year, while the collection of basic data on the aquifer systems is declining. Many critical parameters in groundwater flow and solute transport models are being changed with each succeeding modeling effort—not based upon actual data, but upon model calibration. Models, therefore, are generating the data upon which the models are based. The resulting groundwater models are not necessarily more accurate and can lead to water management decisions based not on science, but on conjecture.

Sustainable water management requires that new, high-quality hydrogeologic data be added to each new generation of models to make reasonable and valid decisions. This requirement also includes the addition of meteorological data and water-demand projections so that flexibility can be added to the decision-making process.

Defining Sustainability within Modern Water Management Framework

Historically, groundwater management in Florida has been based on alleviating crises by shifting withdrawal locations and by various permitting schemes. Considerable effort has been spent on developing "safe yields" of aquifers, or minimum flows and levels. Groundwater management as a sustainable resource has not been achieved because the concept of "safe yield" and minimum flows and levels are both grounded within the water budget myth (Bredehoeft, 2002).

The water budget myth is the assumption that the safe or sustainable yield for pumping an aquifer is less than the rate of natural recharge (Bredehoeft et al., 1982; Bredehoeft, 1997; 2002; Alley et al., 1999; Devlin and Sophocleous, 2005). Conclusive proofs have been published concerning the invalid nature of the "safe yield" assumption, beginning with Theis (1940), followed by Bredehoeft et al. (1982), Bredehoeft (1997; 2002), Sophocleous (1997), Alley and Leake (2004), and most recently Devlin and Sophocleous (2005). The biggest point of confusion appears to be that sustainable pumping can be achieved in excess of the natural recharge rate (Devlin and Sophocleous, 2005).

Unfortunately, the definition of sustainability as applied to groundwater can be quite variable. The "sustainable yield" of an aquifer is the withdrawal of water for consumptive use that allows long-term continuity of use without causing aquifer mining or adverse environmental impacts. An even broader definition of "sustainable water resource systems" was proposed by the American Society of Civil Engineers (ASCE) Task Committee for Sustainability Criteria (1998): "Sustainable water resource systems are those designed and managed to fully contribute to the objectives of society, now and in the future, while maintaining their ecological, environmental, and hydrological integrity."

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Unfortunately, the concept of sustainability is commonly based solely on the natural water budget without considering the increase in natural recharge induced by pumping, natural systems impacts (good and bad), reduction in flooding potential, and potential remedial measures that can be used to increase the withdrawal rate artificially beyond natural sustainability. Sustainable aquifer management does not require the maintenance of the current hydrogeologic status quo.

Groundwater Resource Development Planning & the Use of Models

A complex water budget process is still one of the primary principles used to plan future water supply development by the five Florida water management districts. Whether the planning is based on the regulatory minimum flows and levels process or on some form of groundwater or integrated groundwater/surface-water modeling process in relation to demand models, it appears that all goes back to a punitive water budget calculation rather than an incentive-based sustainable supply system. It is quite important to assess groundwater models that are being used to plan water resource development in Florida and how to improve the process.

Bredehoeft (2002) thoughtfully asserted that the water budget management concept is a myth and that is why hydrogeologists use models. What Bredehoeft philosophically stated is correct, but he made the assumption that the modeling efforts would be used correctly within the framework of the best or improved hydrogeologic data. The current use of groundwater models, however, appears to become a substitute for the water budget water management method, with little attention being given to data requirements for the models used, sensitivity analyses of the models, and some testing process to produce periodic assessments of the predictive value of the models used. Also, commonly, different models are used by the same district for planning and regulatory purposes with significantly differing results.

Groundwater models used for water management purposes do not produce absolute results because of inherent problems of aquifer heterogeneity and the concept of non-uniqueness. Groundwater models provide only a general guide to the understanding of a groundwater system and can not be validated (Konikow and Bredehoeft, 1992; de Marsily et al., 1992; Bredehoeft and Konikow, 1992).

Perhaps it is important to clarify what definition of "model" is used, because the term is grossly overused. Konikow and Bredehoeft (1992) defined "model" as a "representation of a real system or process" and "conceptual model" as "a hypothesis for how a system or process operates." Krumbein and Graybill (1965) defined "mathematical models" as abstractions that replace objects, forces, and events by expressions that contain mathematical variables, parameters, and constants. Konikow and Bredehoeft (1991) pointed out that most or all groundwater models used today are "deterministic" mathematical models that are based on conservation of mass, momentum, and energy, which, in turn, are balances "of the various fluxes of these quantities"; therefore, although a groundwater model is not necessarily the same as a water balance or water budget, it can function and be used in the same manner.

There are a variety of groundwater flow codes being used by the water management districts in Florida. The most common of these is probably MODFLOW (McDonald and Harbaugh, 1988), which is a finite difference model. Other interactive groundwater/surface-water codes, such as MIKE_SHE/MIKE11 (Danish Hydraulic Institute, 1998a; 1998b), are being used to simulate groundwater and surface-water flows.

Some of the districts have also developed their own internal models that may or may not have undergone a rigorous benchmarking process (e.g. the SFWMD or two by two model, the SJRWMD MULTILAYER/SURDOWN model). For planning purposes, regional models are commonly produced that use a relatively coarse model grid, ranging in size from two miles by two miles to 1,000 feet by 1,000 feet. These models are calibrated to existing data sets, including monitoring wells to measure the potentiometric surface of a given aquifer and to a number of aquifer performance test data points.

The aquifer test data are smoothed using geo-statistical methods, such as kreiging, and are inset into the model domain. Some key parameters, usually those difficult to measure and in many cases not measured, such as leakance, are estimated during model calibration. Sensitivity analyses are performed on the models to assess real-world variations in the aquifer hydraulic parameters placed into the models. ***In the absence of real data, models are used to generate the data being used by the models.***

Upon completion of the "calibrated" groundwater management model, the model is used to assess a variety of pumping stresses and then conclusions are drawn on the resultant drawdowns of water levels for pumping loci contained within the model domain. The models are used for a general assessment of impacts that are concluded to be acceptable or unacceptable, based on the "subjective" scientific, legal, or political processes that define the planning process (see Missimer 2005 for discussion of the water management tetrahedron).

Although this discussion is aimed primarily at groundwater flow models, the same general arguments can be applied to assess the validity of solute transport models, which have an even greater number of hydraulic parameters that are not measured, but have to be estimated.

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Based on this discussion, what is wrong with this use of groundwater modeling in the planning process? Perhaps it is necessary to list the issues in question when using a regional or sub-regional groundwater model for planning purposes. These issues are:

1) How good is the data base used to develop the model in terms of both the special distribution of measured aquifer hydraulic parameters and the heads measured in each layer used in the model?
2) Does the grid space of the model provide really useful water-level impact predictions within the real world framework?
3) Is the model an improvement on the last model of the area, based on either a better code with a tighter mathematical convergence or an improved data base?
4) What are the variations in impacts based on the uncertainties contained within the model?
5) How close does the model come to predicting both average and extreme conditions within the domain?
6) How does the model deal with natural climatic variations that affect recharge and discharge rates from the aquifer being modeled?

The current use of groundwater or integrated groundwater/surface-water modeling in Florida for planning purposes is not following the general principles of sustainable water management. There is a disconnect between the potential errors inherit in the models, the actual planning process, and the regulatory process. In fact a statement recently made by a regulator, was "There is no real connection between the planning and regulatory process, and therefore, we can make decisions independent of the planning models." A similar statement made by district staff was that the district does not have to accept its own planning model for permitting, presumably only if the planning model shows a lack of adverse impacts.

Integrating Groundwater Modeling for Planning with Sustainable Water Management

The question posed is how the planning of future water resource development can be integrated with the groundwater and surface water modeling used to assess impacts on the hydrologic system and also be in concert with the permitting process. There are several issues that must be resolved in this process:

1) The science and data upon which the models are based must be upgraded.
2) Sophisticated long-term meteorological predictions must be integrated with the planning models.
3) Demand models which fail to take into consideration water demand replacement, such as conversions from agricultural to residential use and the impacts of water reuse, must be improved.
4) The overall philosophy of water management by regulation with a disconnect to the planning process must be changed.
5) Integrated water management principles within the context of sustainability must be adopted (all water must be managed as a complete system, including water use, reclaimed water, stormwater, and industrial process water).
6) Water quality should not be left behind as the forgotten stepchild.

Perhaps the first issue to tackle is the adequacy of the hydrogeologic data base. This relates to the primary issue that models are only as good as the data upon which they are based.

There are a few very disturbing facts that should be brought to light. Over the past several years, the number of monitoring wells used to obtain water-level and water-quality data has declined significantly in many regions of Florida. The reasons are:

- The reduction in the U. S. Geological Survey monitoring activities throughout Florida.
- The destruction of numerous wells during the road construction and development process with no requirement by the districts to replace the wells, and budget cuts

made within the districts to curtail the replacement of destroyed wells.
- The decision by the districts to reduce basic data collection efforts.

Most of the districts have chosen to require the individual water users to provide monitoring data and not to collect the data under a rigid quality assurance framework. There has been a wide variation in the quality of data collected by water users, who view the issue as one needed to meet the minimum requirements of a water-use permit with the lowest possible impact on the budget; therefore, as greater quantities of water are needed in Florida, fewer data are being collected for true management and support for model development.

The only large hydrogeologic collection efforts by the districts relate to special projects, such as the South Florida Water Management District's regional aquifer storage and recovery project (part of the Comprehensive Everglades Restoration Plan). A concerted effort must be undertaken by all the districts to reassess the fundamental hydrogeologic data base before improvements can be made in the planning models being used.

The same issue was discussed in the Council of 100 report on future water supply development in Florida (Council of 100, 2003). This report recommended the development of a statewide hydrogeologic data center to be an archive for existing and new information. Each year, hundreds of documents produced by consultants and a variety of other groups are discarded because of a lack of storage space at the districts and other agencies. This is critical information for the continued improvement of the statewide database needed for future water supply development and management.

Most of the groundwater models used in Florida today do not take into consideration issues that fall outside the climatic conditions measured within the state. For example, there are long-term meteorological cycles that greatly affect precipitation patterns throughout Florida. The models used project forward only through the arbitrary planning time horizon, which is from five to 25 years. Commonly, climatic cycles range from five to 25 years and are not synchronous with district planning cycles.

There are also larger-scale issues related to natural global climate variations and the global warming produced by man's activities. A recent example of the disparity between the climate cycles and planning is the conversion from a dry to a wet cycle over the past five years with a significant increase in tropical storm activity. Consider that if a truly sustainable water management system were in place within Florida during the last (2005) hurricane season in South Florida, some of the stormwater could have been collected and stored within a series of surface reservoirs or a subsurface aquifer storage and recovery system instead of decimating the estuarine systems as discharges from Lake Okeechobee severely damaged natural systems.

The groundwater and integrated models must be run for longer time frames within the context of the new climate models to produce assessments of resources that are based on variable recharge rates and provide flexibility to utilities and water managers. For example, the wellfields operated by Tampa Bay Water were cut back because of severe impacts caused during a very dry period. Now during a wet period, more water could be withdrawn to provide lower-cost water and perhaps help alleviate flooding. The modeling could help create a system of balances between when the seawater desalting system should be run and when the Floridan Aquifer System should be used at a higher rate. Sustainability requires flexibility, which in turn must be integrated into the planning models.

Water demand models used in Florida seem to be based more on politics than on facts. Over the past several years, the Florida Legislature has recognized the issues surrounding the problem of integrating the planning process with the water management process. Although several bills have been

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passed and integrated into Chapter 373 (i.e. Senate Bill 444), there still seem to be wide discrepancies in the integration of demographic changes and land use conversions into the demand models.

For example, a variety of population projections are used in the regional water supply plans created by the water management districts each five years, and the use of water by people shows substantial growth in each new projection; however, the agricultural water use never seems to decline in the demand models and actually shows some growth in certain areas of Florida. In areas where there are substantial conversions of agricultural lands to development, it can be documented that there are reductions in overall water use, especially where land used for truck crops is converted to residential housing with mandated reclaimed water reuse (Maliva and Hopfensperger, in review). Significant improvements in water demand modeling must be made to integrate not only population growth, but better deal with changing land uses and climate related issues.

Since exterior home water use is such a large percentage of overall utility water use, when it is raining and flooded, exterior water use does change. Water reuse plans and stormwater management plans must be integrated into the demand models to show which demands are reduced as a result. Overall demand models must take on a more scientific basis instead of a political bias.

Another issue of concern is the disconnect between modeling results and actual impacts on water resources and the environment. For example, there is virtually no significant connection between criteria used for wetland impacts and actual documented impacts to wetlands. The groundwater and integrated groundwater/surface-water models are developed to assess impacts to the aquifer system and the natural system, based on very conservative assumptions. Environmental impacts are commonly assessed viewing the most extreme of climate conditions with superimposed pumping impacts, ignoring real climatic cycles that have affected wetland and other environments prior to the population of Florida.

Certain hardwood wetlands are not very sensitive to minor water-level fluctuations, as long as the changes do not allow fire damage in the wetland areas (Ewel and Mitsch, 1978). Some of the districts use a wetland impact criterion as low as 0.1-foot of drawdown. The seasonality of wetland hydration in Florida and maintenance of the historic hydroperiod is less related to groundwater withdraws than to alterations in the natural drainage patterns. Many wetland plants in Florida are phreatophytes, which means that as natural water levels decline, the root systems of the plants respond by growing deeper. In many cases, the issue again becomes fire-damage potential, rather than drawdown impacts.

In most cases, the seasonal flooding of wetlands, which occurs irrespective of dry-season withdrawals, is sufficient to prevent upland vegetation from becoming established in wetlands. Long-term monitoring data indicate that in some parts of Florida, the potentiometric surface of several import aquifers is rising at the same time the districts are stating that the respective aquifers are over-allocated, based on modeling results. The point is again that models are only as good as the data placed into them; when the model results are in direct conflict with observed changes in the environment, changes must be made in the relationship of the models to both the planning and regulatory processes.

The goal of reaching a sustainability-based water management system in Florida can not be achieved without either better institutional integration of water supply planning and regulation within the districts or the removal of the water supply development function from the districts. Beginning with the removal of the water supply function from the districts, such a proposal was discussed extensively by the Council of 100 in deliberations for their report to the governor (2003). Their ultimate recommendation was to establish a water supply commission with a statewide perspective to ensure an adequate water supply to sustain the environment and accommodate forecasted population growth.

This recommendation was based on several key observations:

1) District personnel stated in interviews that there was no water supply crisis predicted for their respective 25-year planning horizons.
2) There is an inherent conflict of interest for the districts to develop water supplies because they have to seek permits from their own agency.
3) Regulation, not water supply development, has been given priority in the annual allocation of funds.
4) Planning activities are conducted independent of regulatory activities and are often in conflict.
5) Planning and water supply development activities are not well coordinated between the districts and local governments, and the "local sources first law" inhibits the regional development of water supplies.

The Council of 100 report pointed out that perhaps the greatest impediment to achieving a sustainability-based water management program is the number of functions that the districts must perform. The issue of water supply development has been treated under the regulatory function of the districts, prima-

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rily as an environmental protection issue and not as a water supply development issue.

Recognition that water is one entity, irrespective of regulation, is a key issue in reaching a sustainable water management system. Regulation of water in Florida is separated into various categories, and jurisdiction is divided among different agencies. Water use and stormwater management are under the jurisdiction of the water management districts, while domestic and industrial wastewater management and reuse programs are under the Florida Department of Environmental Protection (FDEP). There are also a large number of special water districts that control stormwater management, such as the U. S. Army Corps of Engineers (the Central and Southern Florida Flood Control District) and numerous other special districts of varying size.

Coordinating statewide water management issues within the water supply function is so fragmented that an overall integrated water supply and management strategy is difficult, if not impossible, to achieve. A good example of this management disconnection is the conflict of regulatory flow models used by the various districts at their boundaries, where great conflicts have arisen, creating litigation (i.e. southern Orange County).

Integration of Water Supply & Storage Strategies

The emphasis of this discussion has been the relationship of water supply development, planning, and environmental protection, but there is another very important function that must be integrated into the overall sustainable management of water in Florida: the seasonal and long-term storage of water.

In most years, the total water use in Florida is equivalent to a very small fraction of the total rainfall. For example, the state receives on the average about 56 inches of rainfall per year, and the seasonal distribution of the rainfall is very extreme, with the lowest rainfall occurring during the highest demand period. Only about four inches per year of the total rainfall is actually used. Much of the water is evaporated or transpired back into the atmosphere or runs off into tidal water.

Although some of this excess rainfall is very important to recharge aquifers, and to maintain salinity variations in estuary systems, there is a large amount of wasted water that discharges into tidal water as a result of the elimination of natural storage (i.e. 70 percent of the natural storage of the Everglades is lost to drainage and urbanization), and the low topographic relief of Florida that has little natural storage potential. Large-scale rainfall events such as tropical storms cause flooding and very high rates of runoff, which is water lost from use. Serious environmental damage has been done to the estuarine systems in South Florida in recent years by abnormal discharges of stormwater. The issue of water storage is fundamental to reaching the goal of the long-term sustainability of water supplies in Florida.

New regional storage structures are being constructed, such as the water-supply reservoir in Hillsborough County by Tampa Bay Water and the surface storage facilities being constructed as part of the Comprehensive Everglades Restoration Plan (i.e. C-43 and C-44), but surface storage facilities can store only a small fraction of the stormwater discharge from a single event, and they do not achieve long-term water-supply sustainability. A more comprehensive strategy must be developed to coordinate other storage strategies, such as aquifer storage and recovery (ASR) and temporary water storage on privately owned property.

ASR has been used effectively on a small scale to help public utilities meet seasonal water supply demands and for emergency storage. A large-scale ASR project has been suggested as an integral part of the Comprehensive Everglades Restoration Plan. This rather aggressive and unrealistic plan is

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an attempt to store water in 333 wells with individual well capacities of 5 MGD. No preplanning modeling or investigations were conducted to support these capacities, so it is likely that only a small fraction of this capacity will ever be constructed.

ASR storage of stormwater, reclaimed water, and some freshwater from shallower aquifer is another important part of the overall development of a sustainable water management plan. The ASR strategy needed to achieve sustainability is not short-term storage, but long-term freshening of saline-water aquifer systems for large-scale use in dry climatic cycles. Other storage strategies, such as the creation of salinity barriers using stormwater and/or reclaimed water, must also be developed.

The capture and storage of water from a single large-scale rainfall event could supply the needs of South Florida for decades. This would require the integration of surface reservoir construction with the development of ASR wells. Recent modeling has shown that a series of deep wells tapping the boulder zone in South Florida could store as much as one foot of the Lake Okeechobee area with 90 days of pumping. If only 10 percent of this water were recovered, this would amount to billions of gallons of water available for use.

Another more controversial strategy is to store more stormwater on private property after a major rainfall event. It is possible to develop a strategy, where willing landowners would be paid a fee to make certain lands available for stormwater storage on an as-needed basis after a major event. There are projects using this strategy in other parts of the world. The temporarily stored water would subsequently be discharged into the surface water system of a regional drainage system after floodwaters have receded, or some of the stored water could be added to some of the holding reservoirs for storage in ASR systems or be injected into the boulder zone.

Based on the current water supply and management strategies, it is obvious that additional innovative approaches should be taken to store excess stormwater in Florida. The quantities are so vast that true sustainability could be reached in the overall supply for the state.

Integration of Alternative Water Supplies

Alternative water supplies are also a significant factor in the overall strategy of achieving sustainable water supplies in Florida. The use of brackish-water and seawater desalination has been steadily progressing as key water supplies for municipal governments in Florida. Also, a variety of water reuse strategies are being used to supply irrigation water for golf courses, agricultural users, multi-family and single-family users, parks, road medians, and certain industrial users. All the alternative water supply strategies will be further developed in the future and integrated into the overall planning processes. Alternate water supplies will be developed where they are the most economic solutions to regional water supply issues.

Conclusions

Florida has one of the most innovative legal systems of water management in the world, with the integration of need balanced with appropriated uses of water, protection of the use of water by permitted users, and all waters being held in trust by the state for the use of the people. The three-prong test for issuing a water use permit under Chapter 373 requires that water uses be reasonable, beneficial, and in the public interest. Chapter 373 and the fundamental principles written in the Model Water Code, upon which the law was based, are not the fundamental problem in achieving a sustainable water management system, but the political pressures of constantly redefining the public interest is a major problem.

While the legislature appears to be interested in linking water supply, environmental protection, and planning, there is currently no functional link in this process within the districts. The models being used for water supply planning are commonly different from those being used for regulatory purposes, resulting in continuing emphasis on regulation, rather than true supply development. Some progress is being made on the financing of water supply development projects (444 financing), but a more integrated strategy is needed to link planning, water supply, and storage strategies to achieve long-term sustainability.

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Water resource management is the activity of planning, developing, distributing and managing the optimum use of water resources. It is an aspect of water cycle management. Water is essential for our survival. The field of water resources management will have to continue to adapt to the current and future issues facing the allocation of water. With the growing uncertainties of global climate change and the long-term impacts of management actions, the decision-making will be even more difficult. It is Therefore, the development of water resources for economic growth, social equity and environmental sustainability will be closely linked with the sustainable development of cities. Ecosystems. Perhaps the most important challenge to sustainable development to have arisen in the last decades is the unfolding global ecological crisis that is becoming a barrier to further human development.Â Water-related disasters are the most economically and socially destructive of all natural disasters. Recent papers in Sustainable Water Resources Management under Climate Change. Papers. People. Pak Waters - Threat or Survival.pdf. The myth of Water Scarcity in Pakistan is exploded with detailed analysis regarding Theft/ Seepage, Polluted and Saline Water and what can be done to stop/ remediate this precious Resource. Save to Library. Download.Â Desert research, research and development of sustainable greening methods, greenhouse management, forestry, agriculture and cultural industries are the primary fields of the concept and greening deserts projects. The greening and research camp with a greenhouse, office or laboratory containers or tents for the research and development of greening and irrigation methods is the primary objective for open pit mines. Request PDF | On Jan 1, 2007, Thomas M. Missimer and others published Sustainability and the management of water resources in Florida | Find, read and cite all the research you need on ResearchGate.Â Coastal communities often rely on groundwater resources for water supply. Ensuring a safe and adequate supply requires a balance that meets community demands while preventing deleterious hydrologic and environmental impacts.