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# Water Sustainability in Florida—Issues Of Development, Population, and the Environment with Special Reference to the Everglades

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## Abstract

Florida is a water-rich state. The geological framework formed over millions of years created the aquifer systems upon which man relies for water resources. It is estimated that more than two quadrillion gallons of freshwater are in the state's aquifers. Approximately four trillion gallons of water recharge the Floridan aquifer system each year. Three trillion gallons are naturally discharged annually, mostly via Florida's more than 320 springs. One trillion gallons per year are withdrawn by pumping. Surface-water discharge from the major rivers is more than 14 trillion gallons per year. Many areas of the state do not have the needed freshwater supplies. Alternative supplies from mineralized waters and subsurface storage of excess water are being used.

The Florida Everglades are a vast wetland in southern Florida. The Everglades formed over thousands of years as a result of freshwater sheet flow. Man has dramatically altered the Everglades through attempts to control water. The ecosystem was drastically altered. Now, man is attempting to restore the ecology of the Everglades. The restoration requires a restructuring of water policy and use in southern Florida. Congress has passed legislation to provide funds for the restoration.

Many water-sustainability questions arise. These include: 1) What is the level of infrastructure development and population growth that is supportable by the state's water resources? 2) Should mineralized waters be considered as part of a sustainable water supply? 3) How much impact on the environment is acceptable? 4) How do we balance ecological sustainability with human needs and economic growth?

## Introduction

Water, on the most basic level, is arguably the most important factor in the ecosystem that affects mankind. Without sufficient water, the ecosystem will collapse and humans cannot thrive or possibly even survive. The development and sustainability of our quality of life is directly attributable to water resources.

Florida provides an interesting opportunity to study water-sustainability issues, both water quantity and quality, affecting the United States and the world. With its burgeoning population and development pressures, Florida's water-management officials are attempting to develop a balance between human water requirements and those of the natural environment. Water is needed not only to maintain the ecosystem but also to restore systems such as the Everglades, which are heavily impacted by human activity.

Many aspects of life in Florida are associated with water. Florida has 1,197 miles of coastline, more than 7,700 lakes, more than 1,700 streams and rivers, three million acres of wetlands, and 27 first-magnitude springs (Patton and DeHan, 1998). Florida's warm climate and abundance of recreational opportunities have led to a dramatic population increase from 1.8 million in 1940 to 14 million in 1990 (Patton and DeHan, 1998). In addition, tens of millions of people visit the state each year. These changes have led to stress on the environment and water resources.

Florida is anything but water poor. Vast potable ground-water resources, estimated at more than two quadrillion gallons of potable water, exist within the Floridan aquifer system and other regional aquifers. Surface water is also abundant. Demand for water, however, is concentrated in the most populous cities and counties, often near the coasts where water resources are limited. Pumping water to these areas is restricted not only by water's low unit value but also by a myriad of regulatory requirements and saltwater intrusion. In order for development to continue, areas with limited potable water supplies have begun to utilize reverse-osmosis treatment of subsurface saline water, wastewater reuse, and aquifer storage and recovery of treated surface water.

The water quality of Florida's water resources is generally good (Livingston et al., 1998). Surface waters are susceptible to significant contamination from a number of sources including agricultural, municipal, urban, and from hydromodification. Contaminated surface waters pose a threat to ground-water supplies because a portion of the recharge comes from this source. The geologic framework dictates the susceptibility of ground water to contamination (Scott et al., 1991; Maddox et al., 1993). Large areas of the state have permeable sediments lying directly on limestone, allowing infiltration of contaminated water. Also, abundant sinkholes over much of Florida allow direct access to the Floridan aquifer system. This framework, which allows up to 90% of surface-water base flow to originate from ground water, can cause surface water to be degraded by the discharge of polluted ground water into lakes, streams, and rivers.

## Geological Setting

The Florida Platform is primarily a thick sequence of Mesozoic and Cenozoic carbonates that extends to the south from the southeastern portion of North America. The carbonates are overlain by a varying thickness of later Cenozoic siliciclastic sediments (see Scott, 1992). The Florida peninsula is the exposed portion of the platform and lies east of the platform axis. Florida is the only state in the United States that lies entirely within the Coastal Plain Province. It also has the lowest high point (105 meters) of any state and limited relief.

In central and northern peninsular Florida, and in the eastern panhandle, carbonates occur at or near the surface and are karstified. Numerous karst features including sinkholes, caves, and springs occur within this area. The sinkholes provide direct access to the Floridan aquifer system, allowing for rapid recharge and making the aquifer system highly susceptible to pollution. More than 320 springs are known in Florida. These springs discharge more than 8 billion gallons of water per day (Rosenau et al., 1977).

Ground water in Florida occurs within the Floridan aquifer system, the intermediate aquifer system and confining unit, and the surficial aquifer system (Southeastern Geological Society, 1986). The Floridan aquifer system is composed of the Eocene to Miocene carbonates. The intermediate aquifer system and confining unit is composed of Miocene and Pliocene sediments. The surficial aquifer system occurs in Pliocene to Holocene carbonates and siliciclasitcs. Within the surficial aquifer system, there are two regional aquifers: the Biscayne aquifer in southeastern Florida and the Sand and Gravel aquifer in northwestern Florida.

## Water Resources

Florida's surface- and ground-water resources are important in maintaining ecological integrity and reasonable growth and development. Sixty percent of freshwater utilized in Florida comes from ground-water sources. For drinking-water uses, 93% comes from ground-water resources (Berndt et al., 1998). Surface water is primarily used for agricultural purposes and power generation (Marella, 1998). The proper management of these resources is paramount to maintaining not only the ecological integrity of the state but also a healthy economy and a good quality of life for its citizens.

### Ground Water

Florida is blessed with tremendous quantities of potable ground water. Nearly all of Florida's freshwater originates from precipitation (Berndt et al., 1998). On the peninsula, which is much like an island, the "bubble" of freshwater in the Floridan aquifer system exceeds 640 meters thick in west-central Florida. In the panhandle, the thickness of freshwater often exceeds 230 meters. Using an average thickness of freshwater in Florida's aquifer systems and average porosities, we conservatively estimate that there are more than 2 quadrillion gallons of potable water present. The amount of water in the Floridan aquifer system far exceeds the amount of freshwater in the intermediate aquifer system and confining unit and the surficial aquifer system (including the Biscayne aquifer and the Sand and Gravel aquifer which are limited in thickness and areal extent).

Recharge to the Floridan aquifer system from precipitation occurs over approximately 55% of the state and ranges from less than 2.5 centimeters per year to as much as 50 centimeters per year (Stewart, 1980). We have approximated that nearly 4 trillion gallons of water naturally recharge the Floridan aquifer system each year. Artificial recharge through spray fields, percolation ponds, and other means is insignificant compared to the natural recharge. Natural discharge from the Floridan aquifer system is estimated at nearly 3 trillion gallons per year (Berndt et al., 1998). Almost one trillion gallons of water are pumped from the Floridan each year (Marella, 1998). These figures are rough approximations for comparison purposes within the Floridan aquifer system. The same trends can be observed in the intermediate aquifer system and confining unit and the surficial aquifer system.

Utilizing these approximate calculations, the natural recharge to the Floridan aquifer system is roughly equal to natural discharges and pumping. In general the Floridan potentiometric surface fluctuates in response to natural conditions. Most of the state has experienced declines of less than 3 meters since 1980 (Berndt et al., 1998). Only in areas of heavy demand has the potentiometric surface shown a significant decline (Berndt et al., 1998). In fact, as the result of water-management changes in the state, the Floridan potentiometric surface has recently risen in areas where significant declines had occurred prior to 1980 (Berndt et al., 1998).

Vast quantities of nonpotable mineralized (saline) water are present within the Floridan aquifer system. Treatment of mineralized waters to produce potable water by reverse osmosis (RO) or desalinization has become a viable option as water demand has exceeded local supplies in some areas of the state. RO is more expensive than treatment of potable ground water and produces a brine as a by-product. The brines are generally injected deeper into the Floridan aquifer system, below the mineralized water-producing zones.

The storage of excess surface water in the subsurface is gaining acceptance in Florida. In this method, Aquifer Storage and Recovery (ASR), freshwater is stored in saline portions of the Floridan aquifer system. Excess water during the wet season is pumped into the subsurface where it forms a freshwater bubble. The water can then be retrieved for use during times of peak demand. The stored water interacts with the limestone which alters the water composition (Arthur et al., 2001). Currently, there are more than 35 ASR sites in Florida (Ellison, 2000). As many as 300 ASR wells are proposed as part of the South Florida (Everglades) Restoration effort. These are designed to capture one billion gallons of water per day during the wet season and make it available during the dry seasons for maintenance of water flow to the Everglades and for other uses.

## Florida's Springs

Florida's abundant springs are an important natural resource that draw visitors to the state each year. The springs are the result of the extensive karstification of much of Florida. Of the more than 320 springs that exist in Florida, many have undergone degradation due to decreased flow rates and increased nitrate content. With greater demand for freshwater, pumping has lowered the potentiometric surface enough to affect some springs discharge. In some cases, such as Kissengen Spring in Polk County, spring flow has ceased.

Nitrate levels in Florida's ground water have historically been less than one milligram per liter. An alarming trend recognized in many springs is an increase in the nitrate concentration to near or more than one milligram per liter. This can have dramatic effects on the aquatic cave flora and fauna. The Florida Department of Environmental Protection has recognized the major threats to Florida's springs and created the Florida Springs Task Force in 1999. The Task Force is preparing recommendations and springs protection strategies that will be submitted to the 2001 Florida Legislature. The protection of this valuable natural resource is a major component of the water sustainability in Florida.

## Surface Water

Florida has an abundance of surface water including numerous lakes, streams, and rivers and extensive wetlands. Florida's surface waters, which result from precipitation and ground-water discharge, provide approximately 40%of the state's freshwater consumption (Berndt et al., 1998). Surface water is primarily used for agricultural and power-generation purposes. The 13 largest rivers have a combined annual average discharge of approximately 14 trillion gallons of freshwater. Significant amounts of freshwater are stored in lakes and wetlands.

The health of many ecosystems relies on the availability of fresh surface water. The surface waters of the state have been modified by man for centuries, although the impact has been particularly severe during the 20$^{th}$ century (Mossa, 1998). In man's attempts to control nature and make Florida a more inhabitable place, many ecosystems have been altered. Much of the agricultural land in southern Florida can be utilized as a direct result of drainage projects and ecosystem alteration. The Everglades is a prime example of the alteration of surface waters for man's "benefit."

## The Everglades

*"There are no other Everglades in the World. They are, they have always been, one of the unique regions of the earth, remote, never wholly known. Nothing anywhere else is like them: their vast glittering openness, wider than the enormous visible round of the horizon, the racing free saltness and sweetness of their massive winds, under the dazzling blue heights of space"* (Marjory Stoneman Douglas, The Everglades—River of Grass, 1988).

The Everglades are indeed unique. It is a landscape typified by the perception of flatness and, yet, contains amazing beauty. The diversity of its flora and fauna, the dense entanglement of the tree islands and mangrove forests, the blue-green hues of Florida Bay have attracted explorers and scientists alike. The vast organic-rich wetland sediments caught the attention of agricultural interests that ultimately had dramatic effects upon the Glades. More recently, the suburban expansion of Florida's southeastern coastal cites has invaded the realm of the alligator. Our society's desire to control nature and annex the Everglades for agricultural activities and flood control created a severe water problem, altering the character of the region. Now, in order to save the Everglades and provide for a burgeoning population, water resources must be considered in a new light.

The Everglades, Florida Bay, Big Cypress Swamp, Lake Okeechobee, and the Kissimmee River system have attracted national attention as the result of man's alteration of the environment (fig. 1). The issue has become highly political and many local, State, and Federal agencies and Native American tribes are addressing the issues of water resources and the restoration of the region. It is not only a State issue but, because the Everglades is a national treasure, it is also a Federal issue. In November 2000, Congress gave final approval to the Everglades restoration effort. Now the question is how close can the restoration come to the "original" Everglades ecosystem.

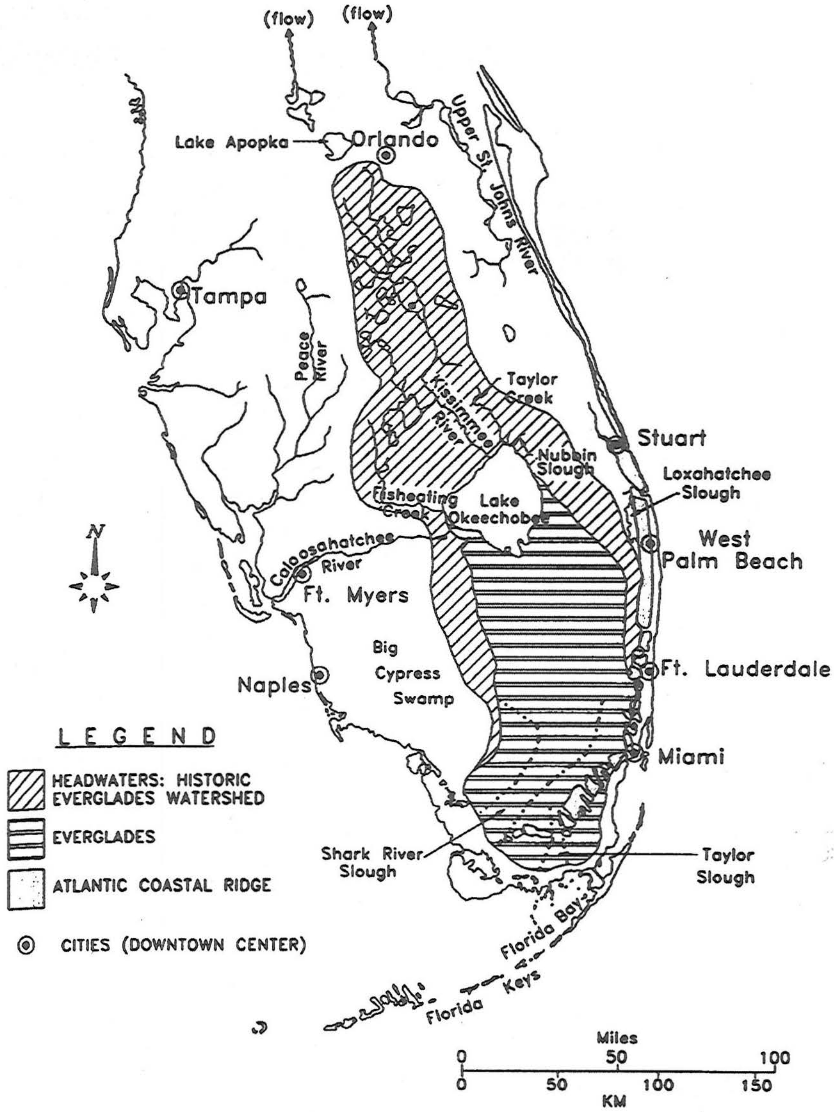


FIGURE 1—The historic Everglades watershed.

## Brief History

Native Americans occupied the region in and around the Everglades for millennia. Their influence on the natural environment was minimal as they strived to survive the floods and droughts. With the advent of cities and towns along the coast and the development of modern technologies, man invaded the Everglades. The modifications to the landscape were designed to control the hydroperiod and flow of water in the region, thereby reducing the threat of floods and improving the land for agriculture and development. As was the mindset of the time, the early Florida Geological Survey was charged with helping to drain the wetlands for agricultural purposes. During the 20th century, dikes, canals, and water-control structures became a mainstay of the southern Florida landscape as attempts were made to control nature. The sheet flow of water through the Glades was interrupted by the shunting of water to the ocean. The modifications to the hydroperiod and the lowered water levels caused numerous environmental changes. Organic soils and peat deposits dried and oxidized, resulting in a lowering of the land surface. The flora and fauna of the region were impacted and concerns for the "Everglades Ecosystem" came to the forefront.

Rapidly increasing populations of the southeastern Florida coastal cities placed a strain on the surface-water and ground-water resources. With less recharge to the surficial aquifer system and over-pumpage, coupled with natural climatic fluctuations, saltwater intrusion occurred along the coast, contaminating water supplies. With the advent of the Central and Southern Florida Flood Control District (later the South Florida Water Management District), efforts to control water use and distribution began in earnest.

## Geologic Framework

The Everglades is just the latest phase of the geological evolution of southern Florida. Millions of years of marine sedimentation interspersed with periods of deposition in freshwater environments created the late Cenozoic geologic framework of this region. However, the Everglades developed during the last 5,000 years as sea level rose in response to the melting of the North American glacial ice sheet. Within the last 100 years, human modifications have had a dramatic effect on the Glades.

The historic Everglades extend from Lake Okeechobee southward to Florida Bay. Thousands of feet of Cenozoic carbonate rocks, comprising the Floridan aquifer system, underlie the Everglades region. The aquifer system is highly transmissive and has interspersed low-permeability layers. The Floridan aquifer system is overlain by a mixture of sand, silt, clay, and carbonate sediments, forming the intermediate aquifer system and confining unit and the surficial-aquifer system. The intermediate confining unit provides an effective seal for the Floridan aquifer system.

The late Pleistocene sediments, approximately 125,000 years old, underlie the Everglades wetlands and vary from north to south. The region near Lake Okeechobee southward to the latitude of Fort Lauderdale is underlain by a mixture of fossiliferous sand and limestone, the Fort Thompson Formation. South of the latitude of Fort Lauderdale, the Miami Limestone underlies the Holocene sediments of the Everglades. Pleistocene sediment deposition along the east coast had an effect on the formation of the Everglades. The Anastasia Formation, a coquina of sand and shell, was deposited to the north of Fort Lauderdale. This unit grades to the west into the Fort Thompson Formation and to the south into the Miami Limestone. The Anastasia Formation and the coastal portion of the Miami Limestone form the Atlantic Coastal Ridge that naturally restricted the eastward flow of surface water to the Atlantic Ocean. This is an important factor in the formation of the Everglades because it forced the water sheet flow to move southward rather than eastward.

Approximately 5,000 years ago, the Everglades began forming. As sea level rose following a glacially induced low stand 17,000 years ago, marshlands of the Everglades formed in response to the sheet flow of water in southern Florida. Not only did this water flow southward, it provided recharge to the Biscayne aquifer, the primary aquifer supplying ground water to the modern cities on the southeastern coast. Some of the freshwater flowing through the Everglades was naturally channeled into Florida Bay, developing a unique and interesting eco-system in the bay. Florida Bay is the present-day site of carbonate (limestone) deposition.

## The Water-supply Problem

A slow-moving, sheet of freshwater historically flowed southward from the Kissimmee River, in central Florida, to the coastal bays of southern Florida. The sheet of water covering much of southern Florida supported a varied and unique ecosystem. At the same time, the water with its varying hydroperiod, rendered a vast area virtually unusable by man. The Everglades was often viewed as worthless wasteland inhabited by "gators" and mosquitoes. Early inhabitants believed that the area needed to be "reclaimed" and developed. In the 1800's, agricultural and development interests began constructing canals to drain the swamp with little knowledge of the impact on the environment. The 1850 Federal Swamp and Overflowed Lands Act gave the Everglades to Florida provided it could be drained. Although private efforts to drain the region failed, public efforts succeeded and, by the 1930's, 400 miles of canals had been dredged. Dredging of canals continued well into the 1900's as Florida's population grew rapidly. In 1948, Congress created the Central and South Florida Project designed to provide water and flood protection for urban development. The project was also charged with providing water for the Everglades National Park, for the preservation of fish and wildlife habitat, and the prevention of saltwater intrusion. As a result of agricultural and development interests, more than 50% of southern Florida's wetlands have been destroyed.

The alteration of the landscape has dramatically affected the hydroperiod and ecosystem of the remaining natural areas. The effects include impacts on ground-water resources, surface-water distribution, degradation of wildlife habitat, and damage to the Everglades and Florida Bay. It becomes quite obvious that the major problem is a water-supply issue—who gets the water, where the water goes, the quality of the water and the timing of its availability. In order to sustain the growth in southern Florida, avoid destroying Florida Bay, and preserve the Everglades, a balance must be achieved. There must be a sustainable water supply to meet these needs.

The water-supply problem is not only a surface-water issue. Ground water is also a major problem in the southern Florida region. The highly productive Biscayne aquifer, the only freshwater aquifer in the area, underlies part of the Everglades. The demand for water can not be met by the Biscayne aquifer alone. This creates competition for water between the human population and the environment.

## Sustainable Everglades Water Supply

Developing a sustainable water supply for the Everglades and southern Florida requires the restoration of the ecosystem and the introduction of technologies to conserve and store water. Both efforts are being conducted simultaneously and will take decades to complete. The efforts include many local, State, and Federal agencies, Native Americans, and private groups.

The restoration of the ecosystem began in earnest in 1972 with the passage of the Land Conservation Act by the Florida Legislature, which authorized the State to purchase environmentally endangered lands. The "Save Our Everglades" program was created by Governor Bob Graham in 1983. The goal of the program, a partnership between the South Florida Water Management District and State government, was to work toward restoring the ecosystem to what it was like in 1900. It affects the region that includes the Kissimmee River basin, Lake Okeechobee, the Everglades, Big Cypress Swamp, Florida Bay, Biscayne Bay, and the Ten Thousand Islands.

The Surface Water Improvement and Management Act (SWIM) of 1987 required the water-management districts to develop plans to clean up and preserve water bodies of the state including estuaries and bays. The South Florida Ecosystem Restoration Task Force, a cooperative effort between six Federal departments, began its efforts in 1993 to restore and protect the ecosystem. In 1996, the task force was expanded to include other Federal, State, and local governments and the Miccosukee and Seminole tribal representatives. The governor's Commission on a Sustainable South Florida, initiated by Governor Lawton Chiles, was active from 1994 to 1999. It was tasked with "making recommendations for achieving a healthy Everglades ecosystem. . . ."

In 1992 and 1996, the U.S. Army Corps of Engineers was authorized to conduct an in-depth review of the Central and South Florida Flood Control Project and to develop a detailed plan to restore and preserve the natural ecosystem in southern Florida. The subsequent review, the Central and Southern Florida Project Comprehensive Review Study (The Restudy), created plans to capture 1.7 billion gallons of water per day which is currently lost to the Atlantic and Gulf. This water will be stored in a series of surface reservoirs and underground through the use of proposed aquifer-storage and recovery wells (ASR) for later use. The Restudy also plans for the return of the proper quantity and quality of water to the ecosystem at the proper times. The project will cost $7.8 billion over 38 years to construct and $182 million to operate each year. The plan calls for 80% of the "captured" water to be returned to the ecosystem and 94% of the pre-drainage flows returned to the Everglades National Park. The plan is to restore the hydrology by 50% by 2010. The Water Resources Development Act of 2000, to enable the restoration plan, was passed by Congress in November 2000.

The implementation of aquifer-storage and recovery technology, in order to help maintain a sustainable water supply for southern Florida, is being considered as a portion of the restoration effort. As many as 300 wells may be drilled to depths ranging up to 3,000 feet in the Floridan aquifer system. The ASR process will be used for short-term storage of seasonal waters (wet season), longer-term storage for use in drought years, to restore ground-water levels and to enhance well-field production. For ASR to succeed, we must have a better understanding of the lithologic parameters, the short- and long-term geochemical processes, and hydrologic characteristics of the rocks. Many questions remain that must be answered prior to the wholesale implementation of major ASR programs. The implementation of the ASR project is estimated to take 20 years or more. The initial pilot project will cost $27 million.

## Sustainable Water in Florida?

Alley et al. (1999) define ground-water sustainability as "development and use of ground water in a manner that can be maintained for an indefinite time without causing unacceptable environmental, economic, or social consequences." The same definition can be applied to surface water.

In light of these definitions, a number of questions arise. Some of these are 1) What is the level of infrastructure development and population growth that is supportable by the state's water resources? 2) Should mineralized waters be considered as part of a sustainable water supply? 3) How much impact on the environment is acceptable? 4) How do we balance ecological sustain-ability with human needs and economic growth?

Statewide, Florida has an abundant supply of potable water. The rough figures for ground water show the relationship between recharge and discharge/pumping. Once the removal of water exceeds the recharge, "mining" of the more than 2 quadrillion gallons of potable ground water begins, and the resource is no longer sustainable.

Mineralized water is being converted to freshwater through RO processing. Should these saline waters be considered as part of the sustainable water supply? By the same token, should ASR water be a portion of the sustainable water supply? Does the inclusion of these waters in the sustainable supply create a false sense of plenty? Should growth management and environmental stability rely on RO and ASR waters? Is it wise to allow growth management and environmental decisions to be based on expensive alternative water supplies or is that simply avoiding the "natural" limitations?

Surface water can be used but we must first determine the amount that can be removed without harming the environment. Also, surface water is necessary for the restoration of ecosystem damage man has already inflicted.

The natural environment and our society both require plentiful, clean freshwater to thrive. Population growth requires land for development and agriculture. Anthropogenic changes in southern Florida upset the delicate natural balance that defined the Everglades ecosystem, an ecosystem controlled by its water supply and hydroperiod. The restoration of the Everglades ecosystem requires a re-allocation of water resources in the region and innovative approaches to supplying water to the environment and to the burgeoning population of southern Florida. Sustaining the restored ecosystem requires a commitment to provide the water necessary to maintain its viability.

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