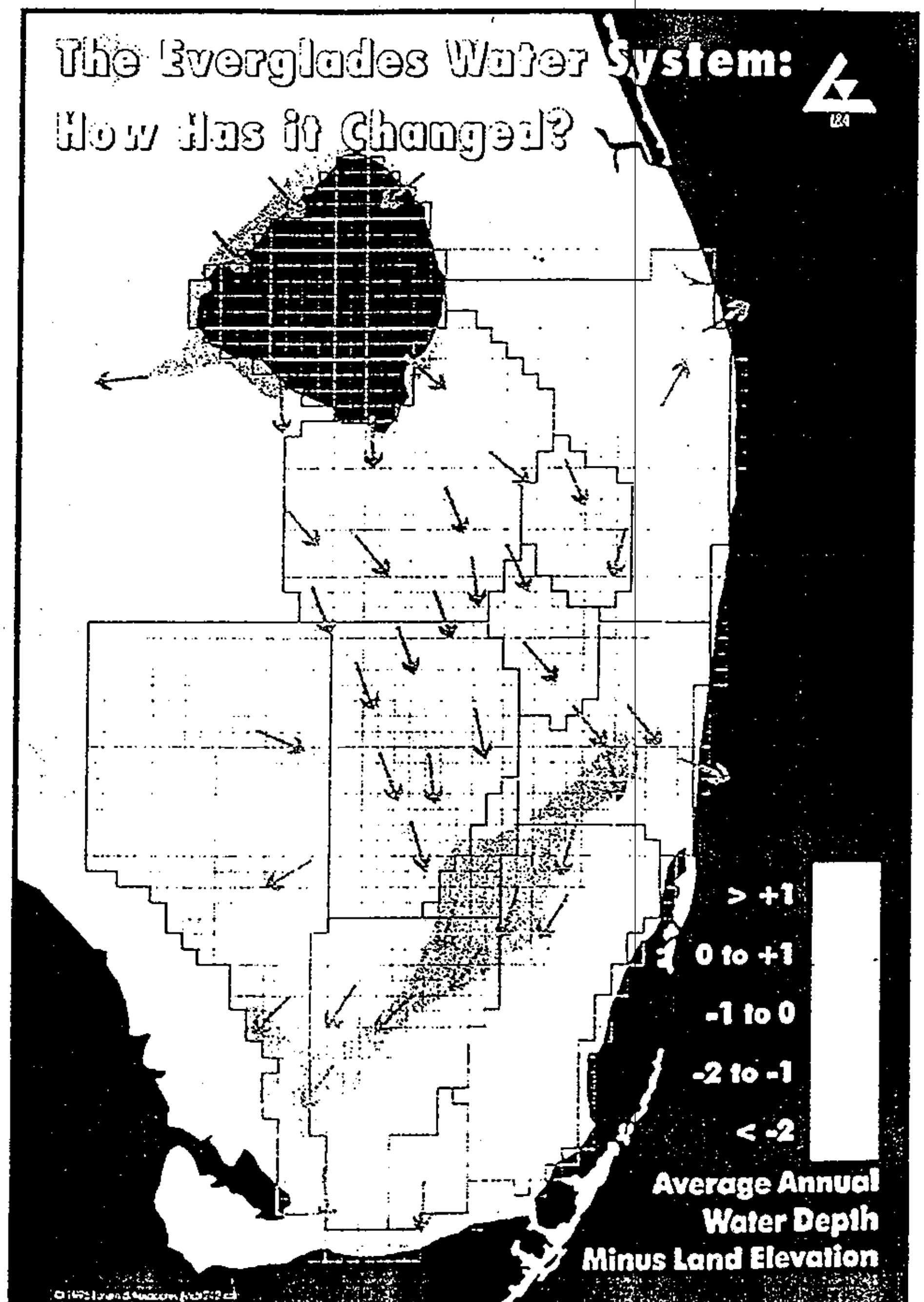
Everglades Water Budget Presentation by Technical Advisory Committee to the Governor's Commission for a Sustainable South Florida

July 20, 1995

Presentation by Mr. Paul Larsen, P.E.

on behalf of Technical Advisory Committee

to the Governor's Commission for a Sustainable South Florida



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Introduction

- This is a consensus document. It is the product of the Technical Advisory Committee (TAC) to the Governor's Commission for a Sustainable South Florida. The Committee met eleven times starting in February, 1995.

- The conclusions reached are based on the judgment of the Committee members and on the results of two hydrologic computer models developed and operated by the South Florida Water Management District. The Natural Systems Model (NSM) predicts pre-drainage flows, the Water Management Model (WMM) predicts flows based on the configuration of the modern system in 1990. Both models utilize rainfall data collected over the period 1965 to 1990.

- The members of the Committee wish to thank the staff of the South Florida Water Management District especially Dr. Wasantha Lal, Mr. Cal Neidrauer, Dr. Jayantha Obeysekera, and Mr. Randy Van Zee for their help in supplying the data.

- Responsibility for this report rests with the TAC Committee. The chairman of the Committee is Mr. Vince Amy and the vice chair, who shepherded the report through the final months, is Dr. Tom Missimer.

- We drew on the accumulated experience and different perspectives of the Committee members to prepare a document describing the physical processes affecting Everglades water regimes and how the system changed as a result of converting wetlands to lands useful for urban and agricultural purposes. We interrogated the NSM and the WMM hydrologic computer models to get numerical estimates of the magnitude of change. Our goal was to describe to the members of the Governor's Commission how the Everglades water system worked before it was affected by drainage and to compare that with how it works now. We believe that such understanding is vital as the Commission wrestles with the task of recommending a sustainable future for South Florida.

- The presentation is designed to be given verbally with two side-by-side slide projectors. This paper report follows the slide format. Nevertheless, it is this document that represents the position of the Committee.

Members of the Technical Advisory Committee

Vincent P. Amy, Chair
Thomas Missimer, Vice Chair

William Brant
  and Jorge Rodriguez
Charles E. Carraher
Michele Correia
  and Deborah Morrison
John Davis
Pat Gleason
Archie Grant
James Harvey
Aaron Higer
Lewis Hornung
William Hunt
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Albert Muniz
Jayantha Obeysekera
Richard Punnet
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Slide Presentation Design:

Dimitry Chamy, Art Direction
Kevin Plut, Technical Illustration

Contents

The Everglades Water System: How has it Changed?

Introduction: Purpose

The purpose of this presentation is to explain to the members of the Governor's Commission for a Sustainable South Florida, general and specific hydrologic concepts important to South Florida natural system enhancement, agricultural water needs, and urban water supply.

Questions We Addressed

- Key Hydrologic Elements
- How did the Predrainage System work
- How does the Modern System work
- Annual Water Budget for the entire region
- Monthly Hydropatterns
- What is the change in the quantities of water that flow to estuaries
- Determine the Predrainage and Modern boundaries of the natural system

Questions to be Answered Later

- Analysis of Seepage Barrier
- Determine quality of water that can be retrieved from urban areas
- Define practical water storage options
- Describe how East Coast Buffer Concept can assist Everglades improvements

Questions to be Addressed in this Report

- What are the key hydrologic elements?
- How did the Predrainage System work?
- How does the Modern System work?
- What is the Annual Water Budget for the entire region?
- What are the monthly Hydropatterns?
- What has been the change in the quantities of water that flow to estuaries from the Predrainage to the Modern System?
- What are the Predrainage and Modern boundaries of the natural system?

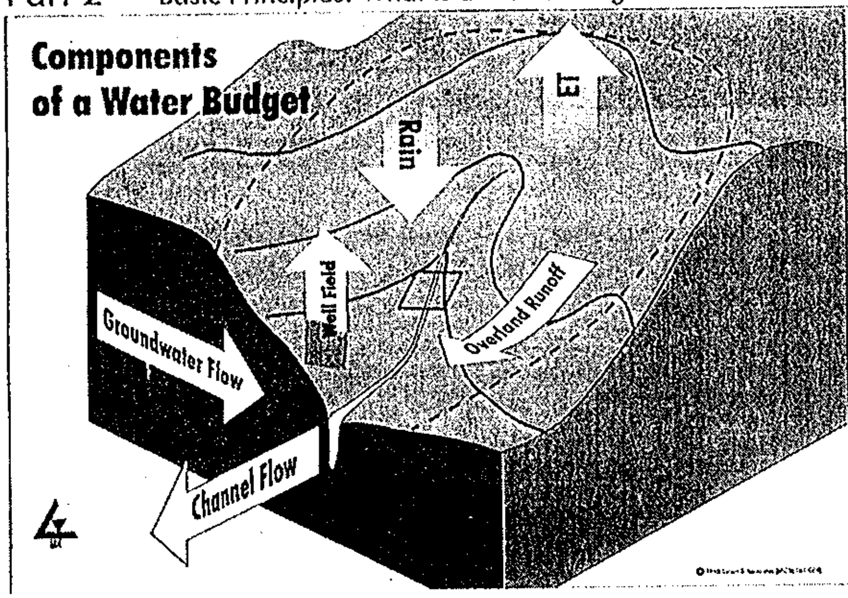
Questions to be Addressed Later

- Discuss the quality of water that might be retrieved from urban and/or agricultural areas.
- Analyze the feasibility of various seepage barriers. Do they work or not?
- Define what water storage options are practically available.
- Describe the East Coast Buffer Concept. What should its purpose be? Enhancement of the Environment? Urban water supply? Other?

Basic Principles:

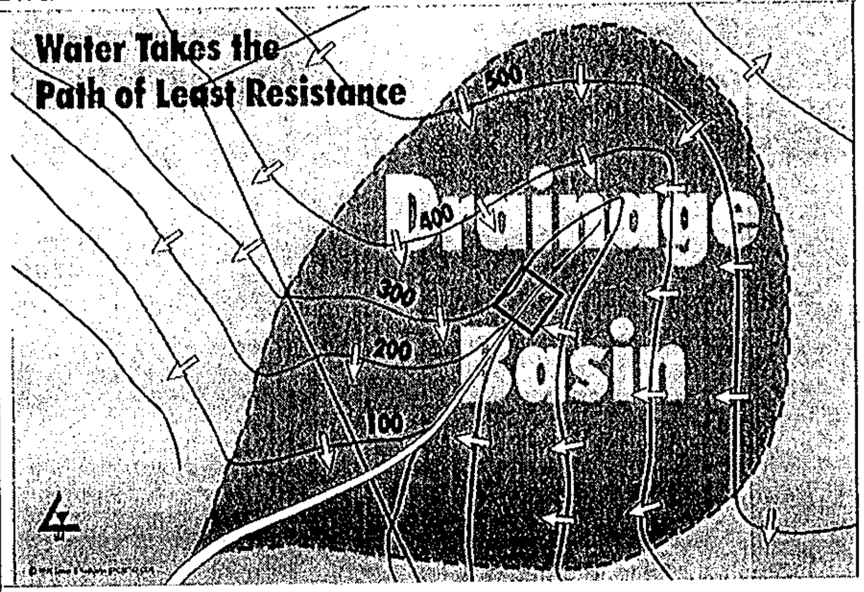
What is a Water Budget?

This part of the presentation deals with general hydrologic principles—the general approach to determining a water budget.



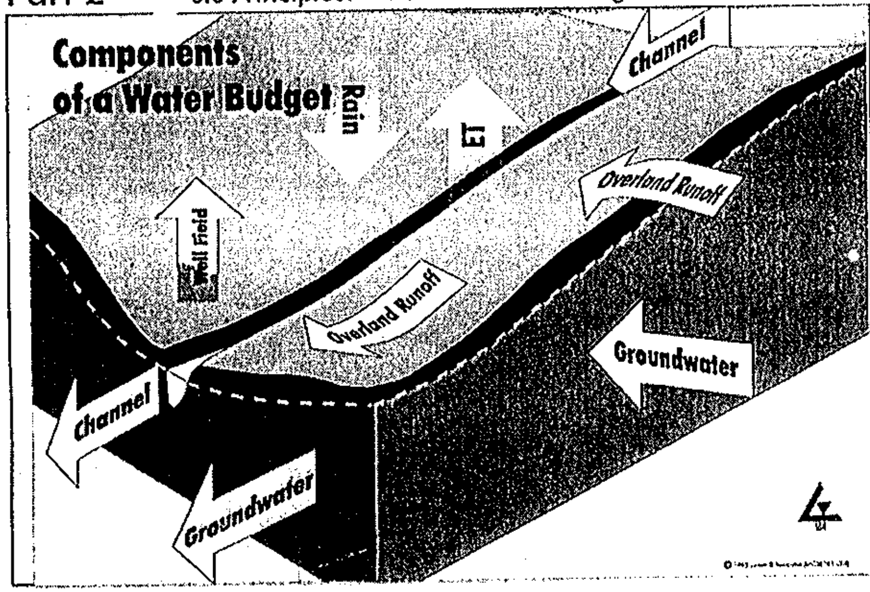
Components of a Water Budget

- Drainage Basins are typically determined by topography. These diagrams show an oblique view and plan view of the same basin. Rainfall within the basin results in overland flow, or infiltrates. Rainfall outside the basin does not contribute.
- Water Budget Components:
  - Rainfall (R)
  - Evapotranspiration (ET)
  - Overland Flow
  - Channel Flow
  - Groundwater Flow
  - Storage in Lakes, Wetlands, and in the Ground
  - Wellfield Pumping



Water Takes the Path of Least Resistance

- The plan view shows contour lines. Surface and groundwater flow is typically perpendicular to these contour lines as shown by the arrows.
- The small square area with a creek running through it is shown in more detail in the next slide.



Time 1:		Total Water Stored in the System (Antecedent Conditions)
	+	Rainfall
	+	Overland, Goundwater, & Channel Inflows
	(-)	Evapotranspiration (ET)
	(-)	Overland, Goundwater, Channel Outflows & Wellfields
Time 2:		New Value for Total Water Stored in the System (new Antecedent Conditions for next iteration)

Components of a Water Budget

- We can evaluate the same factors for any square mile or acre such as the small square area shown on the prior set of slides. For Example, the NSM and WMM hydrologic computer models* divide the Everglades into 2-by-2 mile "cells". The computers keep track of the daily inputs, outputs, and change in storage for each cell—and—how a particular cell interacts with its four neighbors to the north, east, south, and west. The computer repeatedly recalculates the interactions between cells, for each day. This is called a time step of one day.

* NSM: Natural System Model (Predrainage Everglades System)
WMM: Water Management Model (Modern Everglades System)

Analogy to Accounting

- The "Snapshot" of conditions at Time 1 is similar to a balance sheet in accounting.
- Then the effects of rainfall, evaporative processes, and various inflows and outflows are evaluated over a certain time period. This process is similar to an income/expense evaluation in accounting.
- The evaluation or "Snapshot" of conditions at Time 2 depends on the initial conditions at Time 1 plus the various inputs and outputs during the time interval.
- But while financial accounting is somewhat precise, there is substantial uncertainty associated with a water budget.

All Inflow Components are Estimates
(some are more certain than others)

- Rainfall
- Overland Inflow
- Channel Inflow
- Groundwater Inflow
- Increase in Storage

All Outflow Components are Estimates
(some are more certain than others)

- Evapotranspiration (ET)
- Overland Outflow
- Channel Outflow
- Groundwater Outflow
- Wellfield Pumping / Sewer Infiltration
- Decrease in Storage

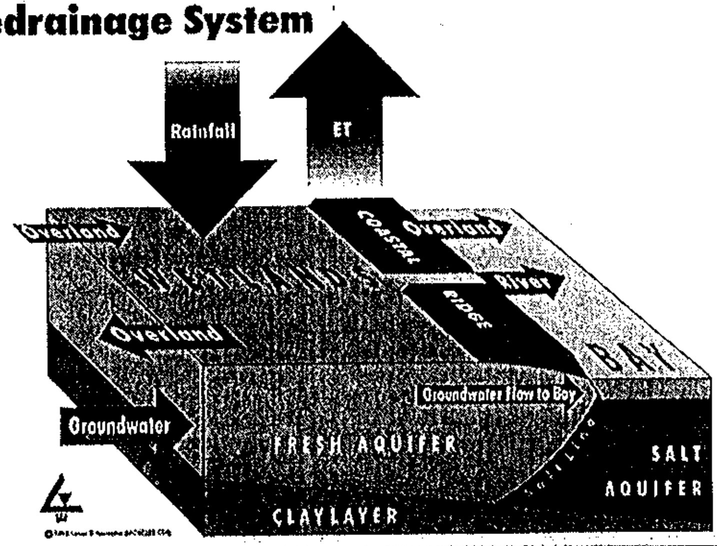
All Inflow Components are Estimates
(some are more certain than others)

- **Rainfall** is measured at a number of stations. The rainfall for a particular station is typically applied to an area stretching halfway to the next station. In this part of Florida, however, rainfall can be very localized. For example, you will recall that at times, television weather reports show very different storm quantities for the Miami Airport and Miami Beach.
- **Overland flow** depends on the depth of flow, slope of the land, and resistance to flow (friction) by vegetation. Flow is extremely sensitive to the value selected for friction and there is substantial uncertainty in the friction term.
- **Channel flow** depends on the shape and size of the channel and the slope of the water surface. Research on channel flow has been extensive and mathematical models are reliable.
- **Groundwater** flow depends on the thickness and properties of the rock and the downward slope of the water table. Mathematical relationships are reliable, however, it is difficult to determine the properties of the rock.
- **Storage** depends on depth of the water table and on properties of the soil.

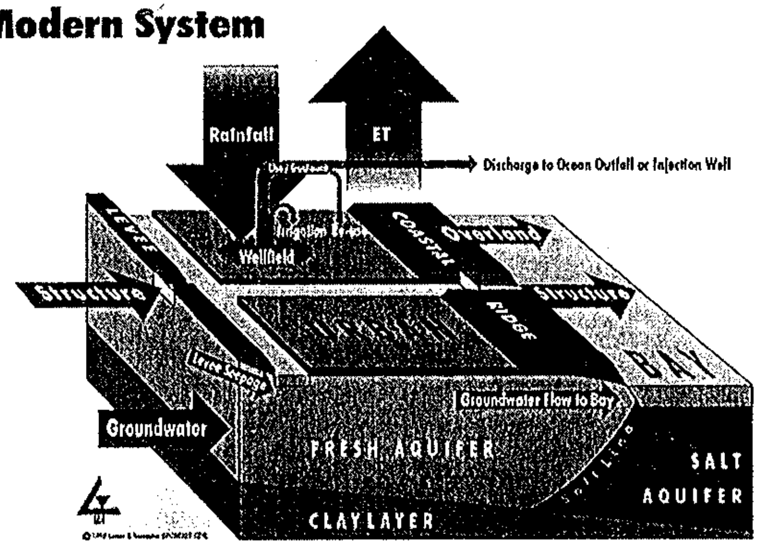
All Outflow Components are Estimates
(some are more certain than others)

- **Evapotranspiration** is influenced by many factors including depth of standing water, depth to the underground water table, sunlight or cloudy days, length of the day, humidity, type of plants, impervious cover such as roofs or pavements, etc. There is substantial uncertainty associated with this term. In the NSM and WMM models, ET is determined by sub-mathematical models.
- **Urban Wellfield Pumping, Municipal Water Supply**. Some water remains in the system as irrigation. Infiltration to sewer systems causes losses.
- See above descriptions for **overland flow, channel flow**, storage and **groundwater flow**. They are the same for inflow and outflow.

Predrainage System



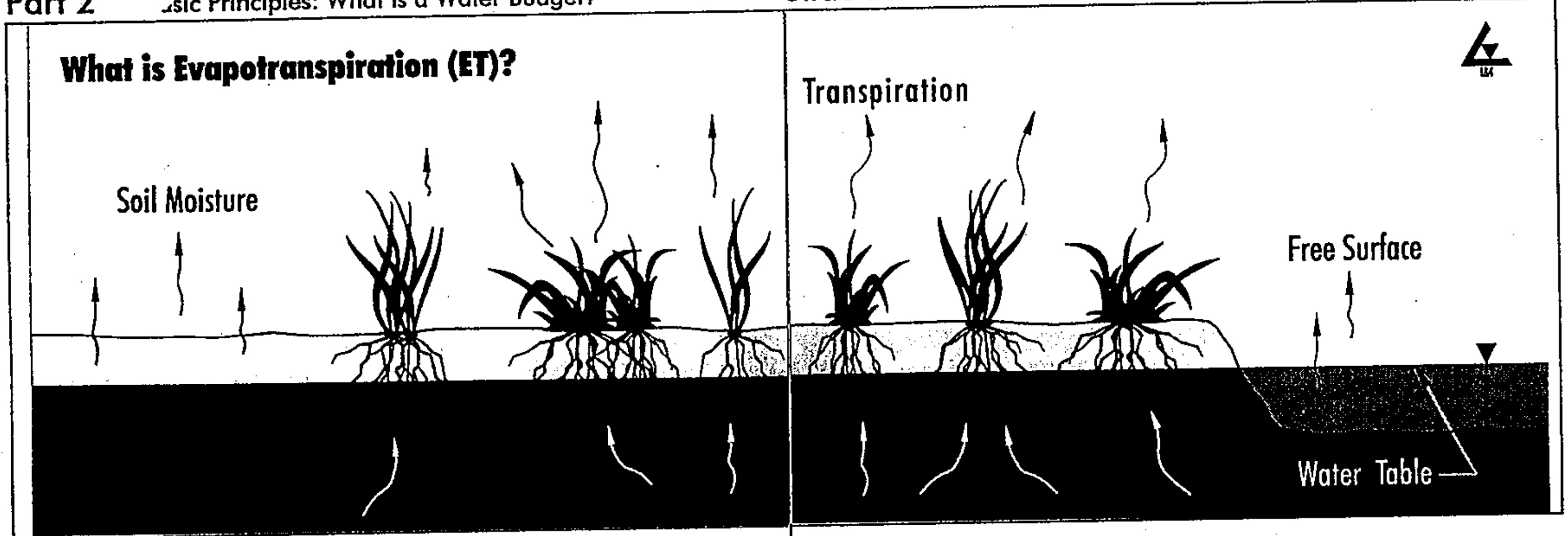
Modern System



Dealing with the Uncertainty of Hydrologic Models

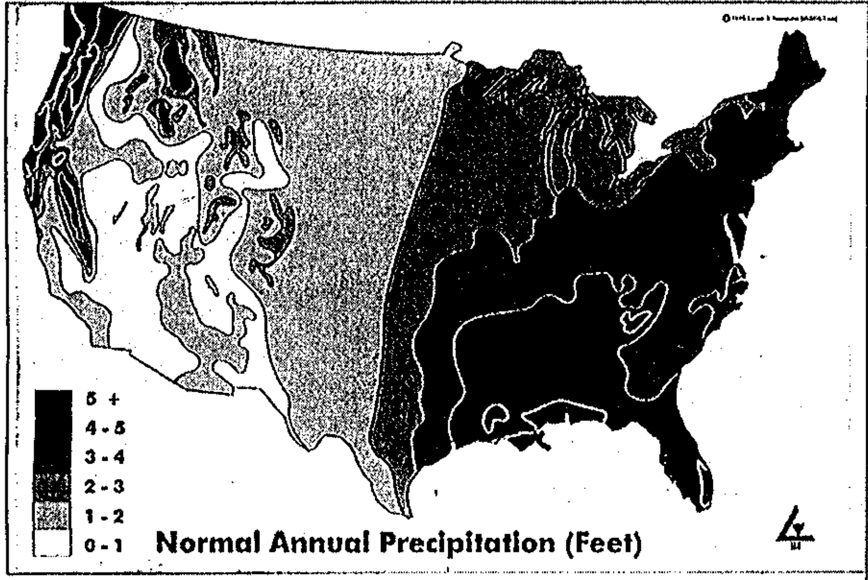
- All hydrologic models are uncertain and should be used with caution.
- The NSM model is more uncertain than the WMM model and its output should be used with more caution.
- Wherever possible, modelers calibrate the various parameters to known flows and data.
- All model results are checked for reasonableness. For example, inputs need to approximately equal outputs.
- An analysis of sensitivity to various parameters is carried out. In South Florida model results are especially sensitive to values selected for:
  - Evapotranspiration (ET)
  - Friction term for overland flow
  - Topography
- It was possible to compare the WMM model with actual data. Of course, there are no direct Predrainage hydrologic data available for the NSM so it is assumed that various parameters for ET and friction, for example, are the same as those in the WMM model.

- The Technical Advisory Committee has reviewed the issues of certainty and calibration and has concluded that the NSM and WMM models represent the best available tools for evaluating relative change between Predrainage conditions and Modern conditions.
- In addition, the Committee concluded that the WMM model is very useful in evaluating relative change between various remedial alternatives.
- The Committee cautions, however, that the NSM model does not represent absolute Predainage hydrological conditions. For example, the NSM is based on rainfall between 1965 and 1990. Modern rainfall may be different than Predrainage rainfall.
- The slides show typical hydrologic components that apply to the NSM and WMM models.



What is Evapotranspiration (ET)?

- In the Everglades wetlands, ET is by far the largest outflow term in the water budget and can amount to 90% (or more) of rainfall.
  - The primary process involved in ET is the relentless wicking of soil moisture from roots to evaporation from leaves to maintain the plant's life processes.
  - A second process is evaporation from a free water surface.
  - A third process is direct evaporation of soil moisture to the atmosphere.



Map Showing USA Rainfall

- This map shows feet of average annual rainfall in the U.S.
- Southern Florida is one of the highest rainfall areas in the country.

Photo of Rain

Units

Time: months or years

Depth: inches or feet

Area: acres or square miles

Volume: acre feet (AF)

Units

- We recognize that there is confusion concerning units—especially concerning those that measure volumes of water. We typically use Million Gallons per Day (MGD) to describe wellfield withdrawals. We use Acre Feet per Year to describe ET from the Water Conservation Areas (WCAs).
- In this presentation we will attempt to use consistent units of Acre Feet (AF) to express volume of water.
- An Acre Foot is a volume of water covering one acre (209 feet by 209 feet) to a depth of one foot. For reference, an acre is approximately equal in area to a football field including the two ten yard end zones and two ten foot wide sideline areas. An acre foot is 43,560 cubic feet of water which is equal to 326,000 gallons. One Million Gallons per Day (MGD) is the same as 3.07 Acre Feet per day or 1120 Acre Feet per year.

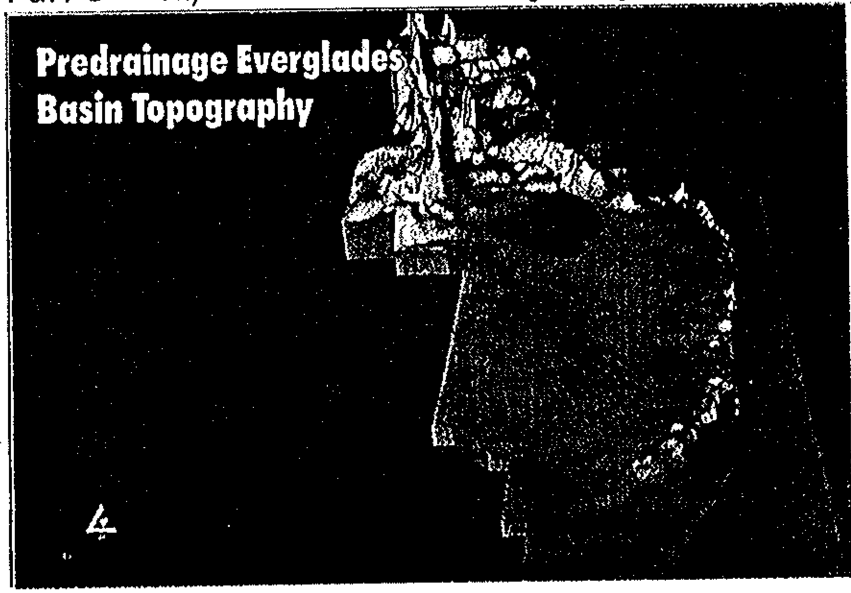
Example: How much water is 1,000,000 Acre Feet?

- 893 Million Gallons per day (MGD) on an annual basis
- 1.20 feet of water covering 1350 square miles of all the WCAs (1, 2A, 2B, 3A and 3B)
- 2.25 feet of depth covering 700 square miles of Lake Okeechobee
- at 179 gallons per person per day, enough water to supply 5 million people for one year
- Approximately double recent past average annual Tamiami Trail flow to Everglades Park

- **Example:** How much Water is 1 Million Acre Feet (AF)?
  - This slide shows values that are equivalent to 1,000,000 AF.
  - **When dealing with Everglades issues, we suggest thinking in terms of 1,000,000 AF. You might call it an "Everglades Unit."**
  - We recommend that various ideas for conserving water such as re-use, Xeriscaping, conservation, water rates, Aquifer Storage and Recovery (ASR), Seepage Barriers and so forth, be quantified in Million Acre Feet units.

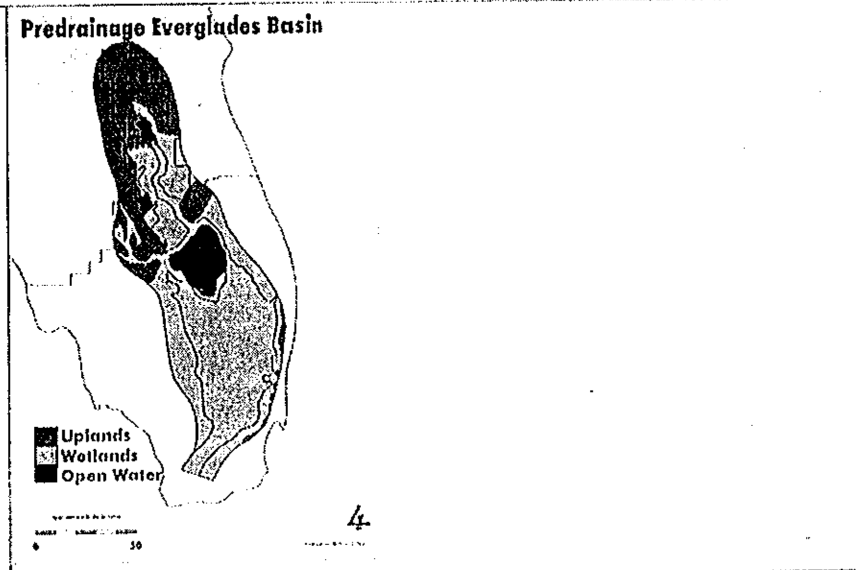
Physical Features of the Predrainage Everglades Basin

Understanding Everglades Issues requires that we understand the Predrainage Everglades Basin (i.e., before 1880) and how it has changed.
This is a brief description of that system and how it worked before being changed by man.



Map of the Everglades Drainage Basin

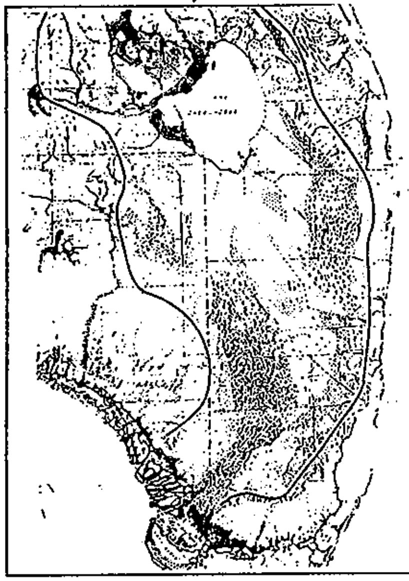
(topography is exaggerated)



Predrainage Extent of the Everglades Basin Based on Topography*

- Wetlands (regulatory definition)
- Uplands
- Lakes
- Coastal Ridge

*Note: Please see slide pair 05 which shows how a drainage basin can be determined by topography



Correlation of Topographic Drainage Basin and Vegetation

- This shows the correlation of the Predrainage topographic basin with the 1943 John Davis Map.

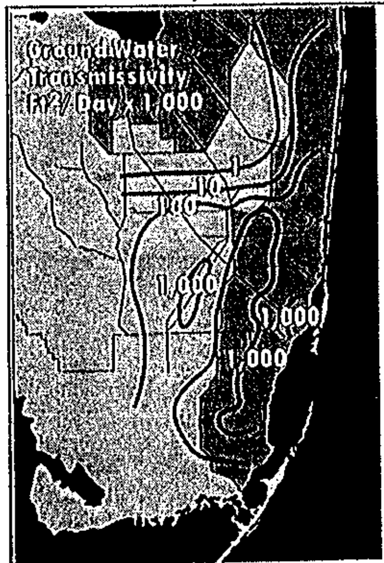
Source: Based on 1943 John Davis Map

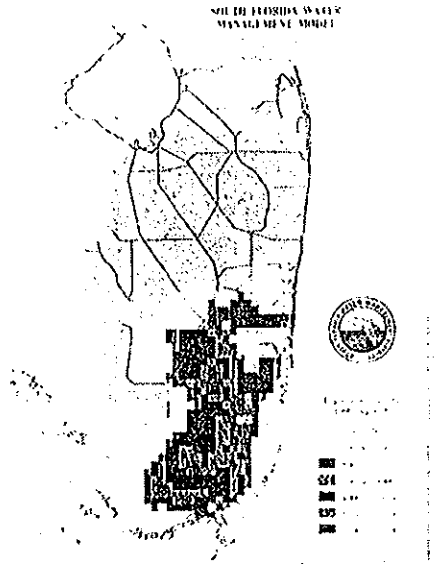
Correlation of Topographic Drainage Basin and Modern Satellite Image

- This shows the correlation between the Modern features as described by a satellite image and the Predrainage topographic drainage basin.

Sources: Satellite Image: South Florida Water Management District (SFWMD)
Topography: SCS, 1942, USGS Quad Sheets

Note: Drainage Basin Limits on both slides are approximate





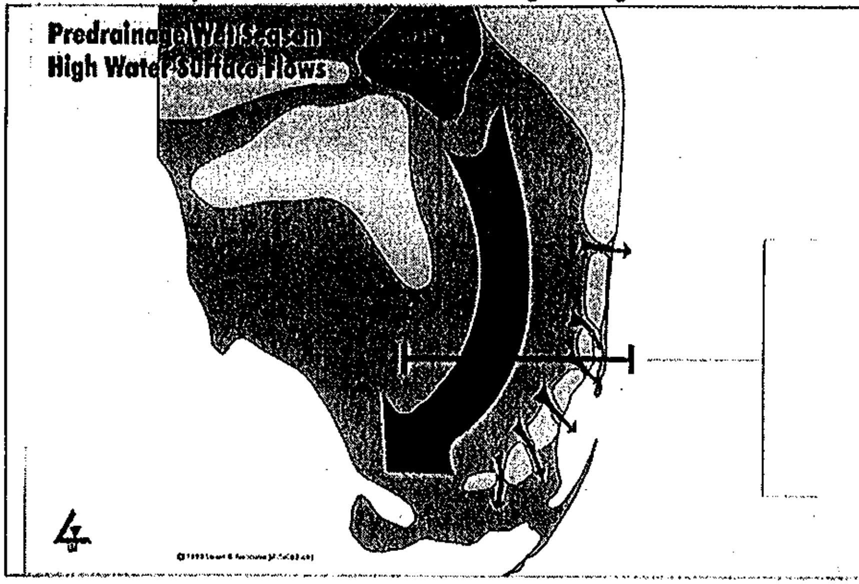
Transmissivity Contour Map

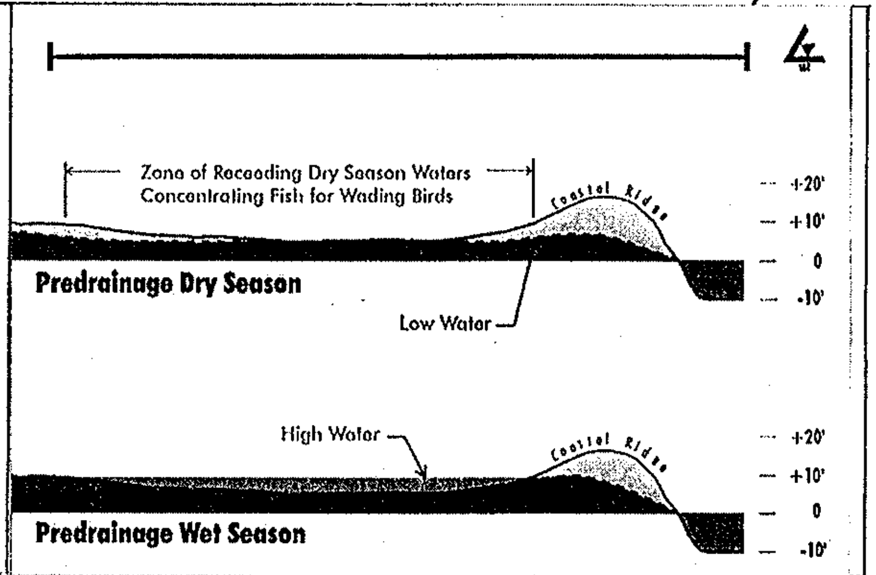
- Transmissivity* is the measure of how easily water flows horizontally through the ground.
- The contour map on the left shows that transmissivity in large parts of Dade County is 1,000 times greater than, for example, in Palm Beach County.
- This means that levees in Palm Beach County are effective in retaining water since low transmissivity limits the amount of seepage under the levee.
- Conversely, the Modern steep groundwater gradients in Dade and Broward County at the North-South Levee, in conjunction with transmissivity values that may be the highest in the world, provide for very high seepage rates under the levees.

* see Part 7 for an explanation of Transmissivity

Transmissivity Cell Map from NSM and WMM

- The map on the right is a cell map from the NSM and WMM models. It shows that the highest transmissivity rock is in the vicinity of the North-South levee that separates the Water Conservation Areas and Everglades Park from East Coast Urban Areas.
- East-West groundwater flow essentially did not exist at the North-South Levee location in Predrainage times. This was because there was essentially no east-west groundwater gradient at this location. Now, a steep gradient at this location results from the need to provide low water tables and flood protection in urban areas and to allow higher water tables to promote Predrainage System values in the adjacent Everglades Park and WCAs.
- Drainage of urban areas is accomplished by a network of canals that presently discharge local stormwater to the ocean. These canals also intercept a large portion of the seepage from the Water Conservation Areas, and discharge it to the ocean as well.
- The issue of transmissivity will be covered in more detail in a later part of the presentation.





Plan View: Function of Predrainage Everglades System*

- Plan view of high water conditions showing some surface overflow through the Coastal Ridge. During the wet season, increasing depths of surface water provided by an excess of rainfall over evapotranspiration slowly worked their way to the south as overland flows to the Estuaries. These flows diminished as a dry season excess of ET over rainfall caused water levels to drop. This all occurred in a gradual, somewhat predictable, cycle.
- The location of the cross section is shown on the left hand slide.

*Note: generalized, not to scale

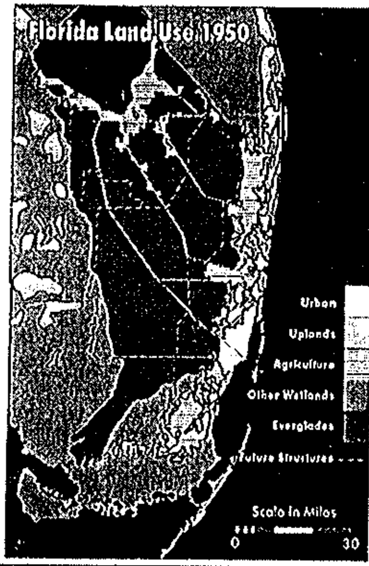
Cross Section View: Function of Predrainage Everglades System*

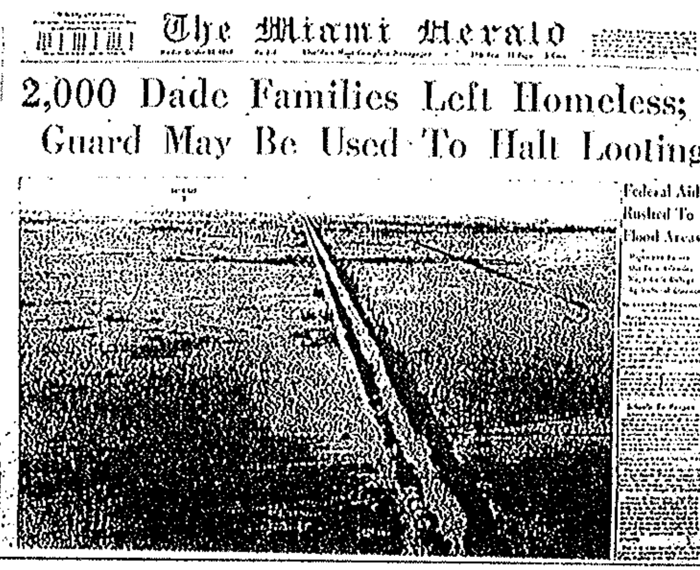
- The slide on the right shows low and high water conditions in a cross sectional view. Falling dry season water levels provided a receding drying edge that concentrated fish in isolated ponds. One theory is that these fish provided food for wading birds during the late winter period of nesting and fledging.

*Note: generalized, not to scale

Physical Changes to the

Predrainage Everglades Basin




The Miami Herald

2,000 Dade Families Left Homeless; Guard May Be Used To Halt Looting

Federal Aid Rushed To Flood Areas

Florida Land Use in 1950

- Conditions in 1950 were substantially different than in 1880—or in 1994. Along the East Coast there was much less urban land and much more agriculture than now. There was much less agriculture in what is now the EAA.
- Efforts to drain the Everglades began in 1880 and accelerated in the early 1900's. By 1920, several canals linked Lake Okeechobee with the Atlantic Estuaries. These canals passed through and served to partially drain portions of the Everglades.
- The early system resulted in overdrainage of wetlands during the dry season with subsidence and fires in natural areas as well as in agricultural lands. There are several instances where the muck soils burned all the way down to the underlying rock.
- By 1940, Lake Okeechobee had already been surrounded by levees and Lake levels had been lowered by about six feet from Predrainage condition.
- In the first half of the century, water was treated as the "enemy" and the drainage plan was simple: route water to the ocean.

Photo of 1947 Flood

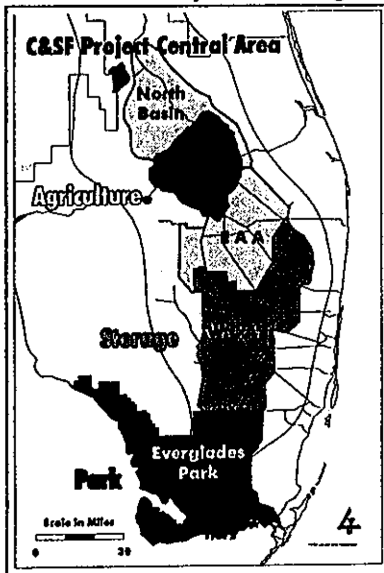
- The Early drainage system was a failure. It likely worked for an "average" year but it did not deal with the extremes of flood and drought.
- The system was inadequate to deal with high rainfall events: in 1947 two back-to-back wet hurricanes caused extensive flooding of urban and agricultural areas which persisted for several weeks. This disaster provided the impetus for creating a new drainage system built under the supervision of the Corps of Engineers called the Central and South Florida Project (C&SF Project).

The North-South Levee

- After the 1947 flood it took months to lower urban water levels as there was no barrier between the Everglades and the urban areas. The key feature of the C&SF Project was the North-South Levee (also known as the East Coast Protective Levee) which allowed East Coast areas to drain to the ocean while vast Everglades areas remained flooded.

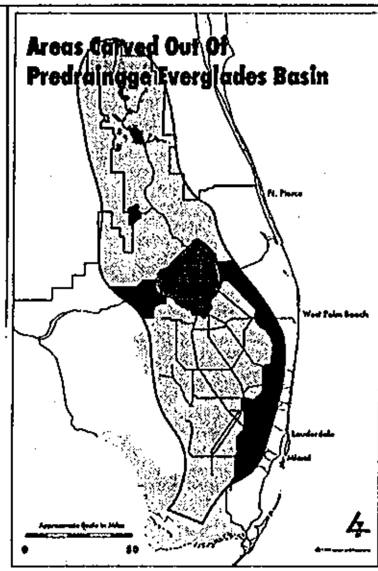
Salinity Gates

- A second feature of the C&SF Project was a series of Coastal Salinity Gates that opened to allow discharge from urban areas to the ocean, when necessary, but kept heavier salt water from migrating up the canals during the dry season when urban water levels and canal flows were low.
- Fresh water in the urban canal system is held at an elevation higher than high tide to stop the inflow of salt water through the transmissive rock (salt water intrusion).
- The issue of salt water intrusion will be covered in more detail later in the presentation.
- Because the rock in urban areas is so transmissive, the water level in the ground is approximately the same as the water level in the canal system.



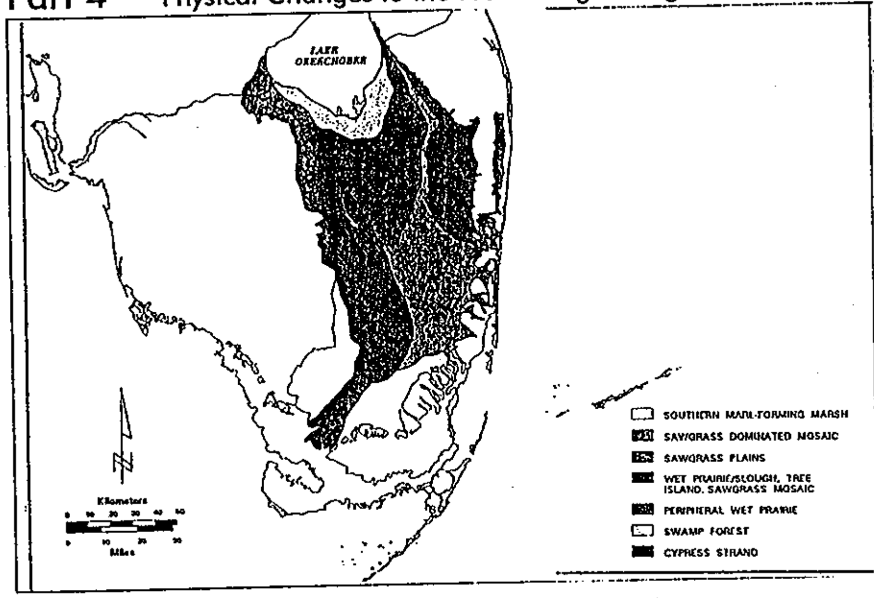
The Central Area of the C&SF Project

- Lake Okeechobee receives water from the north and from pumping from the EAA. The Lake delivers water to the EAA and East Coast via WCA canals during the dry season. In the wet season excess lake water is drained to the St. Lucie and Caloosahatchee Estuaries and, to a lesser extent, to the WCAs.
- The EAA pumps excess stormwater both to the north and south in the wet season. Since 1979, most pumping from the EAA is to the south into the WCAs. The EAA receives water from the Lake in the dry season.
- In the wet season, the WCAs receive excess water from the EAA, from urban pumps in Broward County, and from the Western Basins by gravity flow and pumps. The biggest source of water is from rainfall; the largest loss of water is to ET. Among other purposes, the WCAs serve as storage reservoirs and can supply water to urban areas and to Everglades Park during dry periods.
- Without the C&SF Project replacing the 1950 system, much of the remaining natural area would likely be severely damaged by now due to overdrainage, subsidence, and fires. The C&SF Project increased deliveries across Tamiami Trail to Everglades Park compared with the period just before the system was built.



Lands Carved out of the Predrainage Everglades Basin

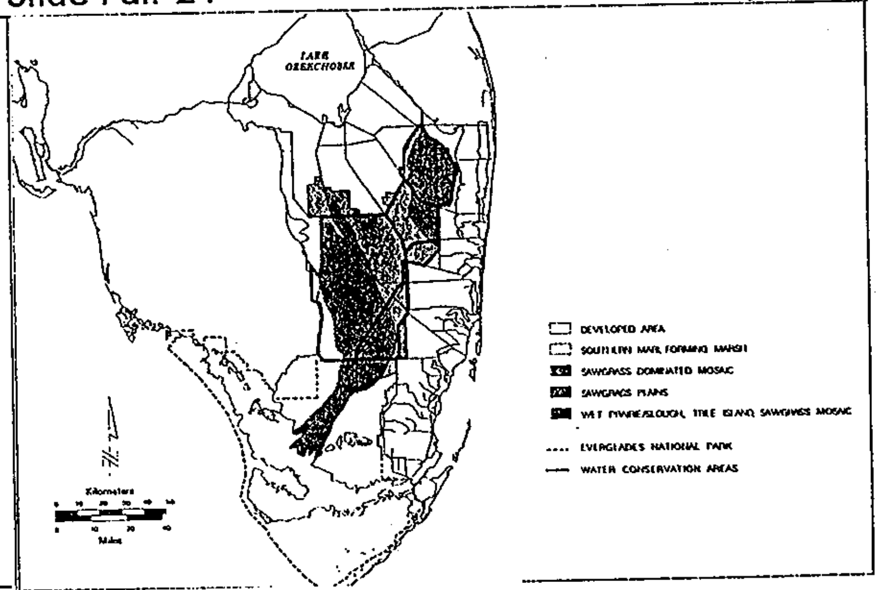
- This shows areas carved out of the Predrainage Everglades Basin. Most of this land along the East Coast has been urbanized.
- This included the lands of highest rainfall along the coast.
- Before drainage, stormwater from these coastal areas formerly flowed west and contributed to the Everglades—now flows have been reversed and vastly increased quantities of fresh water are discharged to the Atlantic Estuaries compared with Predrainage flows.
- Now, instead of contributing **to** the system, these East Coast Urban and Agricultural Areas need to be supplied **from** the WCA system in the dry season.



Predrainage Everglades Vegetation

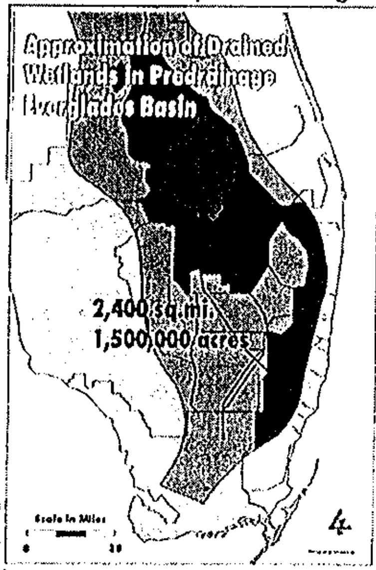
- These maps show the extent of the changes to the Everglades due to drainage, agriculture, and urbanization.

Source: Davis and Ogden, The Everglades, 1994, Plate 7



Modern Everglades Vegetation

Source: Davis and Ogden, The Everglades, 1994, Plate 8



Wetland Areas Drained by the C&SF Project

- Back-of-the-envelope calculations show:
  - The C&SF Project has allowed drainage of approximately 1,500,000 acres of wetlands (since Predrainage) for urban and agricultural purposes.
  - Assuming water levels have generally been reduced about two feet in those 1,500,000 acres, storage has been reduced by about 3,000,000 AF.
  - The approximately 500,000 acre Lake Okeechobee has been lowered about 6 feet, reducing storage by another 3,000,000 AF.
  - Total storage loss from the system may be as much as 6,000,000 AF.
- This previous storage had worked to smooth out the effects of erratic rainfall allowing water to recede gradually during the dry season as well as ameliorating the effects of flood and drought. The flora and fauna of the Predrainage Everglades previously flourished under the gradual wet season-dry season changes made possible by this storage.
- Storage from a previous wet year assisted the system in a dry year.
- The Predrainage Everglades Basin was also adapted to the extremes of flood and drought, nevertheless, conditions were generally wetter and more predictable than now.

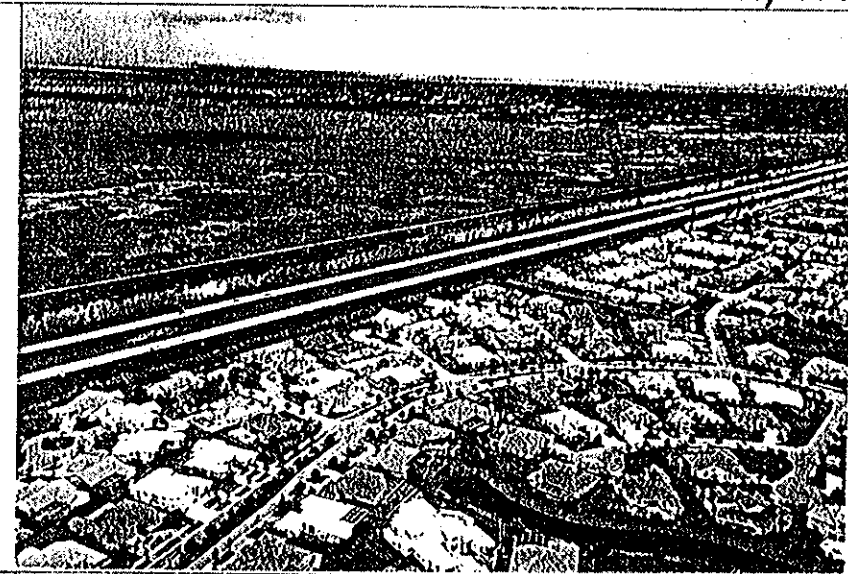
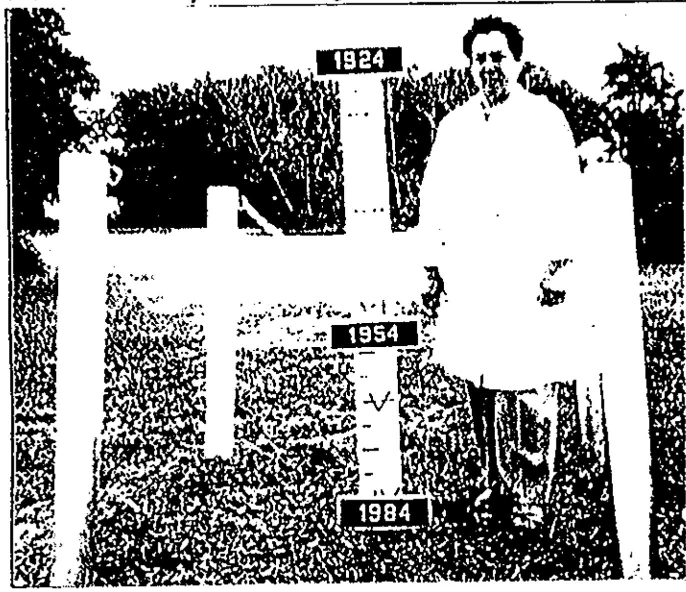


Photo of Urban Area Adjacent to Water Conservation Area

- It is important to remember that these urban areas formerly looked just like the wetlands on the other side of the levee.



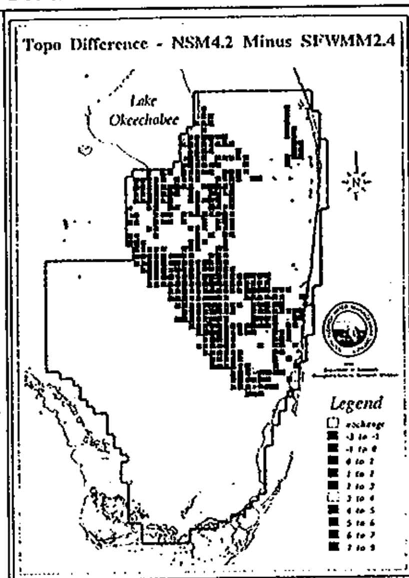
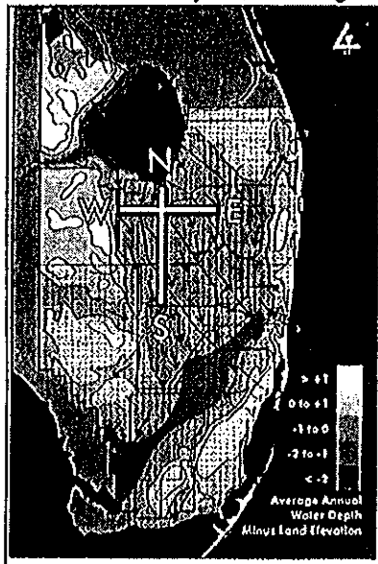


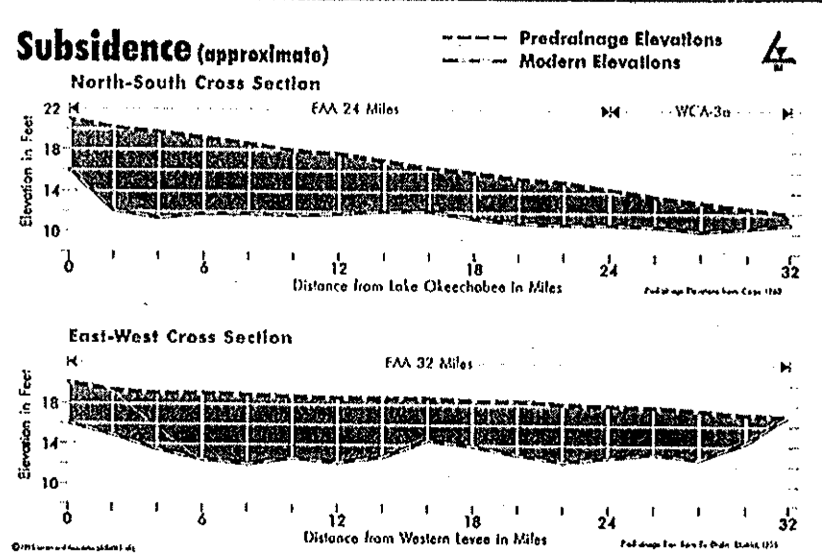
Photo of Post in EAA Showing Subsidence

- Since the early 1900s the area south of Lake Okeechobee (now the EAA) has been subject to drainage which has resulted in severe subsidence.
- Subsidence, an irreversible process whereby organic soils from wetlands compact and decompose after drainage, has been greatest (-5 feet or more) in the northern EAA where the Predrainage muck soils were deepest. The result is that the soil disappears and the level of the land decreases. There has been very significant subsidence in the EAA but this process has also occurred in the Water Conservation Areas and in the Urban areas.
- When overdrained and dried, muck soils are susceptible to fire. For example, there are locations in the north end of Water Conservation Area 3A where the soils themselves have burned all the way down to the underlying rock. These fires were especially prevalent before the construction of the C&SF Project which served to hold more water in the remaining wetlands of the WCAs and the ENP in the dry season and reduced the threat of muck fires.

WMM Model Cell Map Showing Subsidence

- This cell map shows the quantity of subsidence used in the WMM model.
- Subsidence and soil fires have significantly changed the topography of the Everglades creating a subsidence valley stretching southeast from Lake Okeechobee to Miami following the path of the early drainage canals built in the early 1900s. In general, the EAA is now a depression with land elevations that are lower than both Modern Lake Okeechobee elevations and water elevations of Water Conservation Area 1.





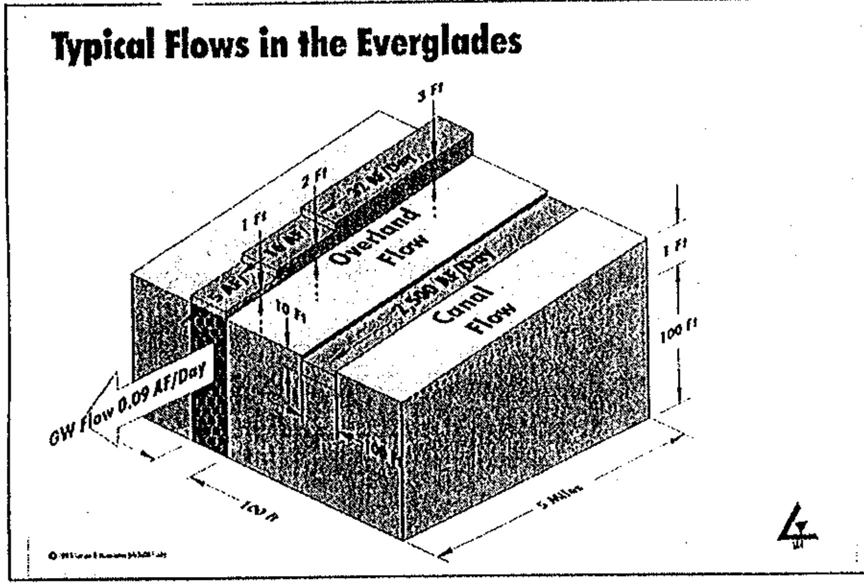
Changes Due to Subsidence

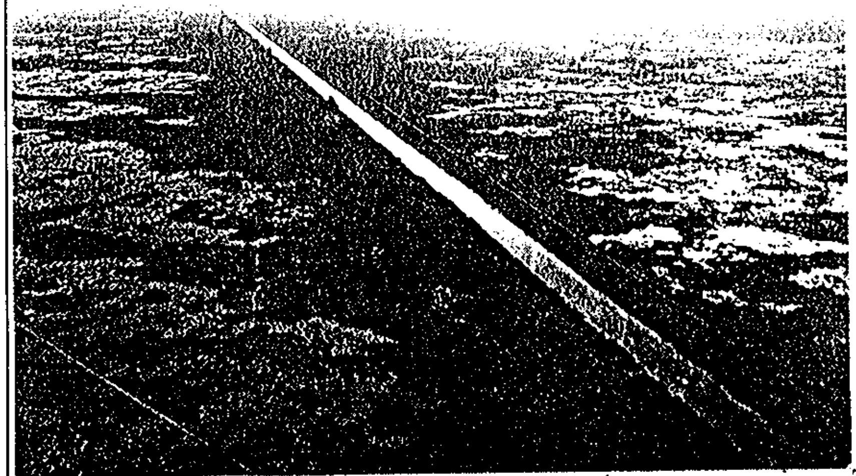
- In Predrainage times there was a gradual topographic slope extending from the Kissimmee River, across Lake Okeechobee and then on through the Everglades south of the Lake. Under the influence of wet and dry seasons, this continuous land slope annually resulted in a gradual wet cycle of increasing water levels and overland flow through wetlands, followed by a dry cycle of decreasing overland flows. A short term dry down of the wetland areas was typical at the end of the dry season.
- To keep the EAA subsidence depression from flooding, the 1948 C&SF Project included surrounding the EAA with levees and the installation of large pumps to discharge drainage out of the depression. In general, an excess droplet of rain falling on a field in the EAA has to be pumped twice: first from a secondary canal to a primary canal and second, from a primary canal north to the Lake or south to the Water Conservation Areas.
- Since 1979, water management policy has minimized pumpage to the Lake and maximized pumpage south to the WCAs. A large portion of present flow to the Water Conservation Areas is derived from drainage of the EAA. The northern portions of the Water Conservation Areas need supplemental water and currently depend on the quantity of stormwater discharged from the drained EAA. The Everglades SWIM Plan noted that the northern portion of WCA-3A was too dry. It is

Cross Sections Showing Approximate Subsidence

likely that volumes of water derived from drainage of the EAA will continue to be important in supplying water to the northern portions of the Water Conservation Areas.

- Any plan for the future of the EAA must include maintaining and operating the drainage system that deals with the shallow depression that comprises the EAA. Otherwise, the depression will fill with water in the wet season creating a huge but very shallow lake with extremely high ET rates. Without drainage, such a plan would probably significantly reduce present discharges to the Water Conservation Areas.

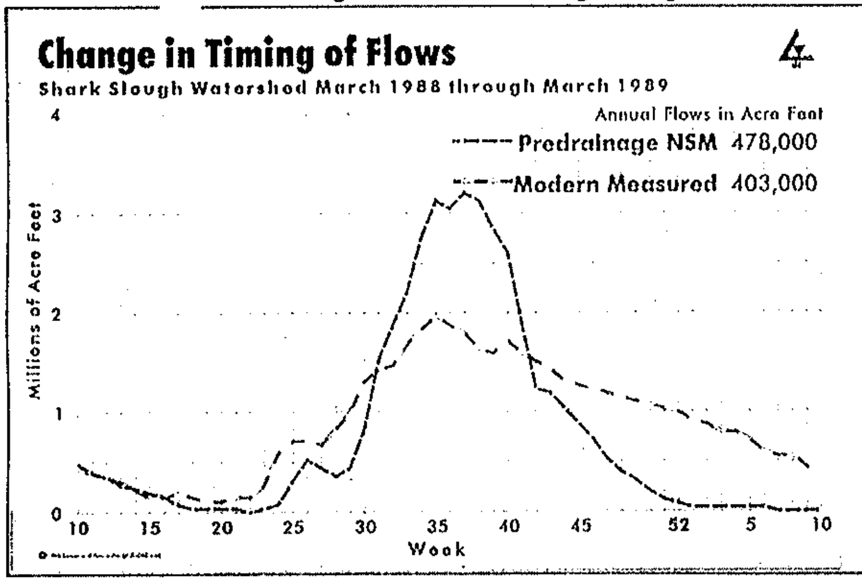




Relative Flow Diagram

- This diagram shows typical flows in the Everglades. The general slope of the Everglades is about 20 feet over the 100 mile distance from Lake Okeechobee to Florida Bay. This equals approximately one foot in vertical drop for every five miles of distance. This is the downward gradient that causes water to flow through the ground, as overland flow through vegetation, and in canals.
- The diagram shows the volumes of flow in acre feet per day for a strip of Everglades 100 feet wide for groundwater, for various depths of overland flow, and for an assumed canal ten feet deep.
- This shows the extraordinary effect of a canal. For example, assuming the typical Everglades land slope of 1 foot in five miles, a ten foot deep and hundred foot wide canal is equivalent in the ability to move water to overland flow one foot deep and 9.4 miles wide.

Photo of Canal in the Everglades



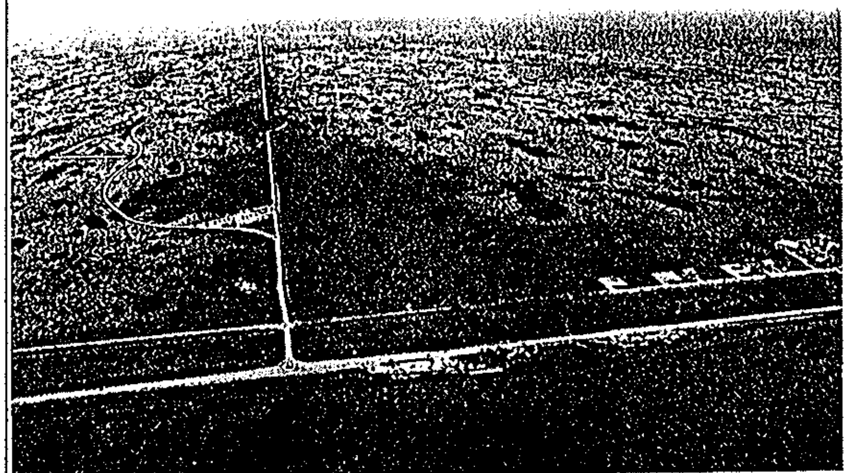
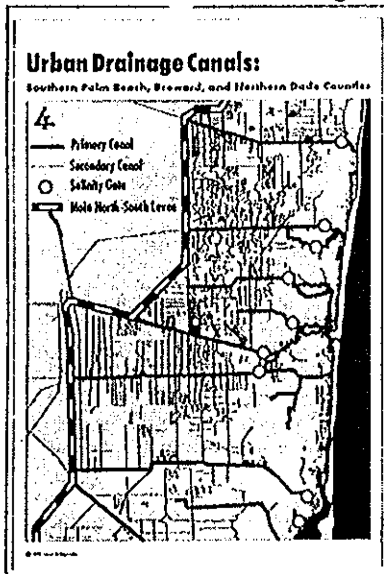


Photo of Shark Slough

Change in Timing of Flows

- In general, drainage increases the rate at which water must be discharged. This chart compares the Modern and Predrainage weekly flows in Shark Slough of Everglades Park. Flows have increased in the wet season and decreased in the dry season. This change in timing and rates of flow may be harmful to biological systems even though annual quantities may not show significant changes.
- Thus, any plans for Everglades enhancement must address timing as well as quantity of flow.



Graphic Showing Urban Drainage Canals

- A portion of the existing system of canals and pumps necessary to provide drainage to East Coast Urban Areas.
- Most urban drainage is by gravity, however, urban pumping capacity from secondary to primary canals is approximately 7,000 cubic feet per second (approximately 0.5 Million AF per month) south of the C-51 Canal. This urban capacity is about the same as WCA pumping stations S-5A and S-6 combined.

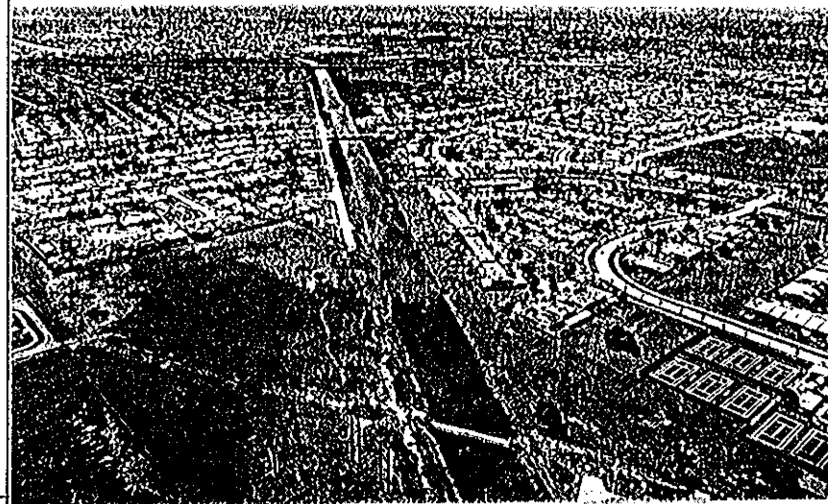
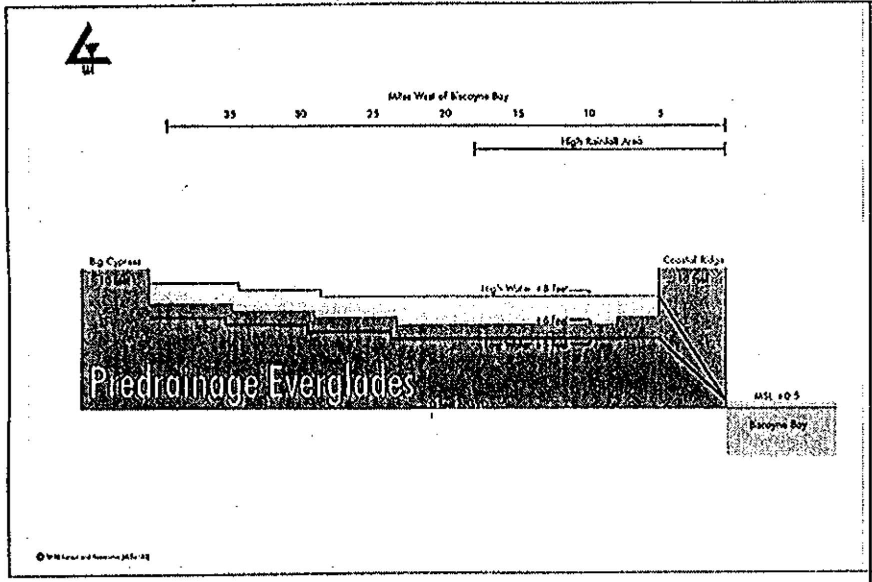
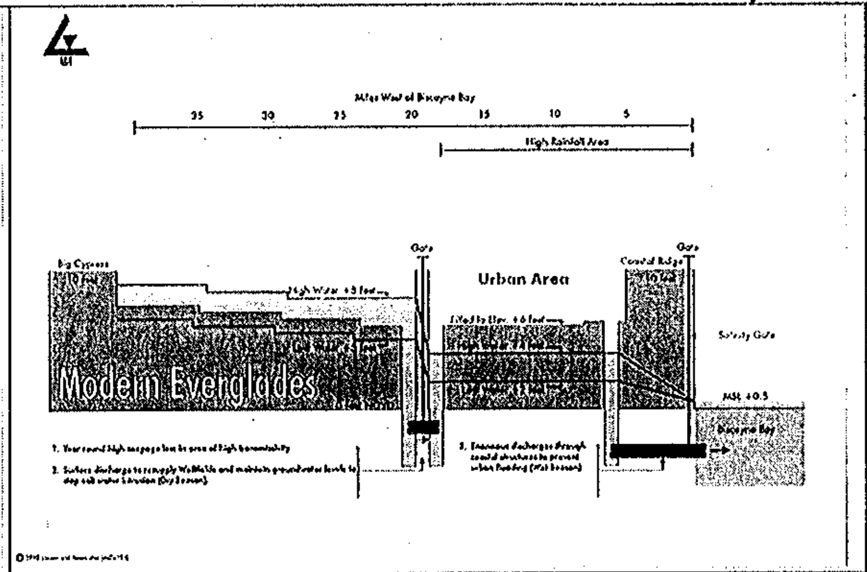


Photo of Urban Drainage Canals



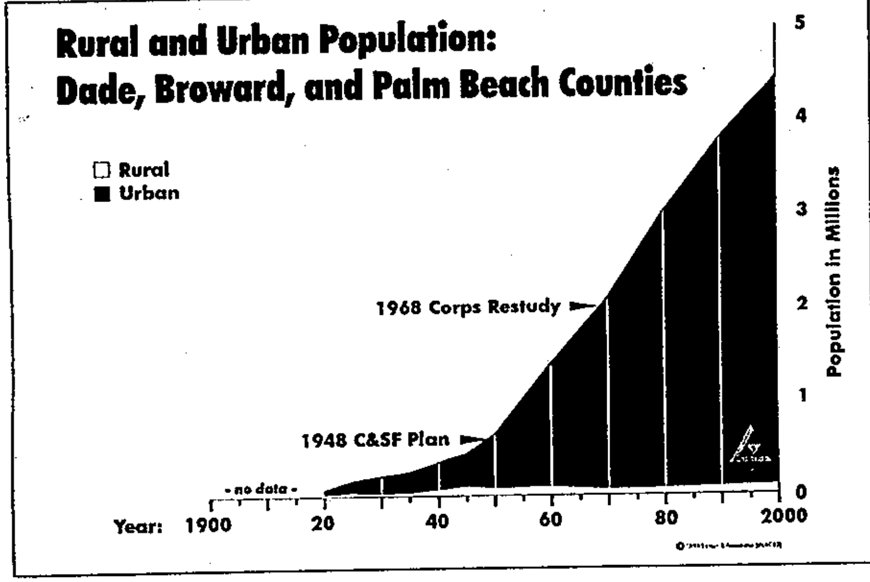
Predrainage Cross Section

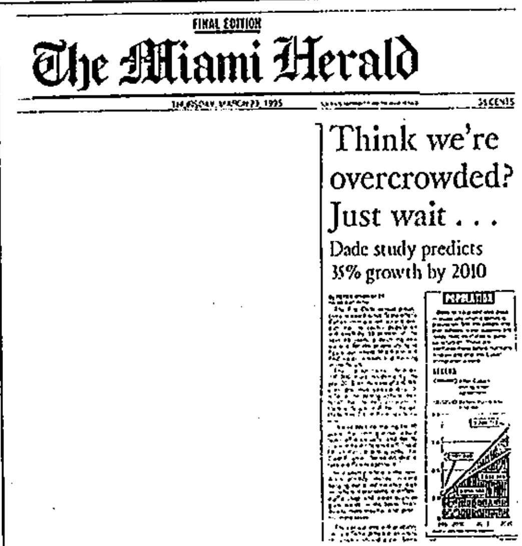
- This schematic East-West cross section shows the Everglades extending east to the Coastal Ridge at a location just north of Tamiami Trail.



Modern Cross Section

- This cross section shows the portion of the area that has been drained for urban purposes.
- Water levels in the urban areas need to be maintained within a narrow band:
  - No lower than 2 feet (which is slightly higher than high tide levels in Biscayne Bay).
  - If urban water levels are below 2 feet, then supplemental water must be supplied from the WCAs.
  - No higher than 4 feet (which provides approximately 2 feet of groundwater freeboard above the water table) to accommodate events of high rainfall.
  - If urban water levels are above 4 feet, then salinity gates must be opened to release water to the Atlantic Estuaries.
- The difference in water levels between the WCAs and the Urban Areas promotes seepage under the North-South Levee.





Population Growth in Dade, Broward, and Palm Beach Counties Since the Turn of the Century

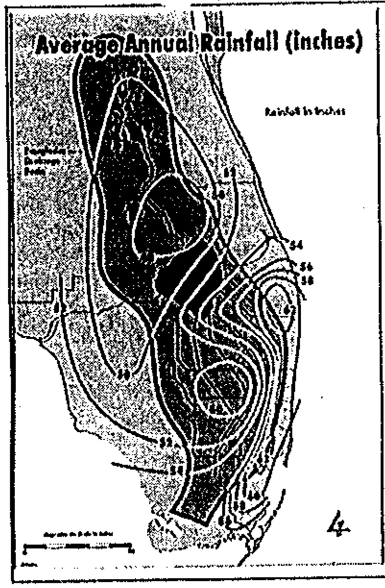
- In 1948 when the C&SF Project was planned, the population of the three counties combined was about 500,000.
- The Corps had no way to predict that an area with a generally agricultural economy would experience a ten-fold population increase in less than fifty years and become a major urban center with more than 2% of the population of the United States.
- This urban growth would not have been possible without the C&SF Project. The 5,000,000 people now living in the three-county area are more population than in 34 states. These people depend on the C&SF Project for flood control and/or water supply.
- Potable water for the population is largely pumped from wells taping groundwater east of the WCAs, however, urban potable needs do contribute to urban demands on water from the Everglades, especially during drought periods.
- At 179 gallons per person per day, 5,000,000 people use about 1,000,000 acre feet per year. A large part of that is treated and then discharged to ocean outfalls or pumped to deep wells and lost forever.
- Urban demand will grow as population grows in the future. At 179 gallons/person/day an additional 1,000,000 people will require an additional 200,000 acre feet per year.

Miami Herald Article

- Headline: "Think we're overcrowded? Just wait... Dade study predicts 35% growth by 2010"

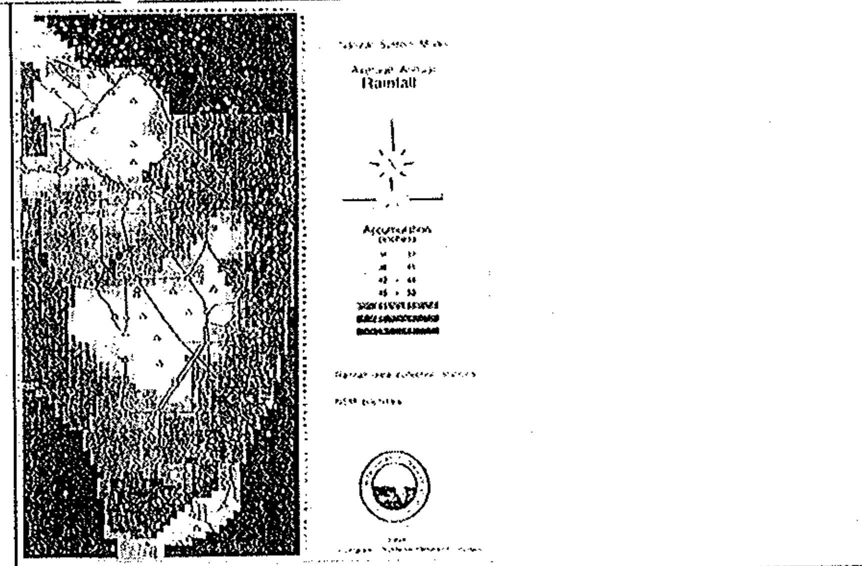
Everglades Rainfall and Evapotranspiration (ET)

In South Florida we depend on rainfall: if it stopped raining this area would be a desert in one year.



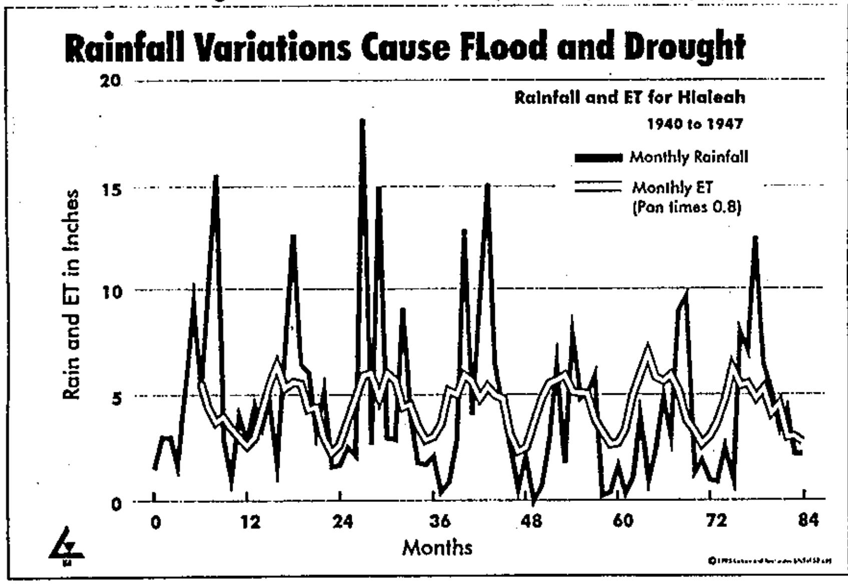
Contour Map of Average Annual Rainfall

- Coastal areas get as much as a foot (12 inches) more rainfall than the interior.
- An earlier slide showed that these high rainfall areas have been cut out of the Everglades drainage basin.
- These high rainfall areas cut out of the system formerly produced run-off that contributed to Everglades flows.
- In Interior areas of the Everglades, average rainfall is only about 50 inches per year and is approximately equal to average annual evapotranspiration (ET). Therefore, in these interior areas not much excess is produced for downstream areas.



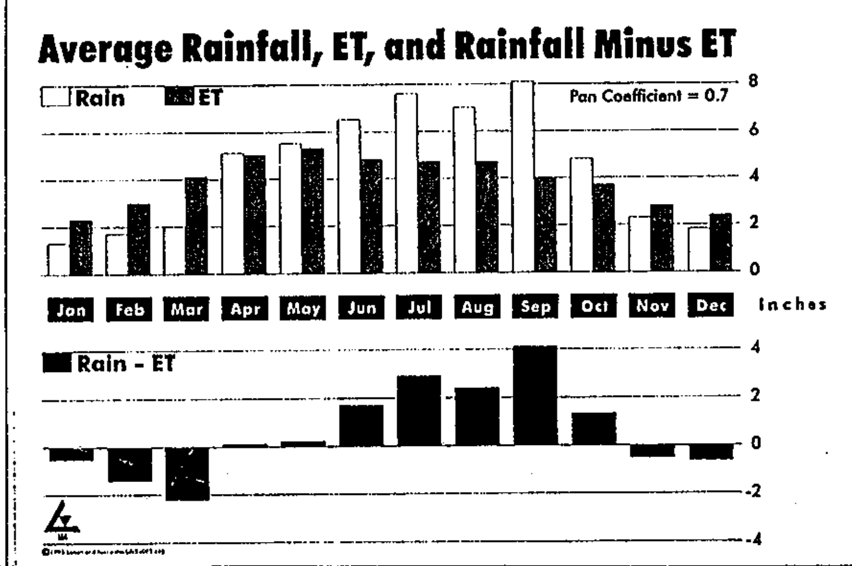
WMM Cell Map Showing Relative Average Rainfall Amounts

- This exhibit shows average annual rainfall amounts depicted in a cell map for the model.



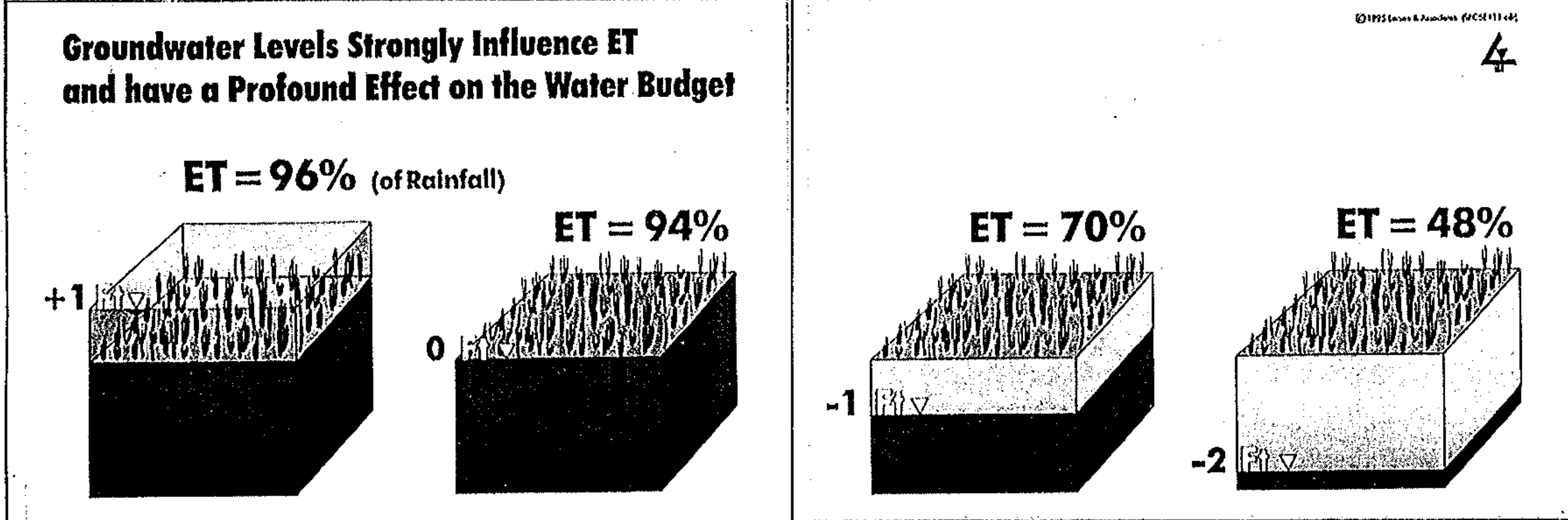
Rainfall Variations Cause Flood and Drought

- This graphic is based on data from USGS (1955, Parker, et al.) book on the Everglades and shows rainfall and ET for Hialeah. This general relationship between ET and rainfall would be the same throughout the basin.
- This graphic shows several years of monthly values showing wide fluctuations in rainfall amounts. A simultaneous plot of representative ET values is provided for reference to show that while ET varies with the seasons, it is much more predictable than rainfall.
- In general, it is rainfall variability that means we have to live with the extremes of flood and drought.



Typical Average Monthly Rainfall and ET

- This shows the familiar wet season effect when rainfall exceeds ET; and the dry season, when ET exceeds rainfall and we draw on stocks of water stored in the system.
- Note that this slide is based on average values and masks the extreme variability shown on the left hand slide.



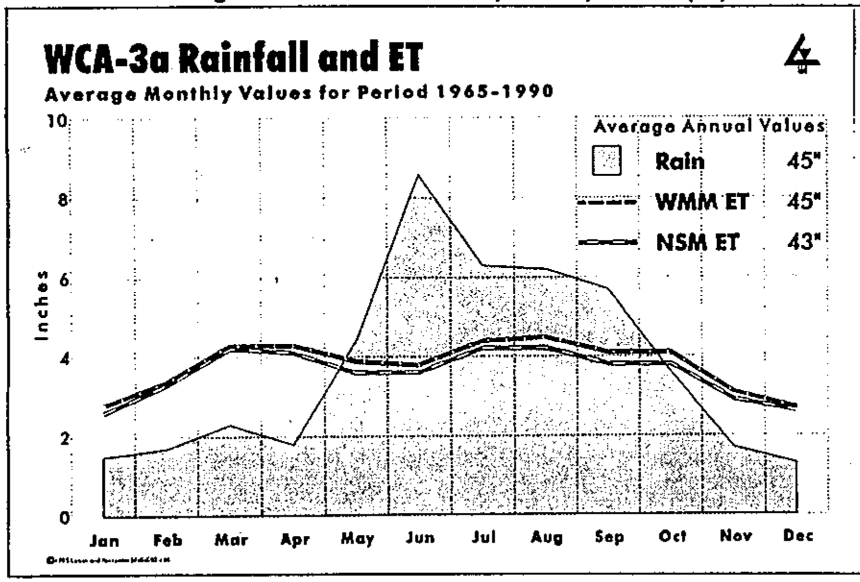
Rate of ET for Water Table at or Above Ground Surface

- These estimates of ET versus water table elevation are based on values used in the NSM model.
- In a sawgrass wetland, the rate of ET is very high when water elevations are at or above the ground surface.

Rate of ET for Water Table Below Ground Surface

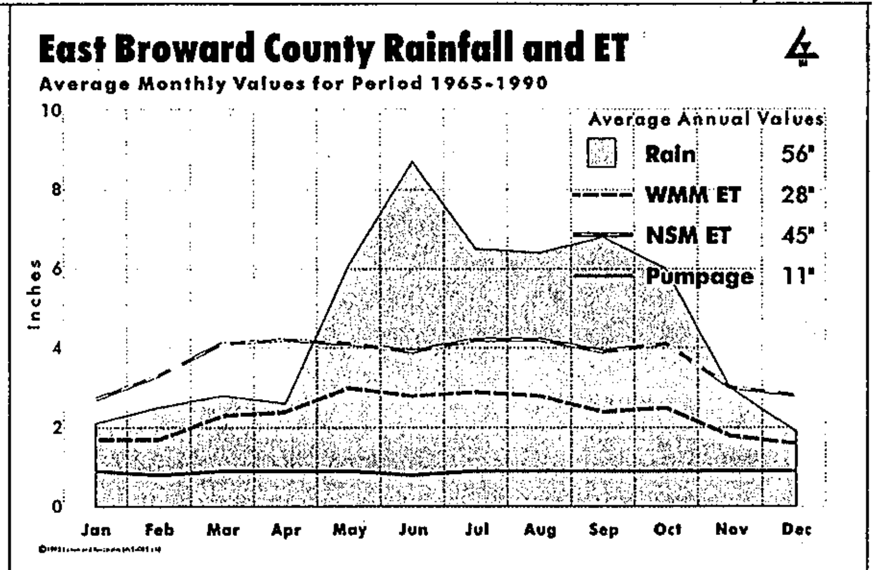
- The rate of ET decreases rapidly as the water table falls* below the ground surface. This is an extremely important point. Because of this effect, wetland drainage (see slide pair 22 which shows drainage of 1,500,000 acres) has a profound effect on the water budget. Draining wetlands causes ET to drop and the discharge (necessary to maintain drained conditions) to increase. For example, if lowering the water table (drainage) causes ET to be reduced by 12 inches per year over the 1,500,000 acres of drained wetlands shown in Slide Pair 22, then the water that needs to be discharged in order to maintain the drained condition generally has to increase by 1,500,000 acre feet. Notice that this increase in discharge is more than the million acre feet needed to supply the urban population.
- Conversely, if the water table is raised in an area that has already been drained, ET increases and, therefore, discharge is reduced.

* Note: the level of the water table is the water level in a small hole dug in the ground.



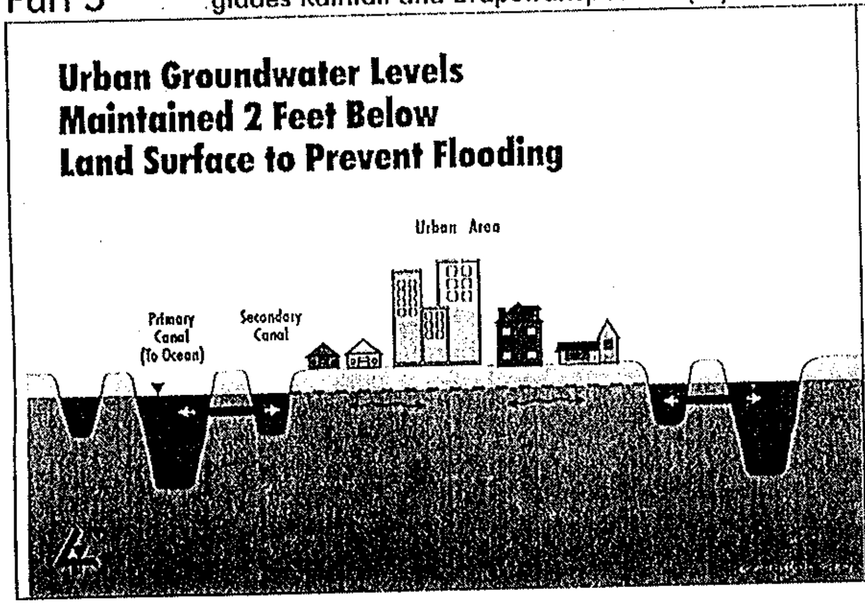
NSM vs WMM Rainfall and ET for WCA-3A

- Annual variation of ET and rainfall
- Annual average values for ET in WCA-3A show little change in ET from Predrainage to Modern times.



NSM vs WMM Rainfall and ET for East Broward County

- Conversly, the models show large changes in ET for Broward County which has been extensively drained and urbanized.
- The reduction in ET causes an increase in the discharge necessary to maintain flood protection.
- This increase in discharge is about 1½ times wellfield pumping.



Urban Area

► In drained urban areas people will not tolerate flooding. This translates into a general requirement to maintain groundwater levels at least two feet below ground surface at all times. This two feet of freeboard provides short term storage for infiltration of the intense rainfall events typical of South Florida.

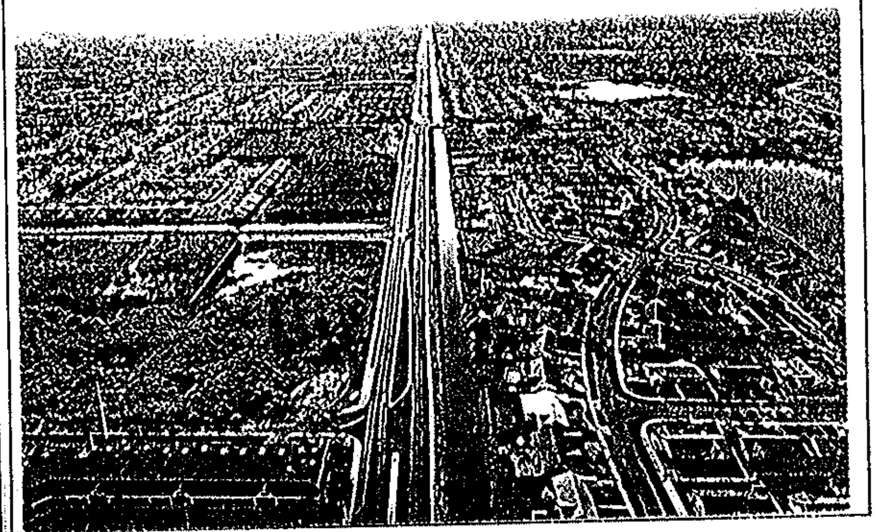


Photo of Urban Area

► Because the underlying rock is so transmissive,* the temporary storage of infiltrated stormwater quickly moves from the groundwater into the network of drainage canals. Water levels in the canals are typically maintained by discharging excess water to the ocean. This system significantly reduces ET and simultaneously increases the need to discharge water to the ocean compared to former wetland conditions.

* For explanation of transmissivity see Part 7

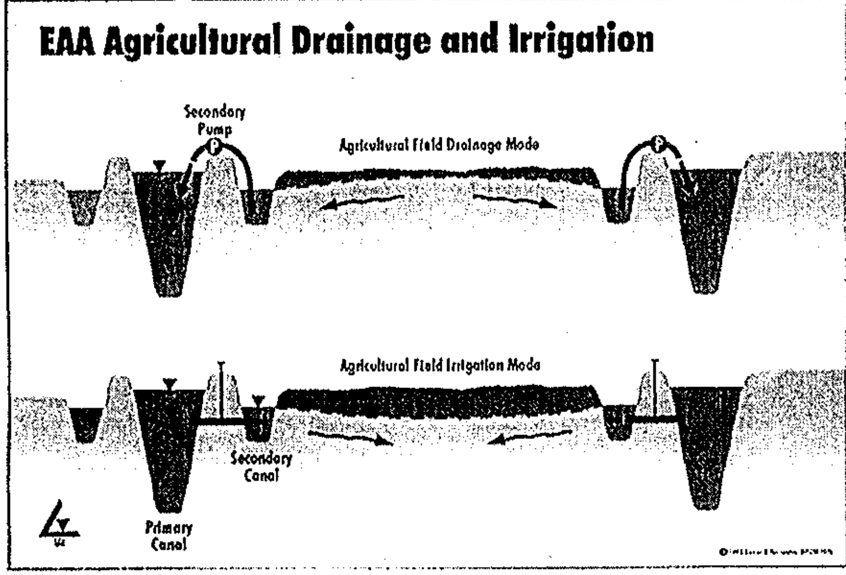


Diagram of EAA Agricultural Area

- Depending on the crop, agricultural areas can tolerate slightly more flooding than urban areas. Sugar cane can tolerate more flooding than vegetables. Nevertheless, the drainage of agricultural lands has the same general effect as the drainage of urban lands. Water tables must be maintained below the ground surface. This significantly increases discharge (necessary to maintain drained conditions) and reduces ET when compared with former wetland conditions. In the EAA most of this extra water is discharged to the Everglades instead of being discharged to tide. Most East Coast agricultural areas, like the Lower East Coast Urban Area, generally discharge extra water to the ocean.

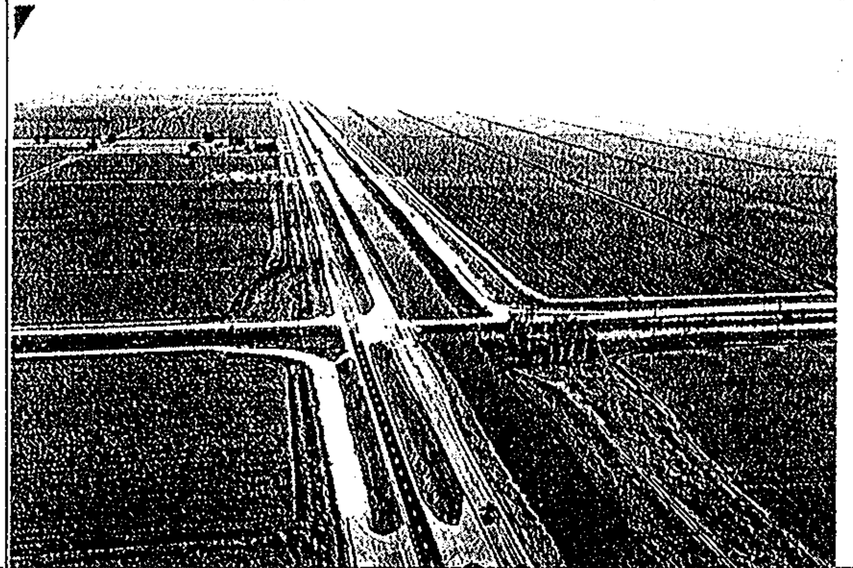
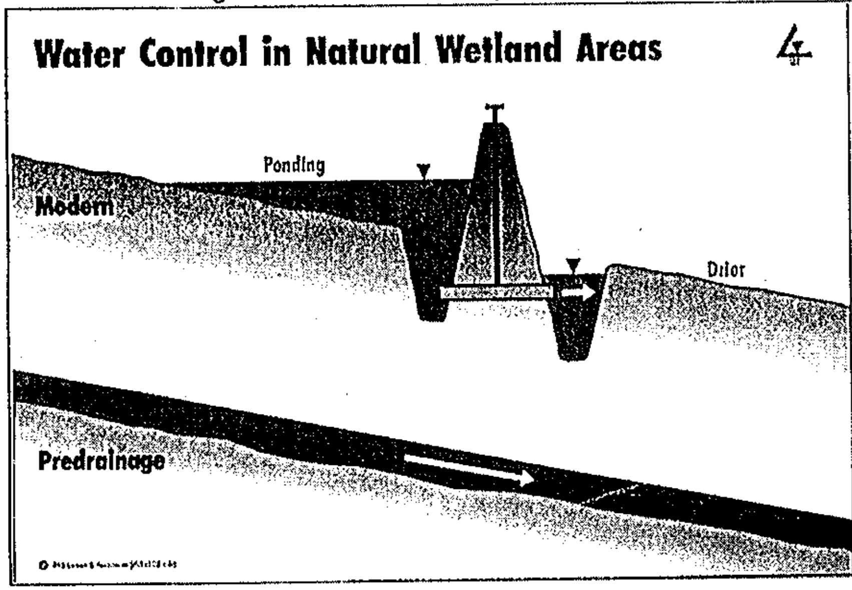


Photo of EAA Agricultural Area

- It is important to recognize that reflooding agricultural areas that are presently drained could increase storage but would also significantly increase ET and would reduce annual discharge. The Water Conservation Areas need supplemental water and currently depend on the quantity of stormwater discharged from the drained EAA. In addition to many other factors, any proposal to reflood the EAA needs to be carefully evaluated in terms of the effect on timing, distribution, and regional storage.



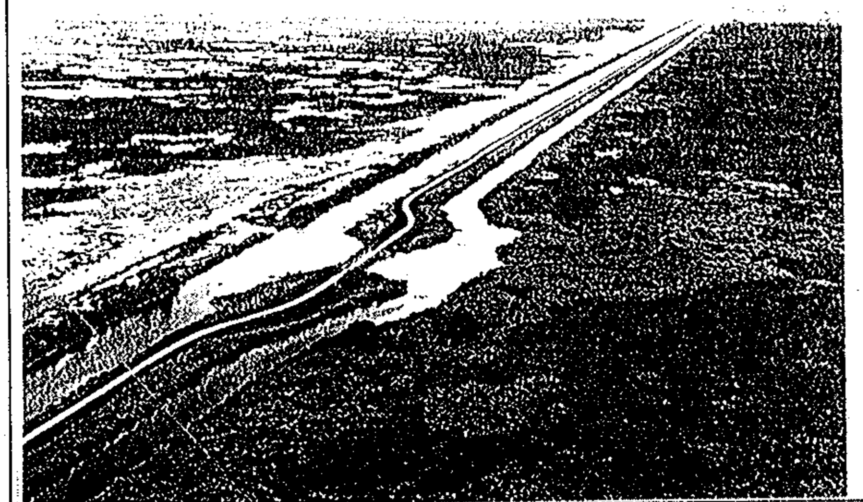
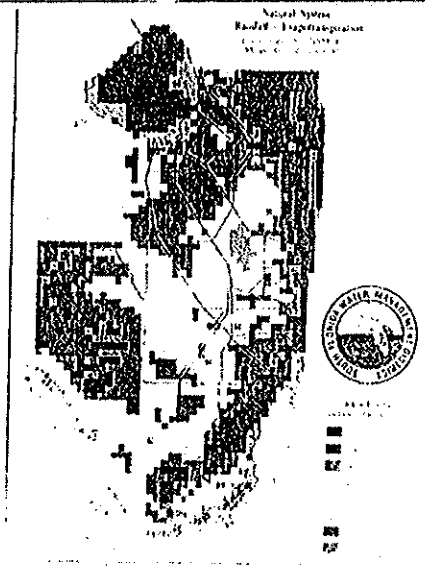


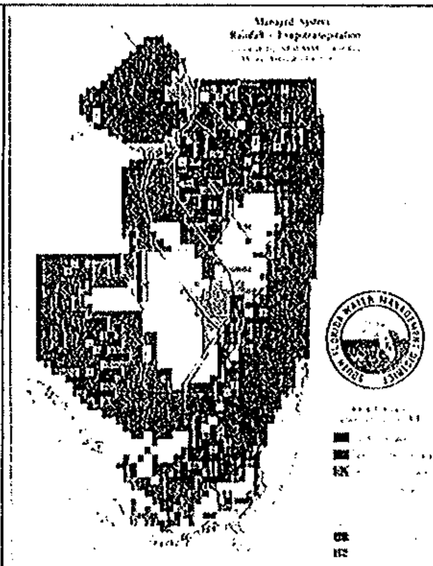
Diagram of Natural Wetlands Area

- There are long and short hydroperiod wetlands. According to the rule that the rate of ET is highly dependent on whether the water table is above the surface of the ground or below ground surface and, if so, how far it is below ground surface, we can see that annual water loss to ET depends on the type of wetland. Long hydroperiod wetlands like the central part of the Everglades have ET rates that are similar to average annual rainfall at that location. In general, annual average ET in a long hydroperiod wetland will be 90% of rainfall. So, for example, you would expect about 45 inches of ET in an area that received 50 inches of rain. Annual runoff would amount to five inches or less.
- But as we will see shortly, average rates of rainfall and ET are useful to get an understanding of general Everglades relationships but they are not at all useful in planning Everglades improvements.

Photo of Natural Wetlands Area

- The amount of water that is available for surface and groundwater flow for agriculture, urban, estuary, and downstream wetlands is generally that left over after Evapotranspiration.
- In other words, the concept of Rainfall minus ET (R - ET) is very important to understanding the amount of water that is available in the Everglades.
- And as we have seen, rainfall is extraordinarily variable—ET is more predictable. However, changing land use, especially draining wetlands and lowering the water table below ground surface, will significantly change ET.
- Likewise, reflooding drained areas will have a major effect on ET and on the availability of water for downstream purposes.





NSM Cell Map Showing Average Annual (R - ET)

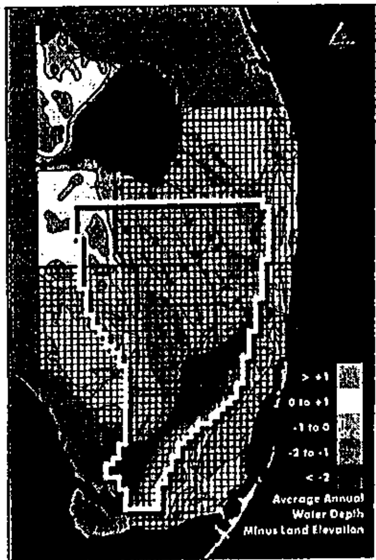
- After admonishing you not to pay any attention to average conditions, the next map we show you is just that, a cell map for the NSM model showing R-ET for *average* conditions. Please note that this shows the extreme variability from cell to cell.

WMM Cell Map Showing Average Annual (R -ET)

- This map represents Modern conditions. It shows the variability from cell to cell and, of most interest, it shows how conditions of water availability based on Rainfall minus ET have changed between Predrainage and Modern Systems.
- The important point is the increase in size of the dark blue areas that show (assuming that rainfall has remained the same) how ET has decreased and, therefore, how discharges (generally R - ET) have increased.
- We acknowledge that we are showing you a lot of variability and no simple answers—except that we start to appreciate the value and perhaps indispensability of the computer models in predicting the effects of various options for improving conditions in the Everglades.

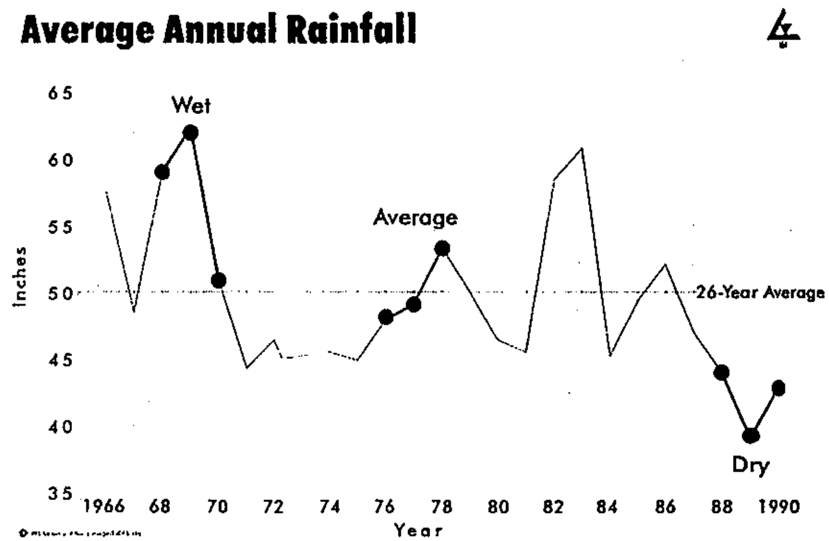
Extremes

not Averages



NSM Cell Map Showing Areas Evaluated for Rainfall and Rainfall Minus ET (R - ET)

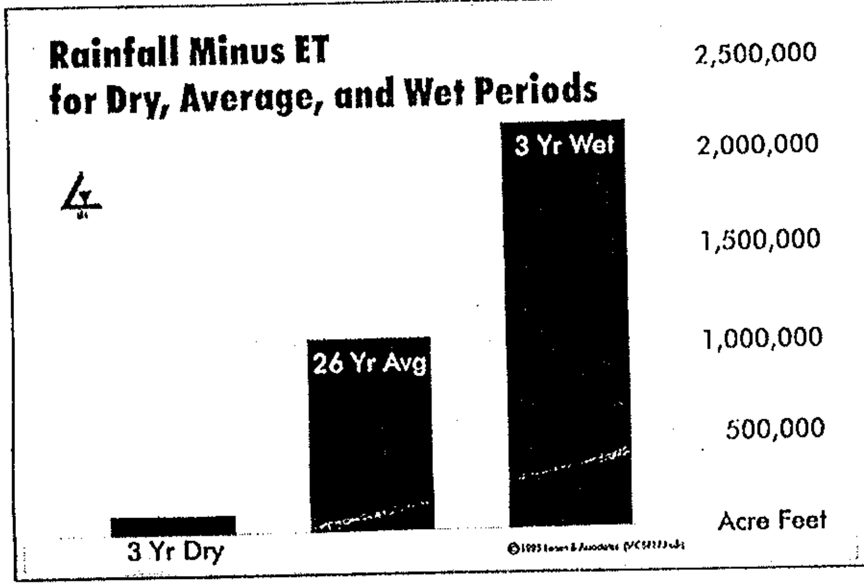
► These cells in the Natural System Model were interrogated for values of rainfall and ET for the 26 year evaluation period. The results we will present in the next few slides are NSM model results and are not direct measurements. It was felt these sub-areas would provide a picture of the variability of water availability as expressed by Rainfall minus ET.



Rainfall Based on NSM

► This diagram shows average annual rainfall for each year from 1965 to 1990 for the sub-area shown on the previous slide. Remember, this is the NSM model which is based on the WMM model with all the man-made features removed.

- The heavy line shows the average annual rainfall for the area.
- The horizontal line shows the 26-year average rainfall of 50 inches per year.
- The groups of three dots along the heavy line show periods of three consecutive years which were selected to represent dry, average and wet conditions.
- Values from the dry, average, and wet three year periods were averaged.
- Thus, we did not select the driest or the wettest year but the average of three consecutive years to represent extreme conditions.
- Since the 3 year average values mirrored the 26 year average, for simplicity we have used only the 26 year average in the following graphics.



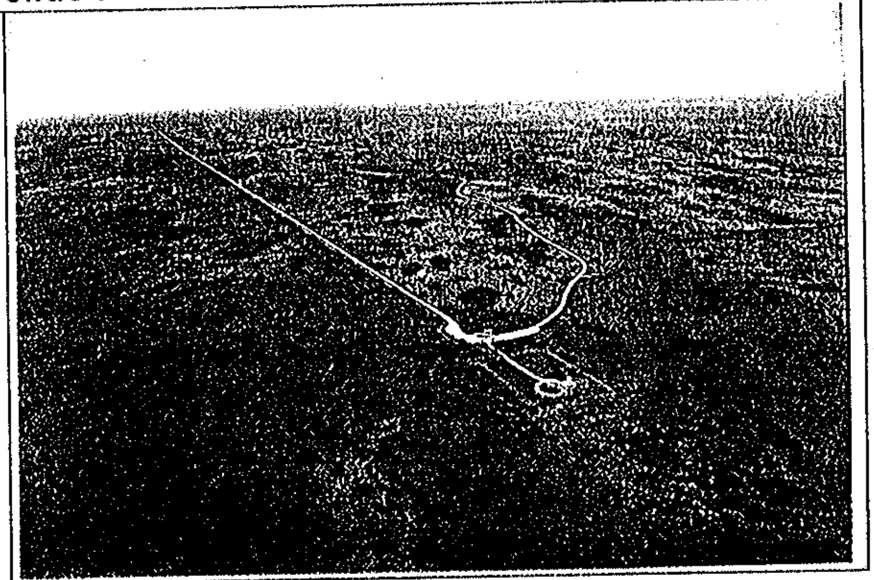


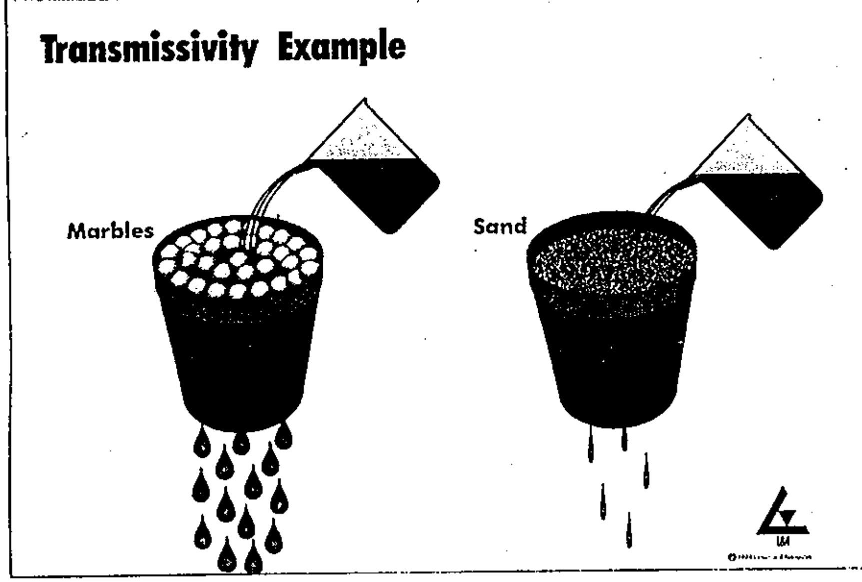
Photo of Wetlands Typical of Everglades

Rainfall Minus ET for Wet, Average, and Dry Periods

- The Rainfall minus ET results show extreme variability in water availability in the 3,948 square mile (2,526,720 acre) study area.
  - The "dry" period: surplus of 111,000 AF / Year (0.5 inches)
  - The 26-year average: surplus of 1,024,000 AF / Year (5 inches)
  - The "wet" period: surplus of 2,160,000 AF / Year (10 inches)
- The difference between the "dry" year and the "wet" year is more than 2 million acre feet. The "dry" and the "wet" years are each a million acre feet different than the "average" year.
- Whatever we do has to work for the extremes of wet and dry. Average conditions are generally irrelevant other than for understanding order of magnitude relationships.

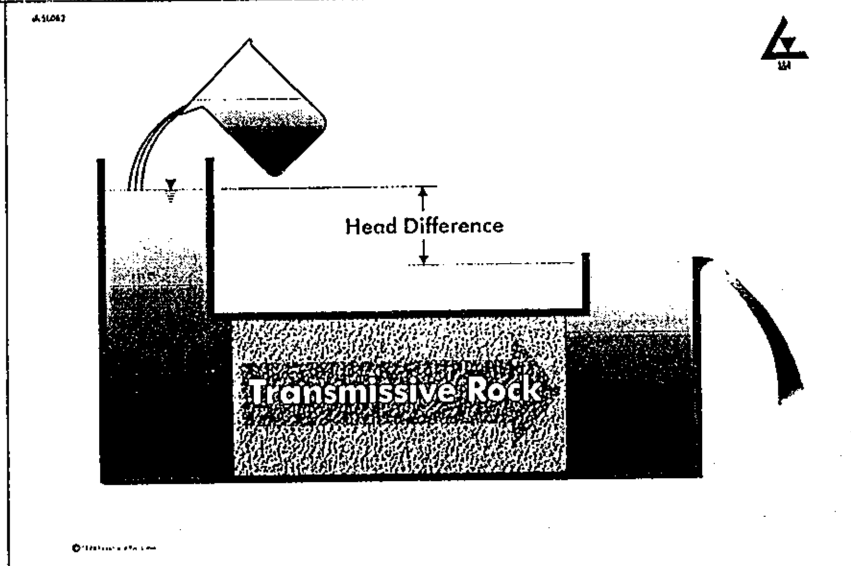
Trans-

missivity



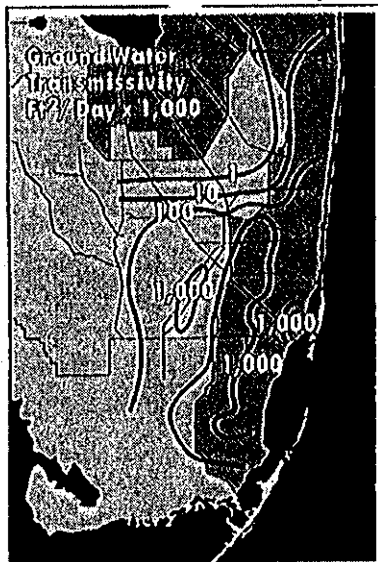
Transmissivity Principles: Flower Pot Diagram

- Transmissivity is a measure of how easily water flows through the ground. For example, water would run out the bottom of a flower pot filled with large rocks much faster than if it was filled with fine sand. The marbles are much more transmissive than the sand.



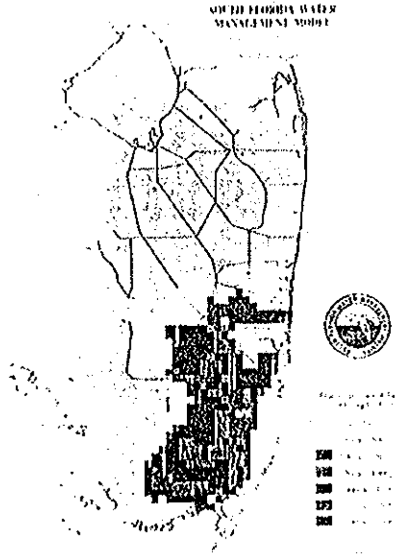
Transmissivity Example: Horizontal Groundwater Flow

- Horizontal groundwater flow is directly related to the transmissivity of the rock as well as to the difference in water levels from upstream to downstream.
- In the real world, this head difference is represented by the slope of the groundwater table. Basically, the steeper the slope the greater the groundwater flow. Typical Everglades slopes were extremely gradual going from about 20 feet at Lake Okeechobee to 0 feet at Florida Bay, 100 miles to the south. This is a north-south slope of one foot over a distance of five miles. East-West slopes in the central part of the Everglades (at the present location of the North-South Levee) were essentially nonexistent.
- In the Central part of the Everglades, even though the transmissivity was very high, historical groundwater flows were extremely low since there was very little slope or head difference.



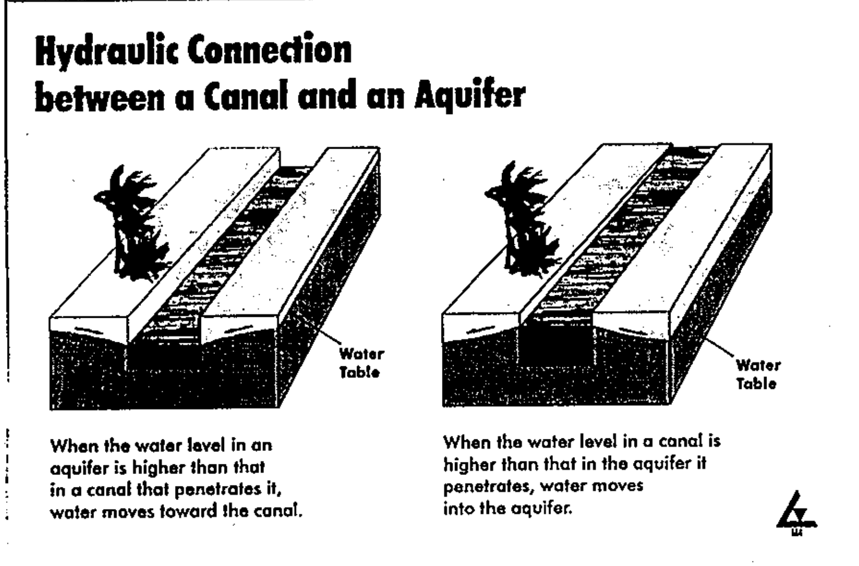
Map of Transmissivity Contours*

- These two slides were shown earlier in the section of the presentation on Physical Features of the Predrainage Everglades Basin.
- The contour map on the left shows that transmissivity in large parts of Dade County is 1,000 times greater than, for example, in Palm Beach County.
- Like the contour map at left, the map on the right hows that the highest transmissivity rock is in the vicinity of the North-South Levee that separates the Water Conservation Areas and Everglades Park from East Coast Urban areas. Also notice that transmissivity along the Coastal Ridge in Southern Broward and Dade County is also very high compared with transmissivity in Northern Broward and Palm Beach Counties, for example.
- East-West groundwater flow essentially did not exist at the North-South Levee location in Predrainage times. This was because there was essentially no East-West groundwater gradient at this location. Now, there is a relatively steep east-west gradient at this levee resulting from the need to provide low water tables and flood protection in urban areas and to allow higher water tables to promote Predrainage System values in the adjacent Everglades Park and WCAs.
- In Predrainage times the waters of the Everglades lapped up against the western side of the Coastal Ridge. This created a relatively steep east-west gradient across the Ridge of as much as ten feet in five miles—ten times greater than the north-south gradient in the central Everglades. Over the more than fifty miles of highly transmissive aquifer interfacing with the Atlantic Estuaries and, over the course of a entire year, the quantity of groundwater flow out of the Everglades to the estuaries was substantial due to the steep groundwater slope and highly transmissive rock. Now, urban drainage west of the Coastal Ridge has reduced the Coastal Ridge gradient and Modern groundwater flow to the Atlantic Estuaries is substantially less than Predrainage flows.



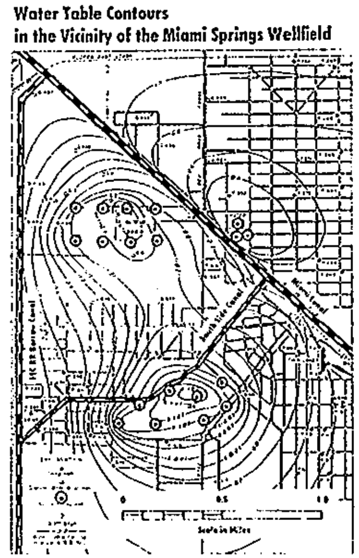
Transmissivity Cell Map from NSM and WWM

* Note: both of these slides are repeated from slide pair 15



Canal in High Transmissivity Area

- This diagram shows how a canal can serve to both drain an area and to replenish groundwater. Whether the canal is replenishing or draining an area depends on the elevation of groundwater relative to the level of water in a nearby canal.
- In the transmissive areas of Dade and Broward Counties, it is generally true that groundwater level is essentially the same as canal levels. Immediately following a heavy rainfall a mound of groundwater will seep into nearby canals and be discharged to the ocean.
- Likewise, as a result of high transmissivity, water that seeps into urban areas from the Water Conservation Areas is largely intercepted by canals and is also discharged to the ocean.

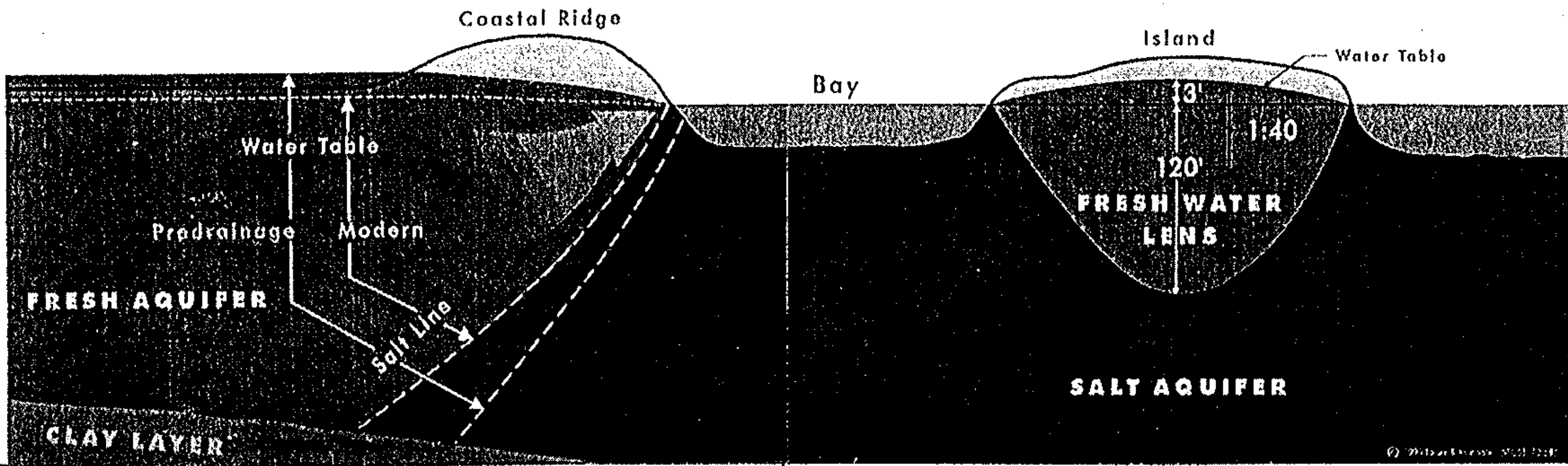


Water Table Contours in the Vincinity of the Miami Springs Wellfield

- For example, for years, the Miami Canal has supplied the Miami Springs wellfield via groundwater flow.
- High transmissivity can be an asset as it facilitates urban drainage as well as the supply of urban wellfields.
- It is a problem, especially in the vicinity of the North-South Levee where it causes substantial quantities of water to leak out of the Everglades.
- Later sections of this report will quantify the amount of seepage.

Salt Water Intrusion

Ghyben-Herzberg Principle

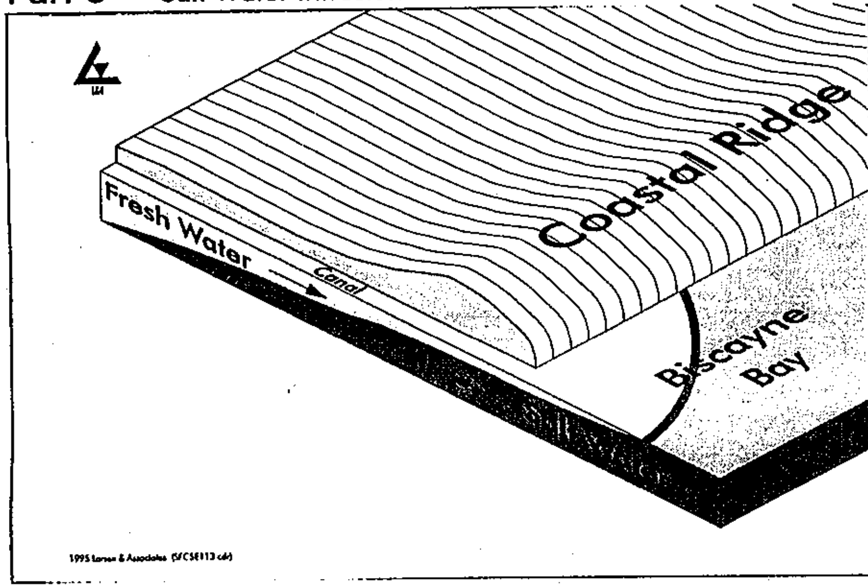


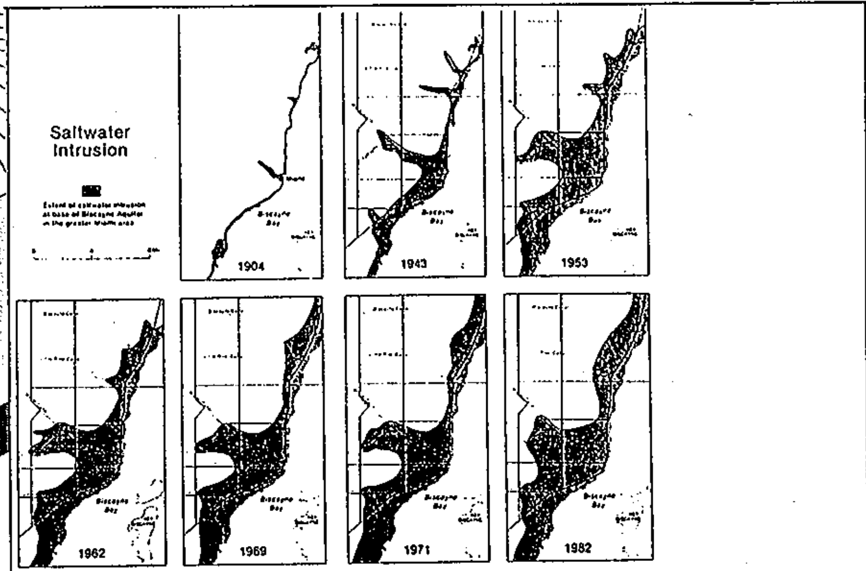
Ghyben Herzberg Bouyancy Relationship

- This pair of slides shows a cross section through an island (right slide) and a coastal ridge (above). Fresh water weighs less than salt water. Like oil on water, fresh water floats on top of salt water. The buoyancy relationship (1:40 ratio) holds that one foot of fresh water above sea level indicates 40 feet of fresh water below sea level floating on top of salt water.
- This is why an island can contain a "lens" of fresh water even though the island is surrounded by salt water. That lens of fresh water is maintained by rainfall on the island. As the mound of fresh water builds on an island it causes groundwater flow and may result in springs of fresh water appearing offshore.
- When fresh groundwater approaches the coast it tends to float up over the heavier salt water and be discharged to the saline areas.

Applied to Biscayne Bay

- In the case of the Atlantic Estuaries, fresh groundwater flow from the Coastal Ridge moves up and into, for example, Biscayne Bay.
- In Predrainage times the groundwater gradient through the Coastal Ridge was much greater and groundwater flows were higher. Now, with drainage of the former wetlands west of the Coastal Ridge, that gradient has been reduced and groundwater flows are lower.
- It is important to remember that groundwater moves only in response to a gradient. No gradient—no flow. Reduce the gradient—reduce the flow. Increase the gradient—increase the flow. The only way to change groundwater flow to the Atlantic Estuaries like Biscayne Bay is to change the groundwater gradient in the Coastal Ridge. Changes in groundwater flows at the North-South Levee or changes in water levels in the Water Conservation Areas, by themselves, can have no effect on groundwater flow to Biscayne Bay.
- Note that lowering the level of fresh water in the aquifer adjacent to the estuary causes a wedge of salt water (at the salt line) to advance inland.





Salt Water Intrusion Up a Coastal Canal

- The danger of salt water intrusion is vastly increased by building drainage canals: when fresh water flows are low, as in the dry season, the heavier salt water will advance in a wedge, inland along the bottom of the canal. This wedge of heavier salt water can advance inland even when fresh water is flowing seaward in the upper layers of the canal.
- During wet season periods of high flow, all the salt water in the canal will be pushed back into the Bay and the canal will be entirely fresh again.

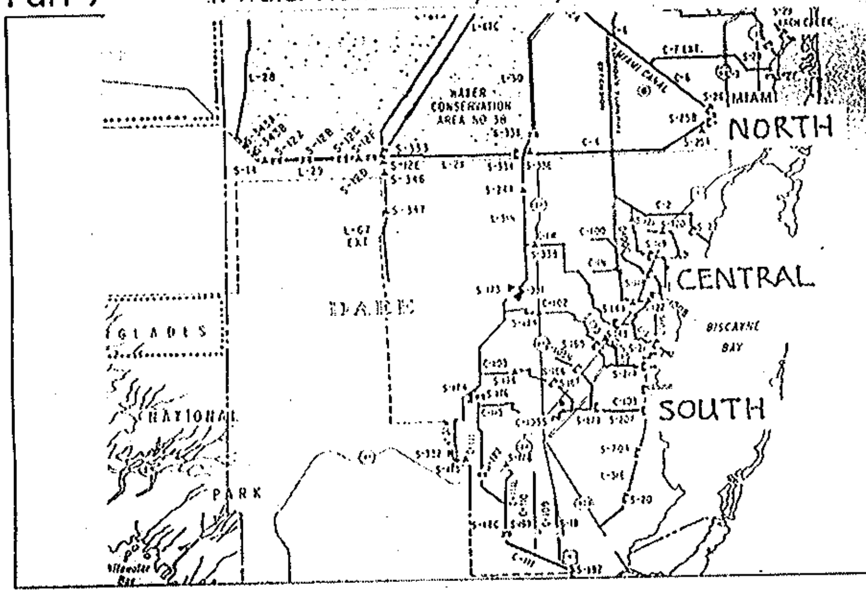
USGS Map Showing Advance of Salt Water Intrusion from 1904 to 1982

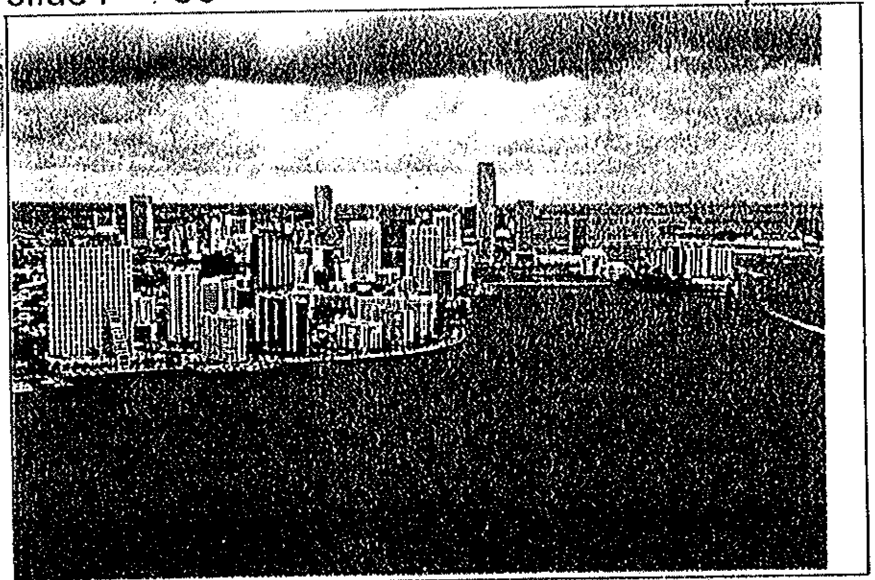
- This map shows the advance of salt water into the aquifer as a result of both lowered fresh water tables, and the advance of salt water up drainage canals.

Fresh Water Flow to Biscayne Bay

A number of people have expressed concern that making changes to the Modern system will change the quantity of fresh water presently delivered to Biscayne Bay.

These concerns have to be evaluated in terms of Predrainage Everglades Basin flows and tidal flushing of the Bay by salt water.



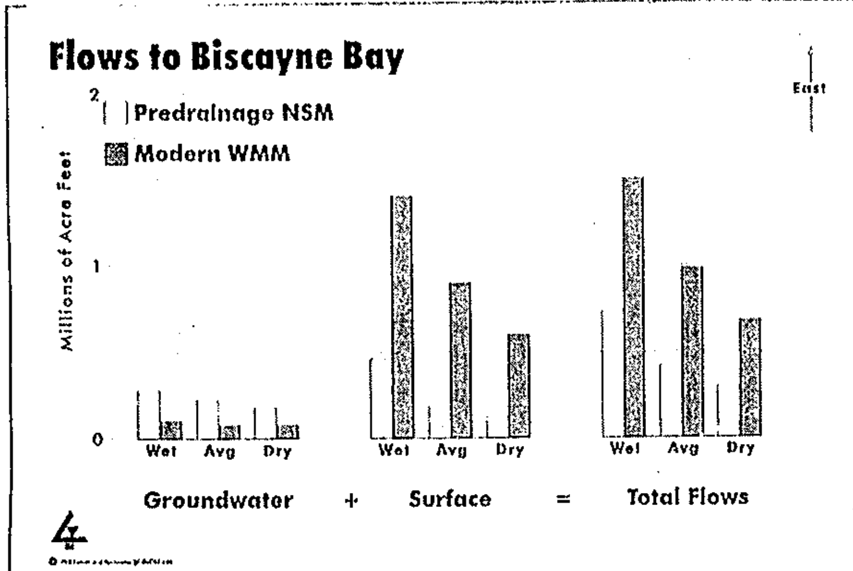


Map Showing North, Central, and Southern Areas of Biscayne Bay

- The flushing rate of an estuary is primarily dependent on the rise and fall of the tide as well as the depth and the shape of the water body. Other factors such as the strength and the direction of the wind can also be important.
- The salinity in an estuary is a question of balance between the fresh water inputs typically on one side and the salt water inputs on the other side due to tidal interaction with the ocean.
- Historically, **North Biscayne Bay** was extremely shallow with major inputs of fresh water from groundwater and surface drains like the Oleta River. North Biscayne Bay may have been virtually fresh—at least during the wet season.
- Then we dredged and filled large parts of the Bay and cut a new opening to the ocean at Baker's Haulover. This dramatically changed the North Bay.
- Urban Canals now deliver urban drainage and seepage from the Everglades to all parts of the Bay.

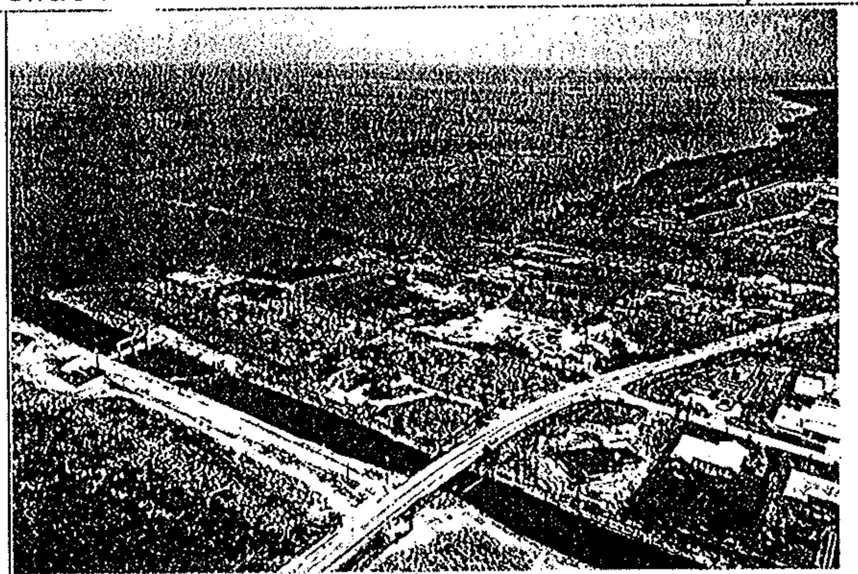
- **Central Biscayne Bay** had very good exchange with the ocean through Bear Cut and the Stiltsville area. In this zone Predrainage salinities were likely very similar to those in the ocean.
- Exchange with ocean water was more limited in **South Biscayne Bay** and it is likely that part of the Bay was somewhat fresher than the central area.

Above: Photo of Biscayne Bay



Bar Chart: Surface and Groundwater Flows to Biscayne Bay Before and After Drainage

- Notwithstanding the relatively minor amounts, fresh water inputs to the Bay maintain its estuary character.
- As mentioned earlier, South Biscayne Bay may not flush as rapidly as North Bay and Central Bay creating a different balance between fresh and salt water.
- Comparison of the NSM and WMM models shows that average annual fresh groundwater inflows to the Bay have significantly decreased. As discussed on the earlier section on transmissivity, this decrease in groundwater flow is due to the reduction of head difference across the Coastal Ridge. This decrease is a consequence of wetland drainage for urban purposes on the west side of the Coastal Ridge.
- Conversely, the models show surface fresh water inflows have significantly increased. These flows have increased as a consequence of urban drainage and seepage from the Everglades Water Conservation Areas. Water which formerly remained in the system to inundate wetlands west of the Coastal Ridge now has to be disposed of into the Bay.
- Predrainage surface water inflows were formerly from features like the Miami River and the Transverse Glades which discharged at times of high water in the Everglades. These Predrainage surface discharges would have persisted over a period of several weeks or months.



Canal Structure Leading to Biscayne Bay

- Modern surface discharges are totally controlled by the gates in the drainage canals. When the gates are opened, large quantities of fresh water are rapidly discharged into the Bay. There is concern about the effects of urban pollutants in this drainage water discharged to the Bay.

Comparison :

Salt and Fresh Water Inflow/Outflow Biscayne Bay*

► **Inflow**		
Salt Water Tidal	350,000 AF	98.3 %
Dade County Canals	3,050 AF	0.9 %
Rainfall	2,430 AF	0.7 %
Groundwater	303 AF	0.1 %
► **Outflow**		
All Above Combined	355,783 AF	100.0 %

*Typical Present Day Values for one 12-hour tide cycle

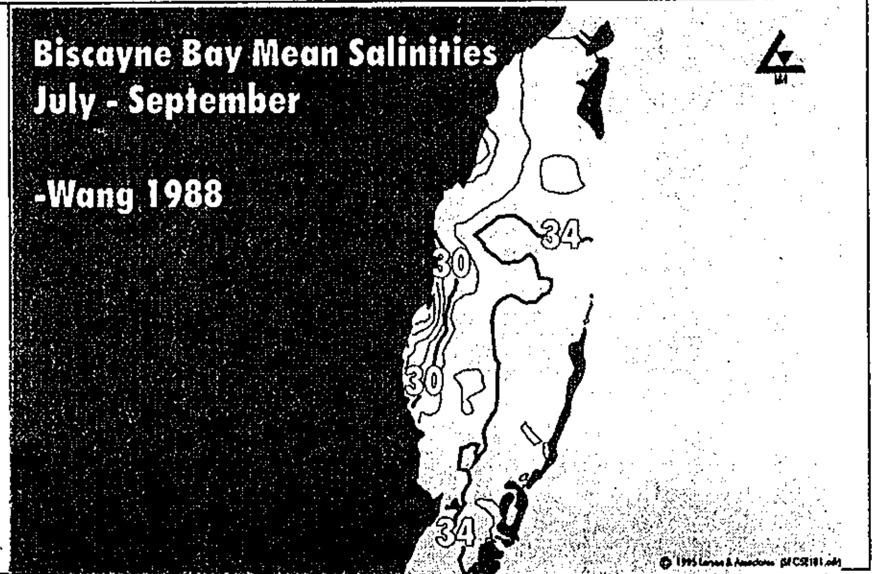


Table Comparing Modern Salt and Fresh Water Inflow/Outflow to Biscayne Bay

- Over a six hour period the entire bay fills with approximately two feet of "new" tidal salt water (called the tidal prism) from the ocean. To a degree, this "new" water mixes with the approximately 10 feet deep "old" water that remained in the Bay at the time of the last low tide. So, at high tide the Bay is approximately 12 feet deep.
- Over the next six hours the tide falls two feet and a mixture of "new" and "old" water returns to the ocean. This process of rising and falling tides repeats every 12 hours and serves to "flush" a portion of the "old" water in the Bay out to the ocean.
- Fresh water discharged into a coastal embayment decreases the salinity and creates density gradients which induce horizontal flow. A measure of the relative importance of these density gradients on water exchange is provided by the ratio between runoff volume and the tidal prism. The total water exchange in the Bay is also dependent on other factors such as wind.
- In relation to high tide depths of 12 feet, two feet (17%) of the water in the Bay is flushed into the ocean every 12 hours.

Biscayne Bay Mean Salinities July to September*

- Dr. Wang's map shows near oceanic salinities (35 parts per thousand, i.e, 3.5% of the weight of ocean water is dissolved salt) throughout Biscayne Bay except along the west shore.

* Source: Dr. John Wang, report, 1988

Estuaries Affected by C&SF Project

- St. Lucie River
- Lake Worth
- Biscayne Bay
- Barnes Sound
- Florida Bay
- Whitewater Bay
- Caloosahatchee River

Estuaries Affected by C&SF Project

- St. Lucie River
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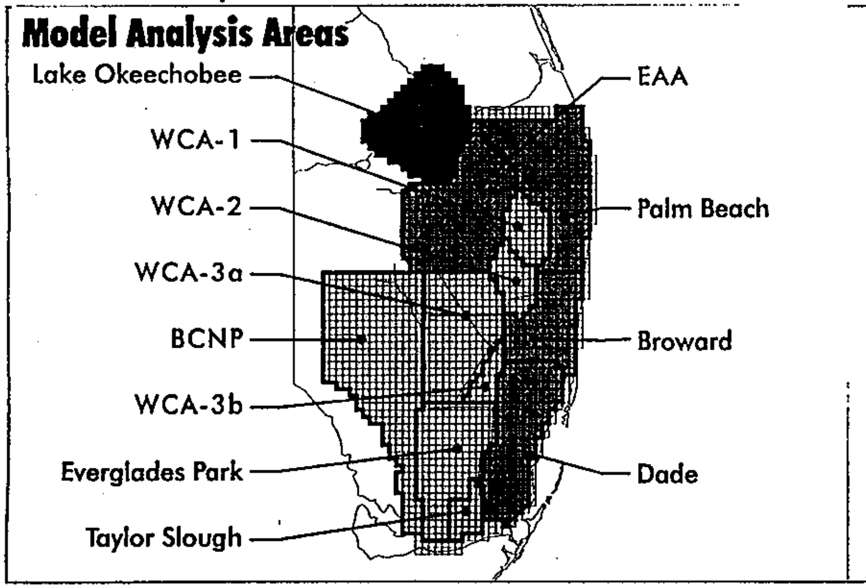
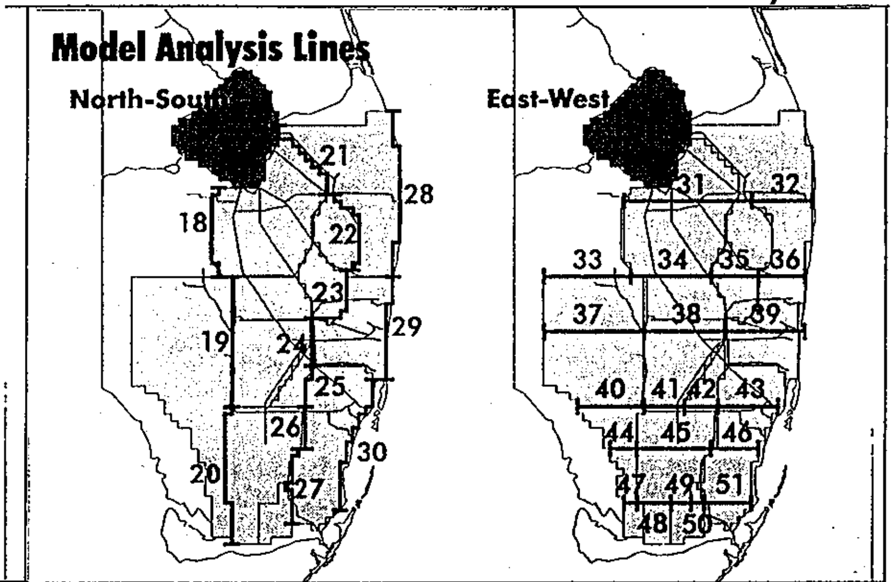
Photo of Florida Bay

- Please note in the case of Biscayne Bay, that the volume of increased fresh water inflows is approximately only 1% of total inflow volume (fresh + salt water). Tidal salt water inputs to the Bay, approximately two feet of water every 12 hours, are so much larger than fresh water inputs that not much change in the salinity of the Bay occurs as a result of increased flows from Predrainage to Modern systems. If there were Predrainage features, such as fresh water springs flowing offshore in the Bay, their effects were local in nature.
- However, effects of Everglades water regime changes on Biscayne Bay cannot be generalized to other downstream estuaries. Small changes in fresh water inflow may be important in other estuaries.
- The interaction of the C&SF Project with Florida Bay, Whitewater Bay, the Caloosahatchee River estuaries, the St. Lucie River estuaries, and Lake Worth are beyond the scope of this report. Effects on these estuaries are very important considerations, however, and could be the subject of a separate analysis and report.

Comparison of Predrainage NSM and Modern WMM Models

- We used 26 years of rainfall data (1965-1990) to compare the Predrainage System (NSM model) and the Modern System (WMM model).
- The WMM is based on the configuration and operation of the Modern C&SF Project as it existed in 1990, whereas the NSM is based on the WMM minus all man-made structures such as levees, canals, pumps and gates; and adding corrections for subsidence as well as flows in various Predrainage channels. In the NSM model, total flows are defined as the sum of surface, groundwater, boundary, and channel flows while in the WMM model, total flows are defined as the sum of surface, groundwater, levee seepage, structure and, where applicable, wellfield pumpage treated and discharged to the ocean or to injection wells.
- In addition to determining average flows for the 26 year period (1965 - 1990), we evaluated three additional sub-periods within that period: a dry period, 1988-1990, consisting of an average of the three consecutive years with the least rain; an average period, 1976-1978, consisting of an average of the three consecutive years with average rain; and a wet period, 1968-1970, consisting of an average of the three consecutive years with the most rain. In general, there were large differences between dry, average, and wet years. Therefore, we determined that the hydrologic system could only be understood in terms of these wet-dry extremes—not in terms of the 26 year average values. Therefore, in the following sections values of **change** will be stated in brackets: [dry, average, wet] in acre feet (unless stated otherwise). For Example: [230,000:dry, 456,000:avg, 827,000:wet] states: **change** of 230,000 acre feet in the average flow for three consecutive dry years, **change** of 456,000 acre feet in the flow averaged over the 26 year period, and **change** of 827,000 acre feet in the average flow for the three consecutive wet years. **Change** is the difference between the NSM Predrainage model and the WMM Modern conditions model.
- Because inspection of our results showed that the **change** represented by the average of the 3 consecutive average years mirrored the 26-year average, for purposes of simplicity, the values for the three consecutive average years will not be shown in the slides.



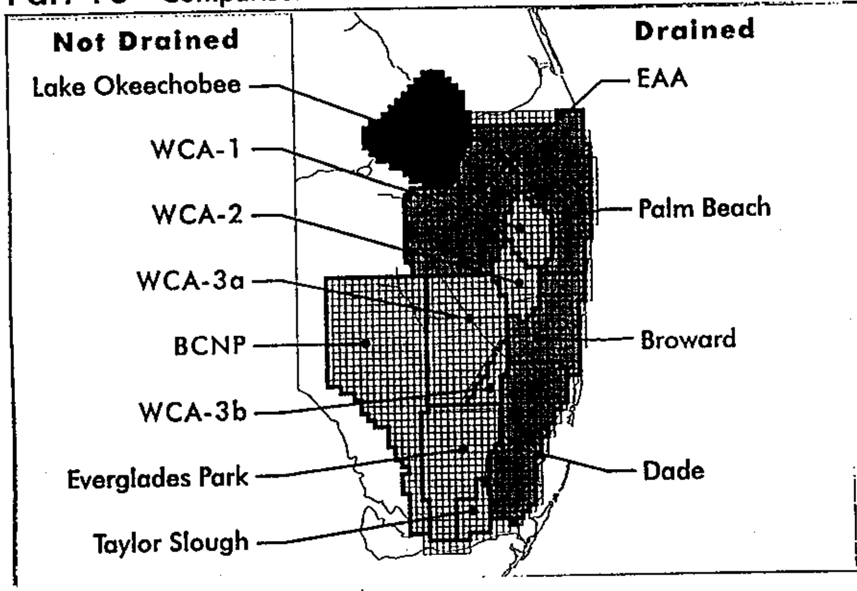


Model Analysis Areas

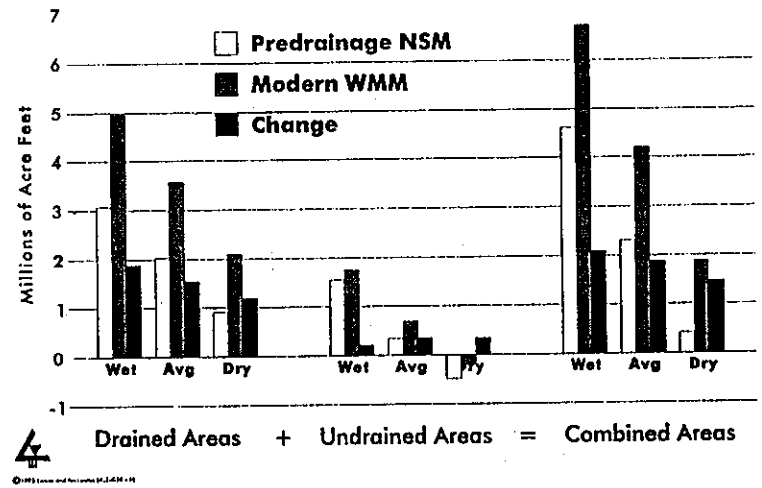
- The 12 areas we evaluated in both the NSM and WMM models.

Model Analysis Lines

- The 13 North-South lines and the 21 East-West lines which were evaluated in both the NSM and WMM models. The change in ET as well as the change in total flow between the two models is summarized in the slides that follow.

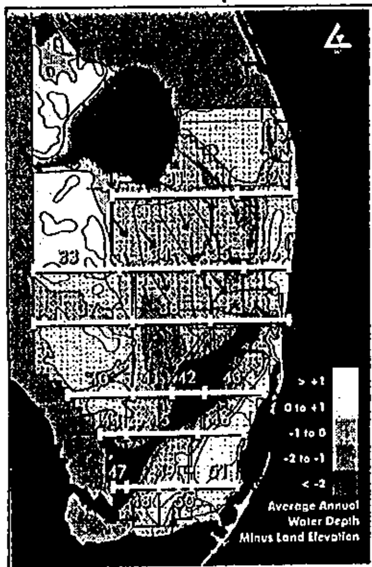


Analyzed Areas Grouped into Drained and Undrained Areas



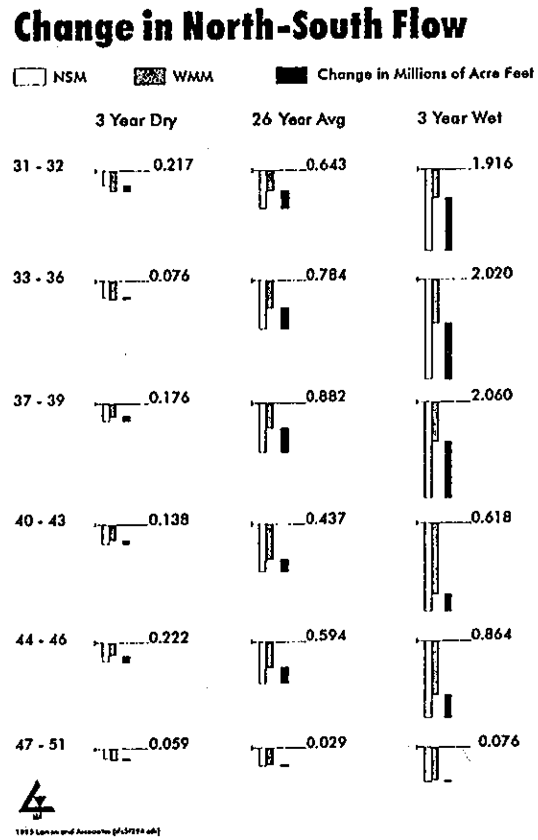
Change in Rainfall Minus ET for 26-Year Average Conditions

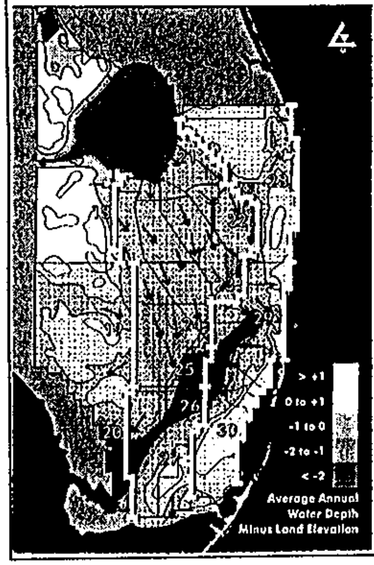
- Please compare the effects of drainage in the EAA, East Palm Beach, East Broward, and East Dade County averaged over the 26 year period of record, 1965 to 1990, with areas that remain undrained. The change in Rainfall minus Evapotranspiration (R-ET)—or potential discharge—in the four drained areas listed above was [1,161,000:dry, 1,543,000:avg, 1,892,000: wet]. All the undrained areas together changed [340,000:dry, 331,000:avg, 187,000:wet]. The total change in (R-ET) in the entire analysis area due to drainage is [1,501,000:dry, 1,874,000:avg, 2,079,000:wet]. This increase in Modern potential discharge correlates with an increase in Modern flows to the Atlantic Estuaries discussed in Slide Pair 58 and in Slide Pair Number 60.

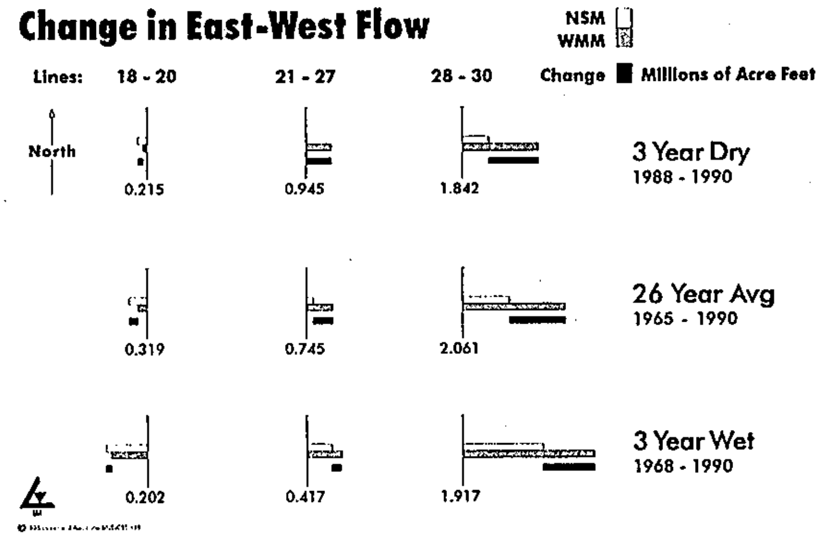


Change in North-South Flows Throughout the System

- Please note that the surface flows in the NSM model are predominantly overland, while flows in the WMM model are mostly in channels. WMM Model values for lines that coincide with locations where channel flows are directly measured are more certain than WMM values for lines where channel flows are estimated.

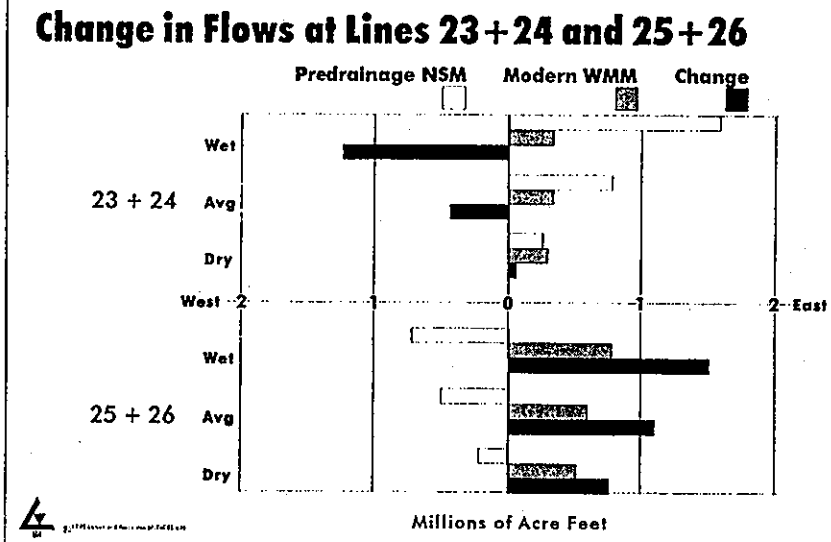






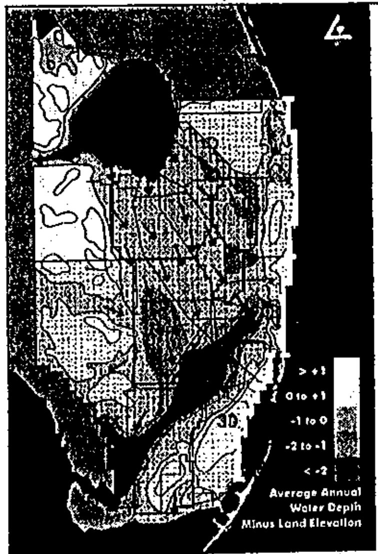
Change in East-West Flows Throughout the System

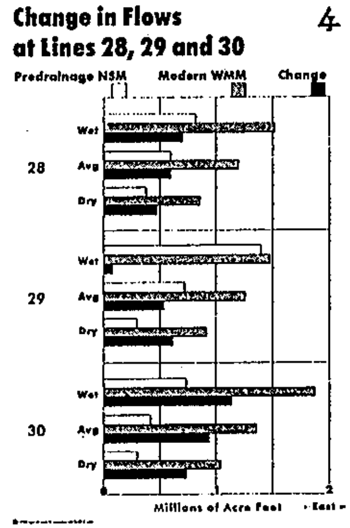
- Please notice that flows across the North-South Levee and flows to the Atlantic Estuaries have changed greatly from Predrainage times.
- The models show an increase of approximately **two million acre feet** of annual flow [1,842,000:dry, 2,061,000:avg, 1,917,000:wet] to the Atlantic estuaries adjacent to Palm Beach, Broward, and Dade Counties.
- The models show an increase of [945,000:dry, 745,000:avg, 417,000:wet] in easterly flows across the entire North-South Levee. This change results from the following factors:
  - The 1950 C&SF Project system drains urban areas next to remaining wet natural areas in an area where the aquifer is extraordinarily transmissive. The difference in water levels between the two areas creates a groundwater gradient that always slopes down to the east resulting in uncontrolled groundwater flow where none existed in Predrainage times. The flow rate is proportional to the difference in water elevation between the Water Conservation Areas and the urban areas. This seepage flow is, therefore, likely to be at a maximum during the wet season when the urban areas don't need the excess water.
  - In the dry season, on the other hand, the urban areas do require supplemental water from the Water Conservation Areas to hold back salt water intrusion as well as to supply urban wellfields. This water flows to the urban areas by uncontrolled groundwater seepage as well as by canals and gates that link the two areas.



Changes at Lines 23+24 and 25+26 on the North-South Levee

- At lines 23+24 Predrainage (NSM) flows were easterly and were comprised almost entirely of **overland surface** flows. Flow values at Predrainage lines 23+24 were [257,000:dry, 785,000:avg, 1,572,000:wet]. At lines 25+26, Predrainage surface (overland) flows were directed to the west [229,000:dry, 500,000:avg, 716,000:wet]. Thus, the NSM model confirms that Predrainage flows in the Everglades flowway were easterly into what is now Broward County and then westerly back toward Whitewater Bay in Dade County. Predrainage **groundwater** flows at the location of these lines were essentially nonexistent as there was minimal groundwater gradient.
- Net Modern (WMM) total flows at all the lines 23 to 26 are directed to the east and comprised of mostly groundwater seepage and canal deliveries to urban areas. Easterly Modern flows at lines 23+24 are [309,000:dry, 335,000:avg, 335,000:wet] and easterly Modern flows at lines 25+26 are [527,000:dry, 606,000:avg, 776,000:wet]. In Dade County, Predrainage surface flows to the **west** have been largely replaced by Modern groundwater and canal discharges to the **east**. For example, net **change** to the east at lines 25+26, alone, is [775,000:dry, 1,106,000:avg, 1,491,000:wet].





Changes in Flows at Lines 28, 29, and 30

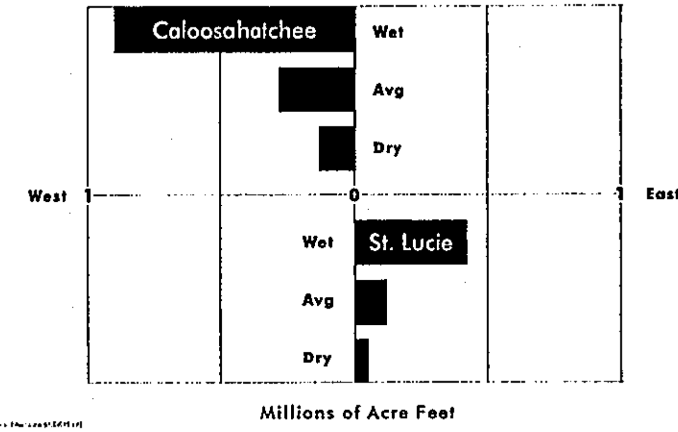
Discharges to the Atlantic Estuaries

► The dramatic increase in surface flow to the Atlantic Estuaries is largely delivered by way of drainage canals cut through the Coastal Ridge. The reasons for the increase in flow are:

- To provide drainage of former wetlands, now urbanized, we need to continually get rid of the water that formerly made wet the wetlands located west of the Coastal Ridge.
- Drainage lowers the water table which in turn significantly reduces the rate of evapotranspiration. Because ET is reduced and rainfall remains essentially unchanged, a larger portion of the rainfall must be discharged than before drainage. Therefore, the volume of runoff from a drained wetland is much greater than before drainage.
- In addition, because features of urbanization such as pavements and rooftops significantly decrease the ability of water to infiltrate into the ground, there is more and faster surface discharge than if the land was simply drained, as would be the case for agriculture. However, these effects of urbanization can be reduced with good engineering design that provides retention and storage of storm water.
- Canals move enormous quantities of water rapidly when compared with previous (natural) overland and groundwater flows.
- In the transmissive rock of Dade and Southern Broward Counties, the canals that drain the urban areas also intercept a major portion of the uncontrolled seepage from the Water Conservation Areas and from Everglades Park.
- In addition, drainage changes the rate of surface discharge generally resulting in more and faster runoff.
- Wellfield pumpage and disposal of effluent to ocean outfalls or injection wells contributes to the change.

► Therefore, the two million acre foot increase in flows to the Atlantic Estuaries results from the combined effects of drainage and wellfield pumpage of the urban areas themselves and from seepage from the Water conservation Areas and Everglades Park in an approximate 50-50 split.

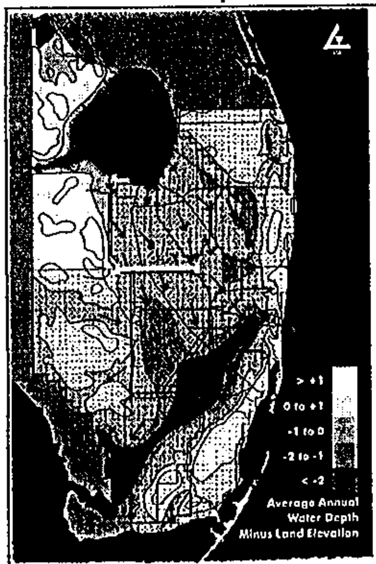
Caloosahatchee & St Lucie Outflows from Lake Okeechobee

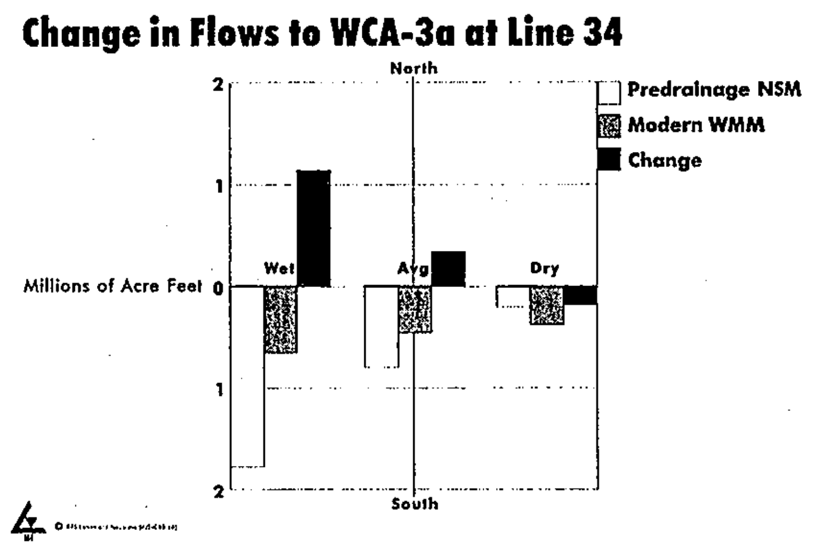


Discharges to Caloosahatchee and St.Lucie Rivers

► The models provide Modern values for discharge from Lake Okeechobee of [134,000:dry, 284,000:avg, 895,000:wet] for the Caloosahatchee at Structure S-77 and [51,000:dry, 124,000:avg, 420,000:wet] for the St. Lucie River at Structure S-308. Specific Predrainage flows are not available but for purposes of comparison are assumed to be zero.

- In the Modern system, maintenance of lower lake levels occasionally requires discharges of large quantities of excess water, by way of dredged canals on the Caloosahatchee and St. Lucie Rivers, to East and West Coast Estuaries. Such abnormal regulatory mass discharges of fresh water have harmed the estuaries. In Predrainage times, before the canals were dredged, these rivers did not discharge significant quantities of Lake water.
- Now, certain smaller discharges of water are required from the Caloosahatchee and St. Lucie Rivers for urban and agricultural purposes and for maintenance of estuaries.

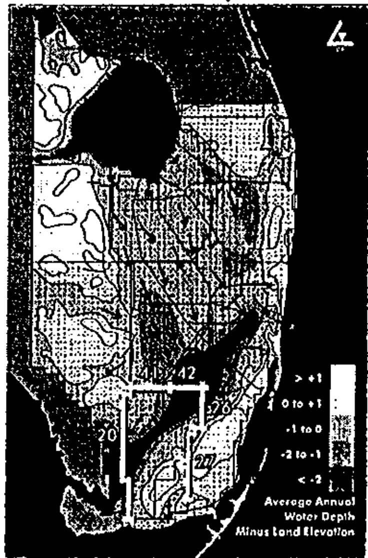


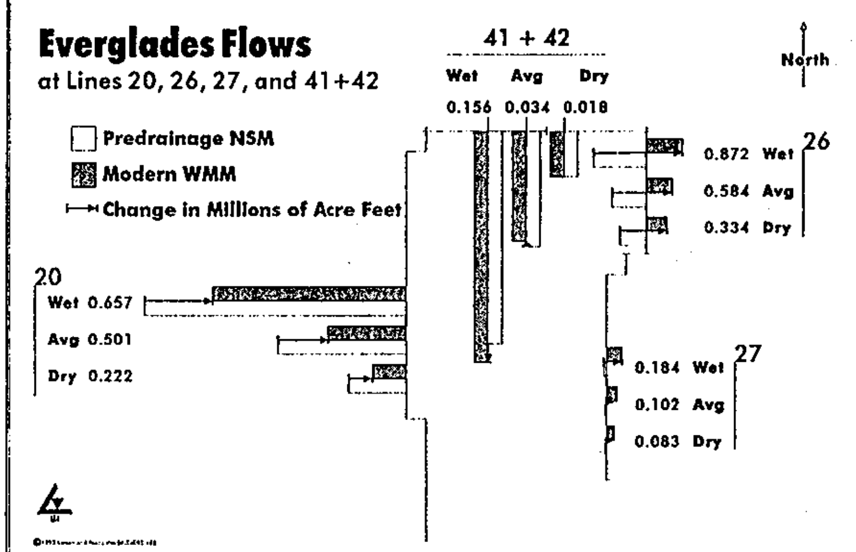


Changes in Flows to WCA-3A

- Flows at line 34 (Modern minus Predrainage) at the north end of WCA-3A have changed as follows [+177,000:dry, (-)342,000:avg, (-)1,131,000:wet]. Approximately 85% of Modern flows to WCA-3A at line 34, [381,000:dry, 453,000:avg, 651,000:wet] are delivered by Pump Station S-8. Please note that pursuant to the Everglades Forever Act it is anticipated that in the future more water will be delivered to the north end of WCA-3A from the EAA.

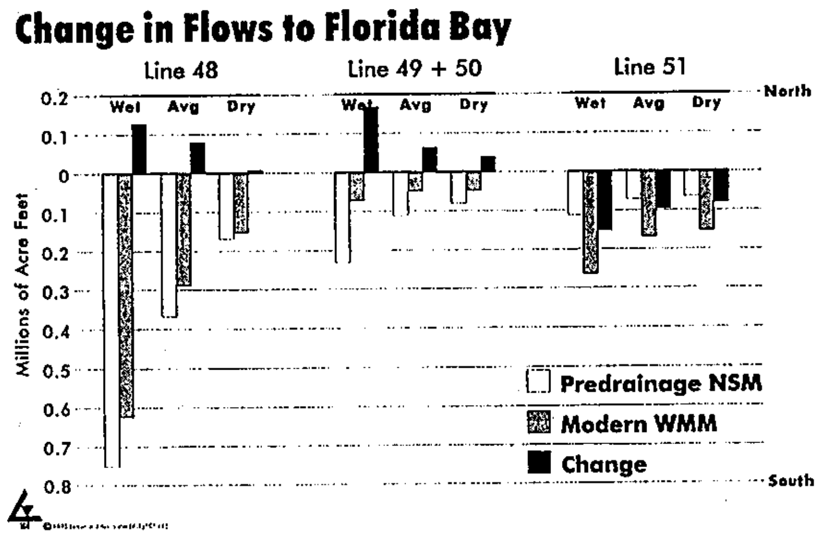
Please note that the WMM values for Line 34 do not include flows from Pump Station S-7 which discharges to WCA-2A.





Changes to Everglades Park Flows at Lines 20, 26, 27, and 41+42

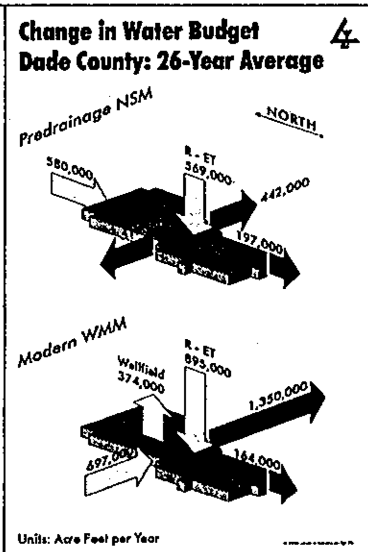
- There is very little change in total flow into the north end of the Park at lines 41 and 42 [18,000:dry, -35,000:avg, 157,000:wet]. There is a large **decrease** in flows to the Park at the northeast side of the Park at line 26 [334,000:dry, 584,000:avg, 872,000:wet]. This change is primarily due to Modern easterly seepage across the North-South Levee out of the Park to urban areas south of Tamiami Trail. You will recall that historic flows at line 26 were overland flows directed to the west.
- The models showed fairly large decreases in flows to **Whitewater Bay** through Shark River Slough. Please see line 20 [222,000:dry, 501,000:avg, 657,000:wet]. In general, these flows represent a 40% decrease in flows to Whitewater Bay based on 26 year average values. Please note that we did not evaluate monthly data which would have shown changes in the rate and time of deliveries during the year. Also please note that these changes may have a large effect on Whitewater Bay.



Changes in Flows to Florida Bay at Lines 48-51

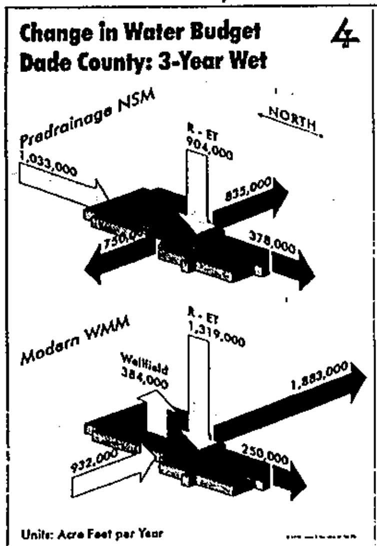
- Line 48 shows a relatively small decrease in southerly flows [10,000:dry, 80,000:avg, 130,000:wet]. Flows at line 49+50 have experienced relatively large decreases [39,000:dry, 65,000:avg, 165,000:wet] while flows at line 51 have increased substanstially [90,000:dry, 95,000:avg, 153,000:wet]. It appears that a portion of flows from line 51 could be diverted to line 49+50. Considering lines 48-51 together there has been a relatively small change in flows to Florida Bay [+41,000:dry, (-)50,000:avg, (-)142,000:wet].
- While the small overall change in flows to Florida Bay was an unexpected result of this analysis, please note that we did not evaluate monthly data which would have shown changes in the rate and time of deliveries during the year. Also please note that such timing changes may have a large effect on Florida Bay.
- Please note that unlike Biscayne Bay, Northeast Florida Bay has very little tidal action and probably has a very low rate of exchange with new water from the ocean. Small changes in the volume and timing of flows, especially in the dry season, could have a very large effect on the salinity and biological regime in Florida Bay.

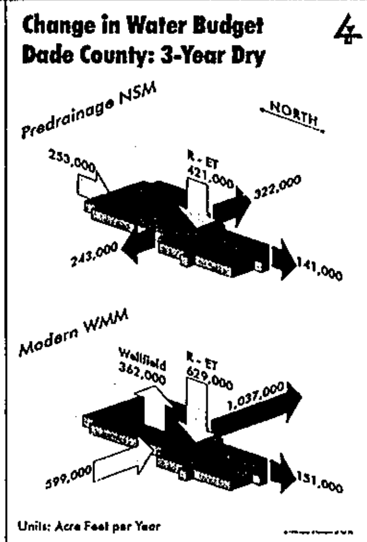
Location Map of Dade County



Change in Water Budget: Dade County, 26-Year Average

- As we have seen, the need to maintain low water tables in Lower East Coast urban areas has had a very large effect on the system. Drainage of wetlands for urban purposes has vastly increased the volume of fresh water discharged to the Atlantic estuaries. As an example, the slide on the right shows average annual water budget terms for Dade County. Inflow values are shown in blue—outflow terms in red. Wellfield pumpage is shown in Green. Please note that most of this pumpage is treated and discharged to the ocean or to injection wells. Therefore, wellfield pumping amounts are included in the WMM model values for discharge to the ocean.
- Most striking is that: inflows from the north have been eliminated, inflows to the ocean have increased substantially, and flows at the East-West Levee have reversed. Former large flows to the west have been replaced with large flows to the east.





Change in Water Budget: Dade County, 3-Year Wet

- Continuing the Dade County example, the slide on the left compares NSM and WMM Model values for wet years. The slide on the right, likewise, compares NSM and WMM flows for dry years.
- Even during dry years, in the wet season, if the urban municipal wellfields were turned off, we would have to discharge their former pumping volume to the estuaries in order to provide necessary freeboard between the land surface and the groundwater table for flood protection in urban areas. In the wet season, turning off the wellfields would not have positive effects on the Everglades.
- In the dry season, urban water tables are presently replenished with additional water from the Water Conservation Areas and Everglades Park. Some of this inflow is used to maintain urban water tables sufficient to prevent salt water intrusion and some of the inflow supplies wellfields. This water is delivered by seepage and by canals that interconnect the WCAs and the Lower East Coast urban areas. It is not clear how much water deliveries to urban areas would decrease in the dry season if the wellfields were not pumping. We do not think it would be a large amount relative to other terms in the water budget. This could be answered by interrogating the computer models but it was not possible in time for this report.

Change in Water Budget: Dade County, 3-Year Dry

- Currently, municipal wellfield pumping is a relatively small component in overall regional water budgets. While additional conservation measures would be helpful, they do not represent a solution to Everglades natural system issues. Proposals to reclaim salt water for municipal purposes would not likely result in benefits in the remaining natural system west of the North-South Levee that would be commensurate with costs.

Recap

The Remaining Everglades Relies on Large Inputs of Water from Beyond its Borders

- Rainfall is not much greater than ET in the central Everglades.
- As a result ,by themselves, the Water Conservation Areas "produce" only small quantities of water for downstream discharge.
- Large external inputs of water from the north, east, and west are necessary to sustain the WCAs and provide downstream flows.

Effects of Drainage: Storage Loss

- Lake Okeechobee lowered 6 feet—loss of at least 3 million acre feet of storage.
- Generally lowered water table two feet to drain 1.5 million Acres of Wetlands—loss of approximately 3,000,000 acre feet of storage.
- Total System storage loss—6 million acre feet. Compare this volume of storage loss with the present total volume of Lake Okeechobee of approximately 4 million acre feet.
- Major changes in the hydrologic system have resulted due to loss of storage.

Effects of Drainage: Change in ET

- Drained wetlands produce much more discharge than before drainage.
- Creating pavements and roofs in urban areas further increase the quantity of discharge. However, good engineering design can reduce these effects.
- As a result of drainage and consequent decrease in ET, the amount of flow in the EAA, East Palm Beach, East Broward and East Dade has increased by [1,161,000:dry, 1,543,000:avg, 1,892,000:wet]

Effects of Drainage: Change in Timing

- The timing of the discharge from drained wetlands and especially urbanized drained wetlands is vastly changed.
- Changes in timing of flows in the Everglades and to estuaries probably has a large effect on biological systems.

Effects of Drainage: Subsidence

- Subsidence has occurred in the EAA and WCA-3A and anywhere else organic soils have been drained.
- A shallow depression has been created in the EAA that is lower than Lake Okeechobee and WCA-1. The EAA has been surrounded by levees similar to a Dutch Polder and pumps are required to keep it from flooding.
- As a result, in any future scenario, drainage of the EAA will have to be maintained.
- A subsidence valley has been created in WCA-3 with consequent effects on hydroperiod.

Effects of High Transmissivity

- Attempts to maintain drained urban areas adjacent to natural wetland areas on top of extraordinarily transmissive aquifer result in large seepage losses out of the WCAs and Everglades Park.
- In Dade County, flows at the North-South levee have reversed from strongly west in Predrainage times to strongly east under Modern conditions.

Changes in Flows Due to Urbanization

- Changes in flows across the North-South Levee.
- Changes in flows to the Atlantic Estuary of approximately 2 million Acre Feet.
- May indicate the quantity of water available for future Everglades, urban and agricultural water supply.

Effects of Municipal Pumpage

- Relatively small component of the Regional Water Budget.
- Conservation of municipal pumpage, while helpful, can't solve the problem.

Keep Water in the System: Re-establish Balance

- In Predrainage times Southeast Florida was a very wet area. Now, drained urban and agricultural areas coexist with adjacent natural wetland areas. The Predrainage system was in balance with annual wet and dry rainfall cycles. The Modern system seems to be out of balance with large flow increases to the ocean.
- Assuming the Modern system receives the same general amount of rainfall as formerly fell on the Predrainage system, then restoring balance requires retaining more of this water in the system and discharging less to the ocean. Because drained and natural areas comprise a single interconnected system, there may be a common solution that solves the region's water problems.
- It is likely that just a portion of increased flows to the Atlantic Estuaries from Dade, Broward and Palm Beach Counties (Modern system flows compared to Predrainage system flows) will be sufficient to meet natural system needs and increased urban needs. This may be the most encouraging result of the analysis.

Improving water conditions in the Everglades and surrounding estuaries does not necessarily mean hardship for urban and agricultural areas. The urban and agricultural areas could be part of the solution—not the problem.

Paradoxically, achieving balance in the Total South Florida System, including more natural Everglades and Estuaries, will require additional structural facilities and increased operational flexibility.