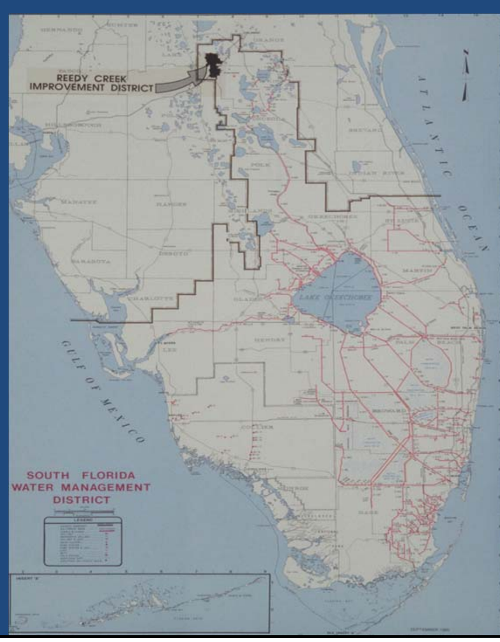
Hydrologic and Nutrient Conditions in the Vicinity of Rapid Infiltration Basins – Reedy Creek Improvement District, Florida

David Sumner – US Geological Survey
Ted McKim – Reedy Creek Energy Services
Andrew O'Reilly – US Geological Survey
Craig Duxbury – Walt Disney Imagineering

USGS

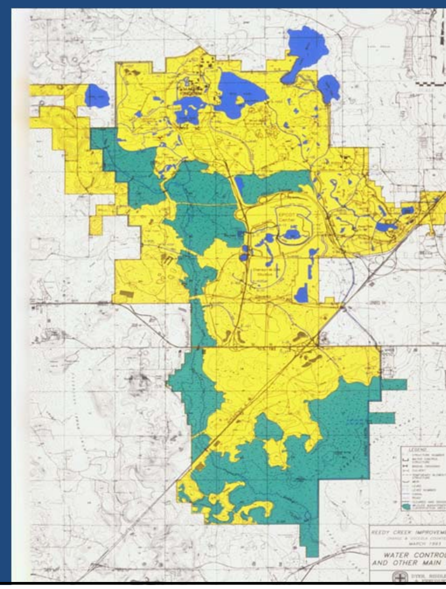
RCID within headwaters of flow system



USGS

A little about Reedy Creek Improvement District

- Special District created in 1967
- Provides services similar to municipality
- Serves 25,000 acres in Orange & Osceola Counties
- Equivalent to a city of 150,000 to 200,000 population
  - 30,000+ Hotel Rooms
  - 60,000+ employed
- 16-20 MGD potable demand; 11-13 MGD wastewater



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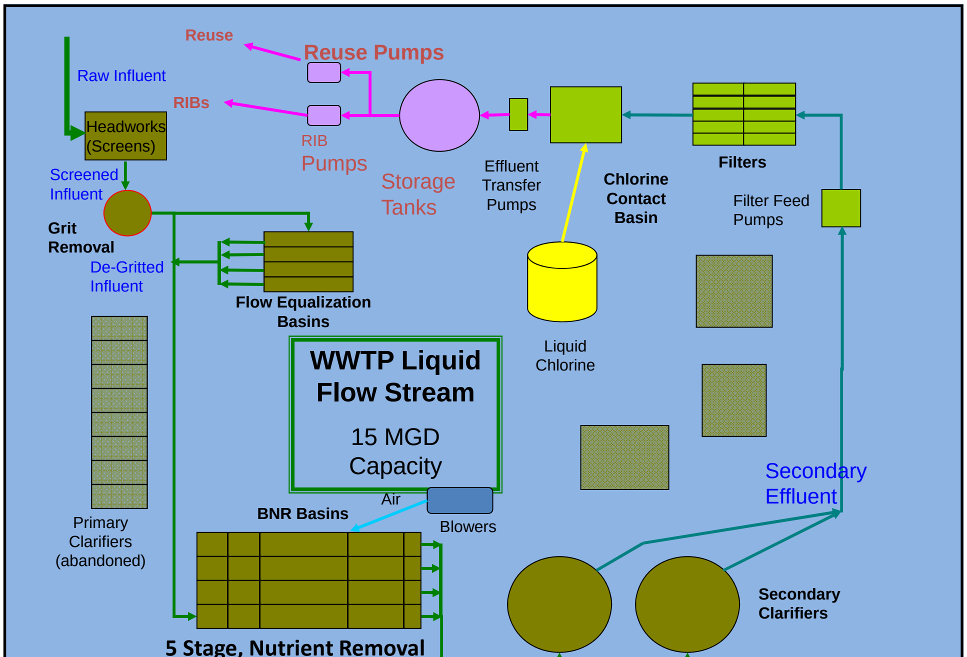


USGS

Water Resource History

- Wastewater
  - Direct discharge to Reedy Creek from 1971 to 1977
  - Wastewater discharged to surface waters via wetlands from 1977 to 1990
  - Rapid infiltration basins for groundwater recharge initiated in 1990
- Water
  - Prior to 1993, almost all demands were met with groundwater; some surface water
    - Surface waters irrigated two golf courses
    - Reclaimed water irrigated a 100 acre tree farm
    - All other demands (98+%) met with groundwater
  - Since 1993, demands met with a combination of groundwater and reclaimed water

USGS

RIBs at RCID

- Initiated operation in summer 1990
- 1,000 acre site; part of Lake Wales Ridge formation; formerly citrus
- 85 basins, about 1 acre each
- Permitted for 12.5 MGD; operate at 5-6 MGD AADF

USGS

Win-Win

Need to dispose of treated wastewater

+

Desire to recharge potable aquifer

+

Desire to further improve wastewater quality

↓

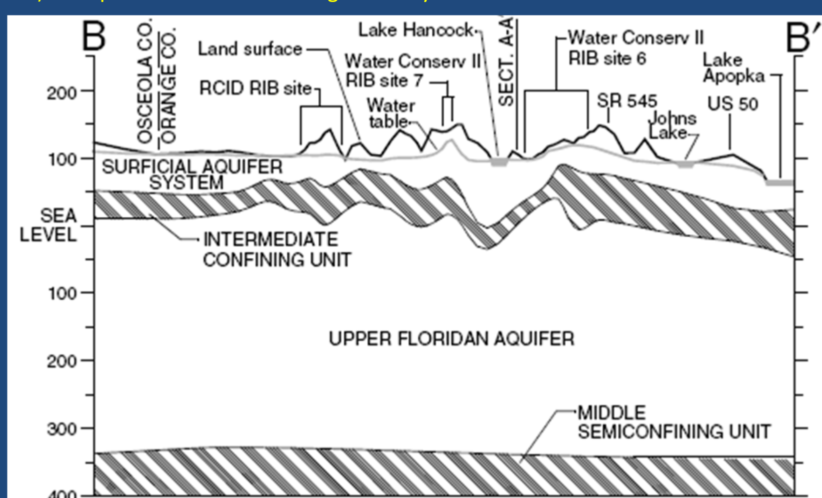
Disposal via rapid infiltration basins (RIBS)

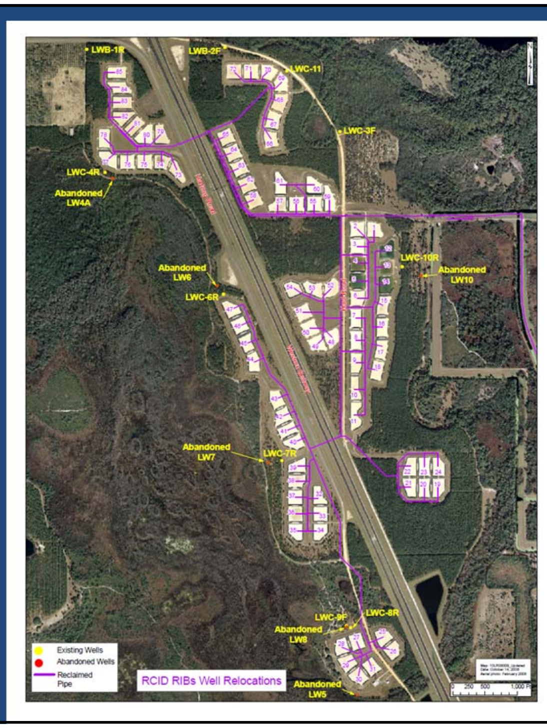
USGS

USGS

RIBS are in area of:

1) Downward flow to potable aquifer
2) Sandy, highly-permeable soils
3) Deep water table in this “high country”





RCID
Rapid infiltration basins

WWTP to east

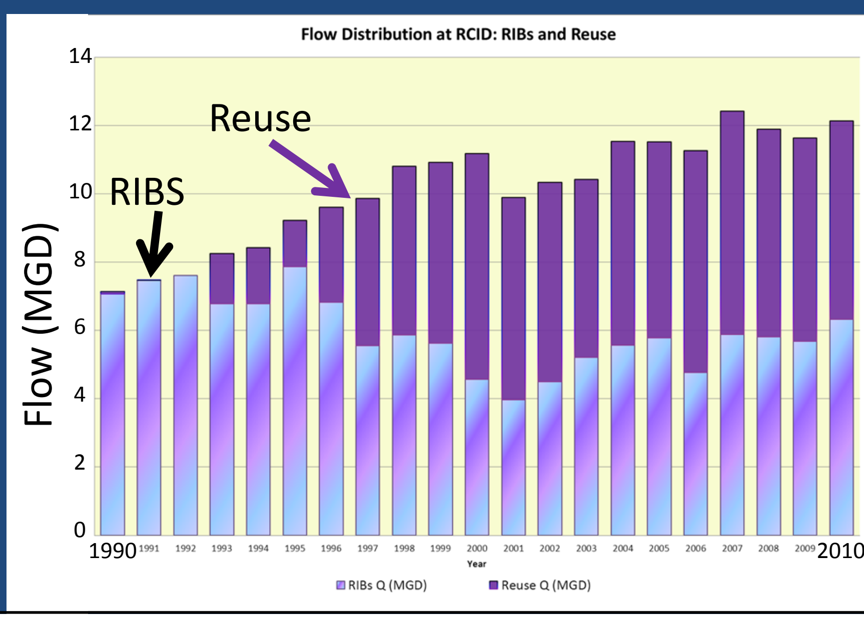
Pipe network (purple) distributes water to RIB system

Surface water drainage to west and east of RIBS

USGS

USGS

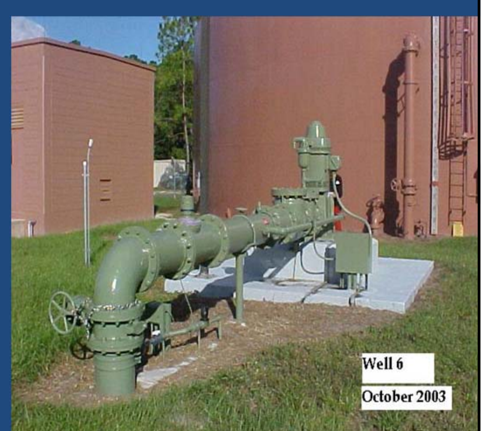
Reuse provides 25+/-% of needs at RCID



Reuse Today – Multiple Uses

Reuse leads to less demand on potable aquifer - Upper Floridan Aquifer

- 11 production wells withdraw from Upper Floridan; 300 to 900 ft deep
- Up to 4,000 gpm /well
- Aquifer is extremely productive and of high quality
- Sustainable Yield Reached
  - Declining potentiometric surface
  - Impacts to wetlands, lakes, springs, and possible deep brine movement



Basin operation (current)

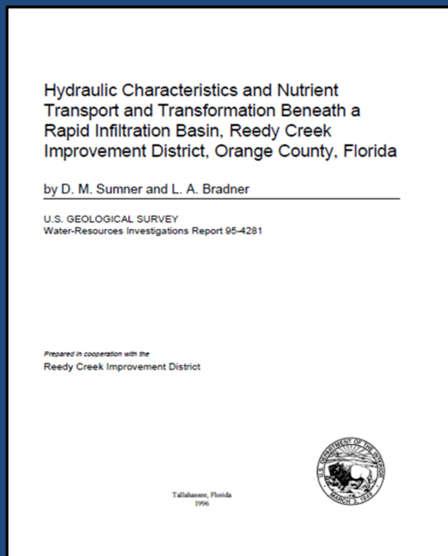
Load 15-17 basins each week

2-3 week basin rest and disking

USGS

- A rapid infiltration basin "in action"

USGS


Hydraulic Characteristics and Nutrient Transport and Transformation Beneath a Rapid Infiltration Basin, Reedy Creek Improvement District, Orange County, Florida

by D. M. Sumner and L. A. Bradner

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 95-4281

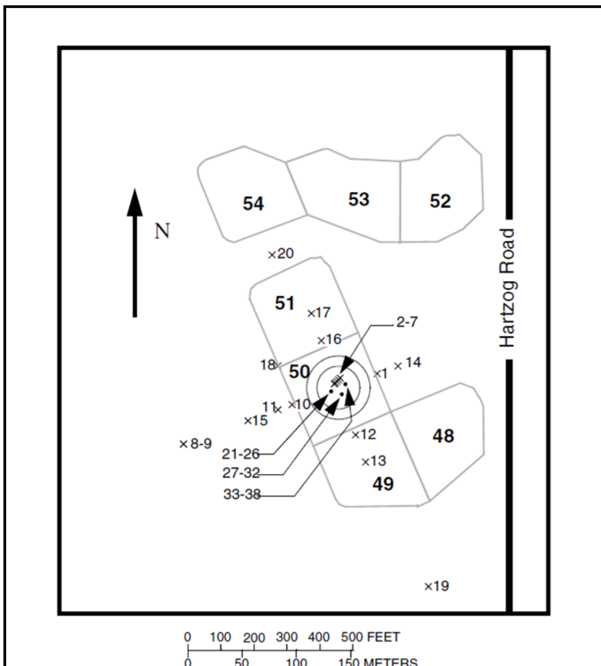
Prepared in cooperation with the
Reedy Creek Improvement District

Tallahassee, Florida
1996

Basin scale characterization of hydraulics and nutrient transport/transformation USGS WRIR 95-4281

1) Definition of sub-basin flow system via flow model
2) Application of model to scenario questions?
3) Transport/transformation of N and P

USGS



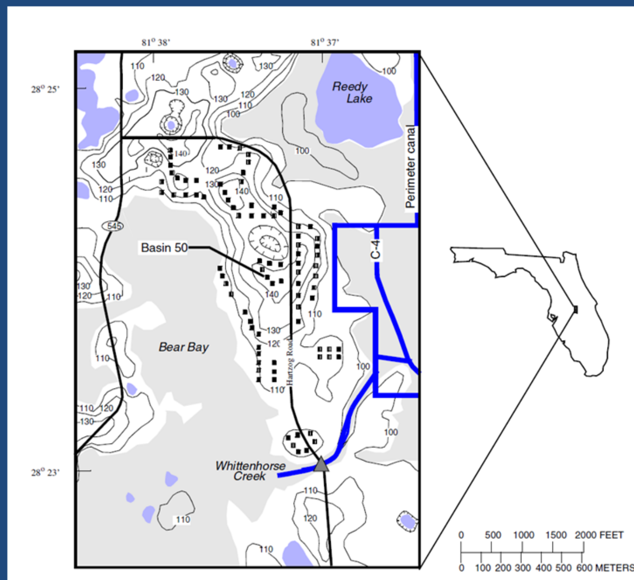
Single basin focus – basin 50

Multiple piezometers

Multiple sampling wells

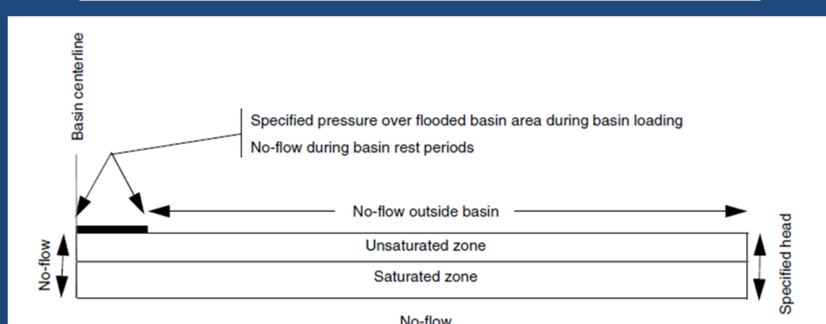
USGS

Location of Basin 50



Radial model of flow system

$$(sS_s - C(\psi))\frac{\partial\psi}{\partial t} = \frac{\partial}{\partial z}\left(K_Z(\psi)\left(\frac{\partial\psi}{\partial z} - 1\right)\right) + \frac{\partial}{\partial r}\left(K_r(\psi)\frac{\partial\psi}{\partial r}\right) + \frac{K_r(\psi)}{r}\frac{\partial\psi}{\partial r}$$



Subsurface flow model

USGS VS2D unsaturated/saturated model

- - captures impact of vadose zone on aquifer recharge

- - allows for vertical gradients below water table

Inverse problem to identify model parameters

Loading stress → Flow model (Kz, Kr, & unsat parameters) → System response

Model calibration

Loading stress = Ponding within circle for 15 days
3 weeks no flow

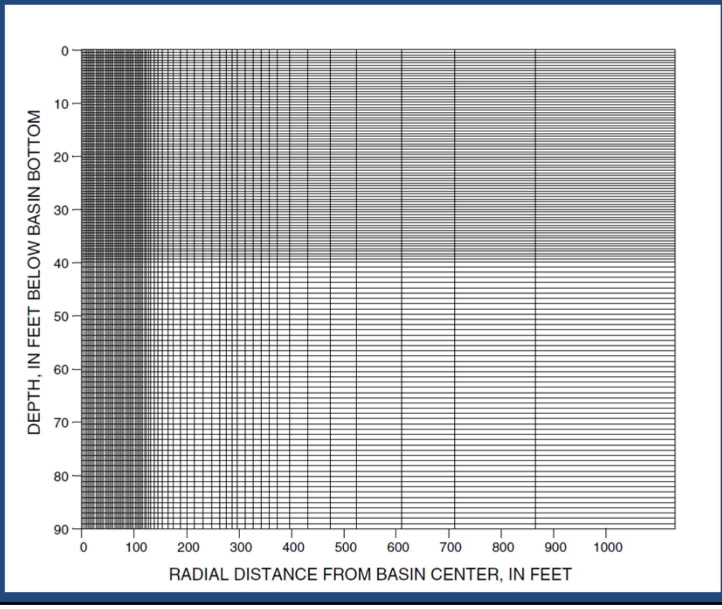
System response = Mounding – both vertical and radial
Infiltration – 10 Mgal

Infer hydraulic parameters – via trial and error calibration to capture observed heads & flows

& guided by ancillary sources (lab tests, slug tests, literature)

USGS

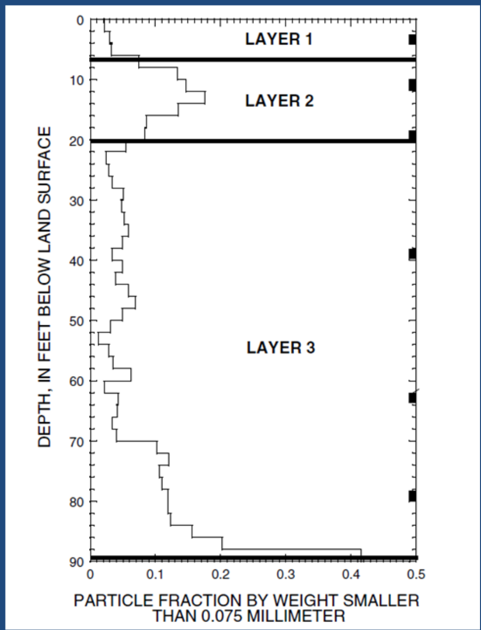
Model discretization



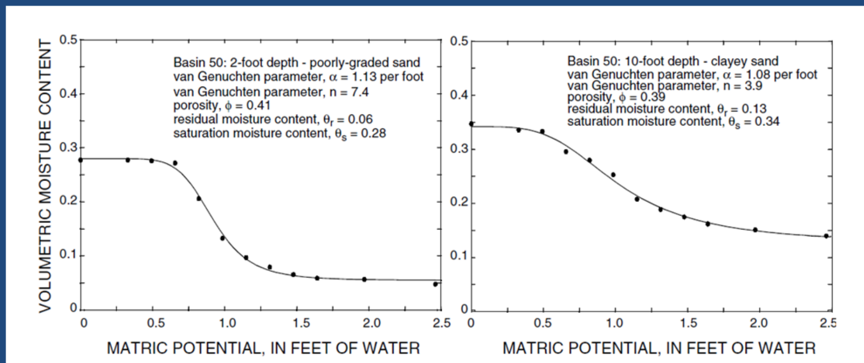
Model layering dictated by lithology

Generally sandy, but high clay content from 7 to 20 feet

Change in radius of flooded area did not change infiltration rate
->
Kvsat1 ~ Kvsat2



Analysis of soil cores to guide unsaturated zone hydraulic parameters



$$(sS_s - C(\psi))\frac{\partial\psi}{\partial t} = \frac{\partial}{\partial z}\left(K_Z(\psi)\left(\frac{\partial\psi}{\partial z} - 1\right)\right) + \frac{\partial}{\partial r}\left(K_r(\psi)\frac{\partial\psi}{\partial r}\right) + \frac{K_r(\psi)}{r}\frac{\partial\psi}{\partial r}$$

USGS

Calibrated model parameters

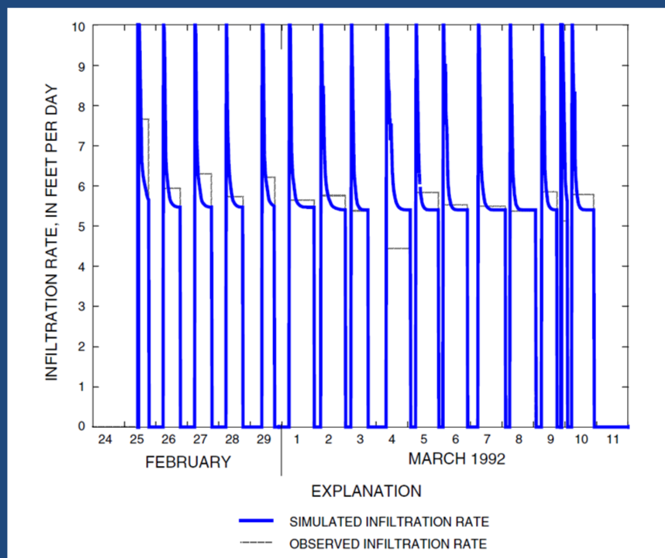
Table 7. Summary of calibration-inferred hydraulic parameters for radial-flow model of subsurface flow in the vicinity of basin 50

[$(K_s)_r$, radial saturated hydraulic conductivity; $(K_s)_z$, vertical saturated hydraulic conductivity; θ_S, saturation volumetric moisture content; θ_r, residual volumetric moisture content; α, van Genuchten coefficient; n, van Genuchten coefficient; --, parameter not reliably estimated by model owing to a lack of sensitivity; ft/d, feet per day; ft^3/ft^3, cubic feet per cubic foot].

Layer	$(K_s)_r$ (ft/d)	$(K_s)_z$ (ft/d)	θ_S (ft^3/ft^3)	θ_r (ft^3/ft^3)	α (ft^{-1})	n (dimensionless)
1	--	5.1	0.28	0.06	1.1	7
2	--	5.1	.35	.13	1.1	4
3	150	45	.45	.04	1.1	7

USGS

Measured and simulated infiltration rates



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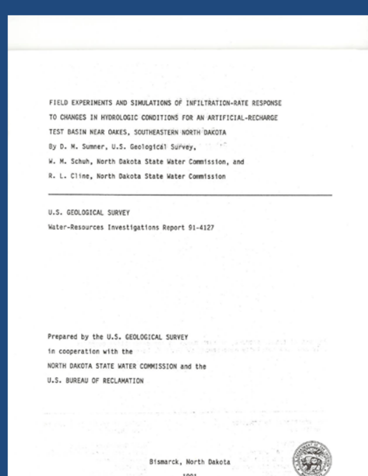
Often, surface crust development impedes infiltration with time



FIELD EXPERIMENTS AND SIMULATIONS OF INFILTRATION-RATE RESPONSE TO CHANGES IN HYDROLOGIC CONDITIONS FOR AN ARTIFICIAL-RECHARGE TEST BASIN NEAR OAKES, SOUTHEASTERN NORTH DAKOTA

By D. M. Sumner, U.S. Geological Survey,
W. M. Schuh, North Dakota State Water Commission, and
R. L. Cline, North Dakota State Water Commission

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 91-4127

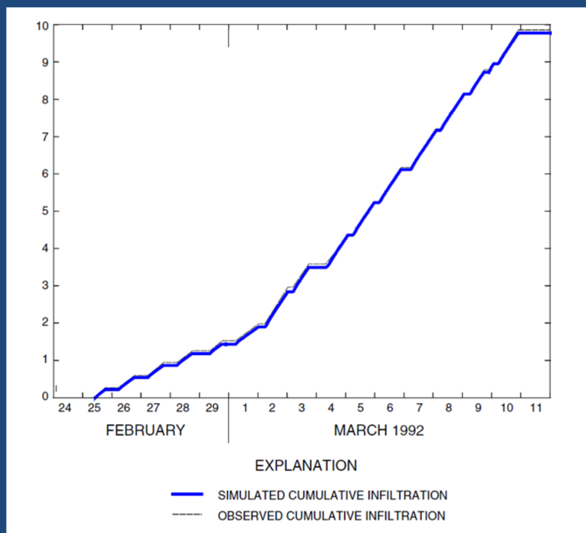
Prepared by the U.S. GEOLOGICAL SURVEY
in cooperation with the
NORTH DAKOTA STATE WATER COMMISSION and the
U.S. BUREAU OF RECLAMATION

Bismarck, North Dakota
1991

….. but no noticeable change in infiltration at RCID RIBS

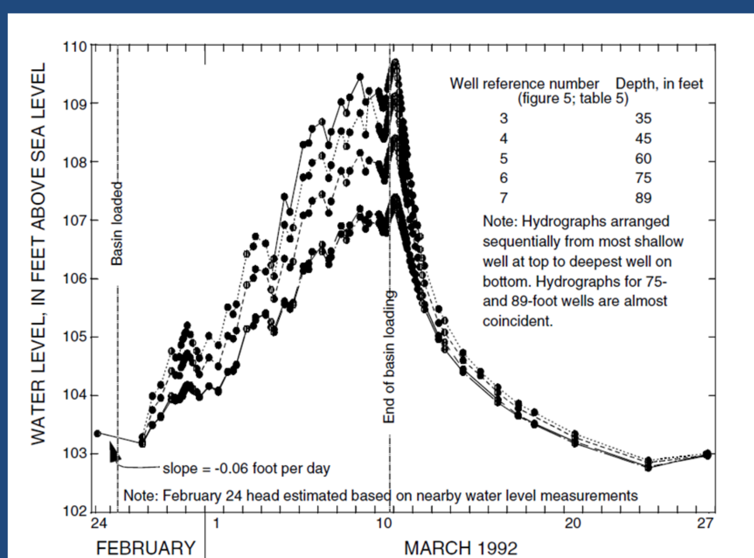
USGS

Measured and simulated infiltration rates (cumulative)



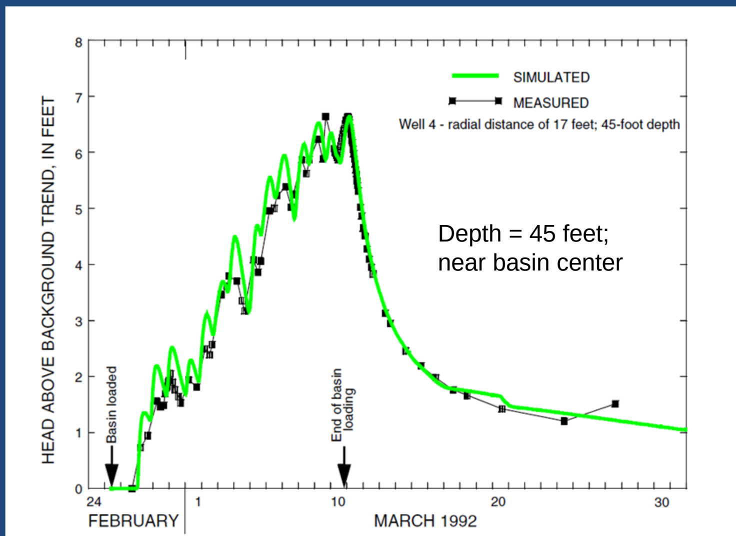
USGS

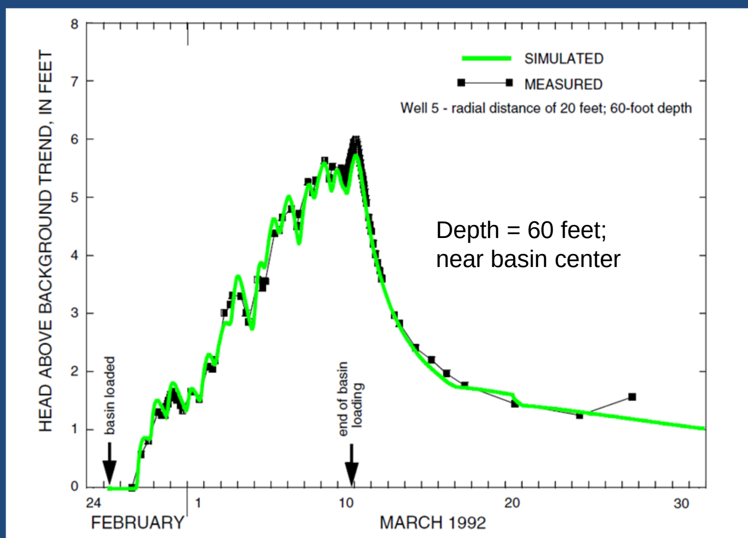
Vertical gradients below basin during loading - - > can separate Kr and Kz

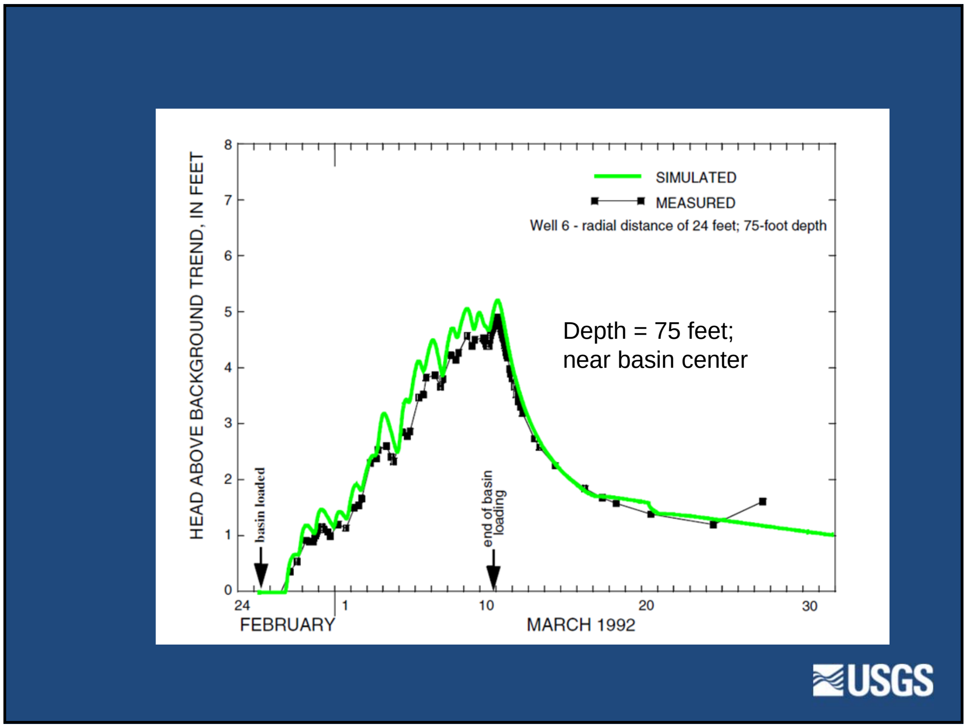


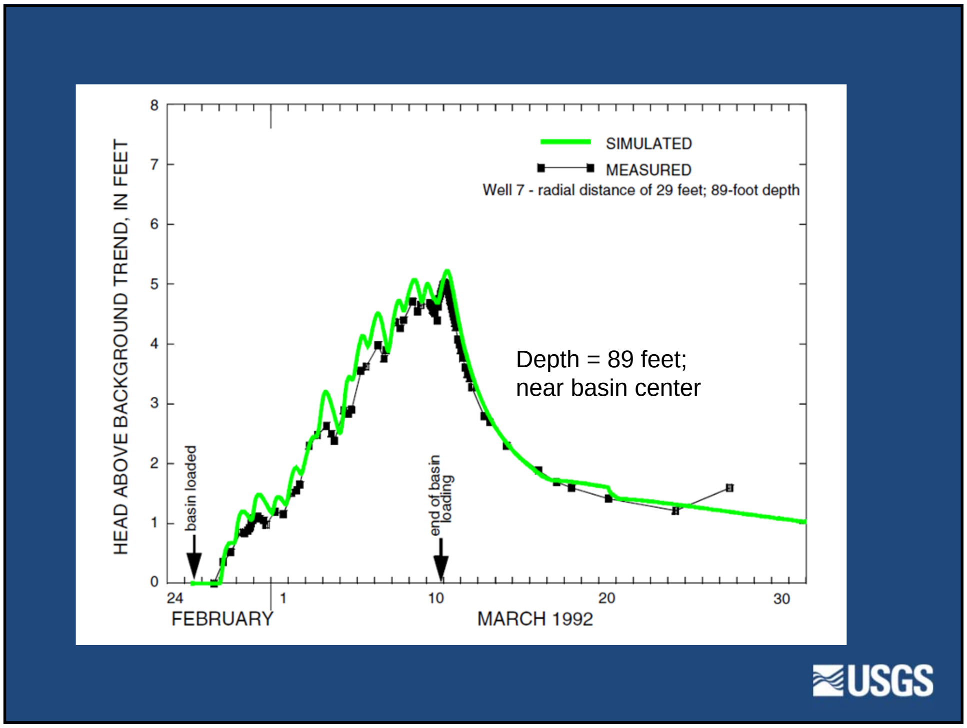
USGS

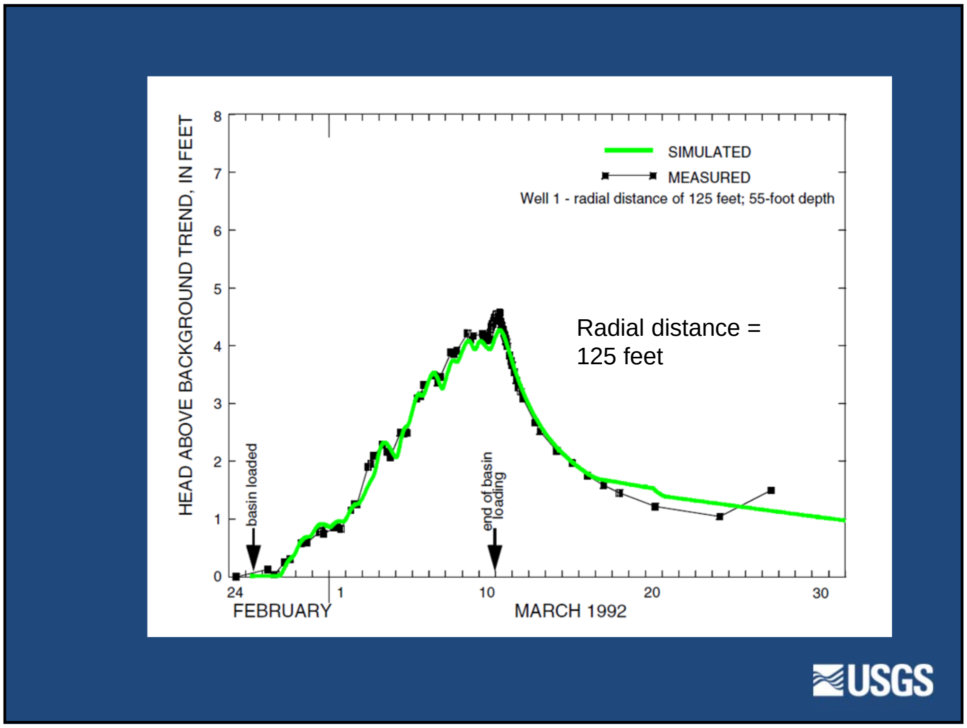
Measured and simulated water table mounding and dissipation

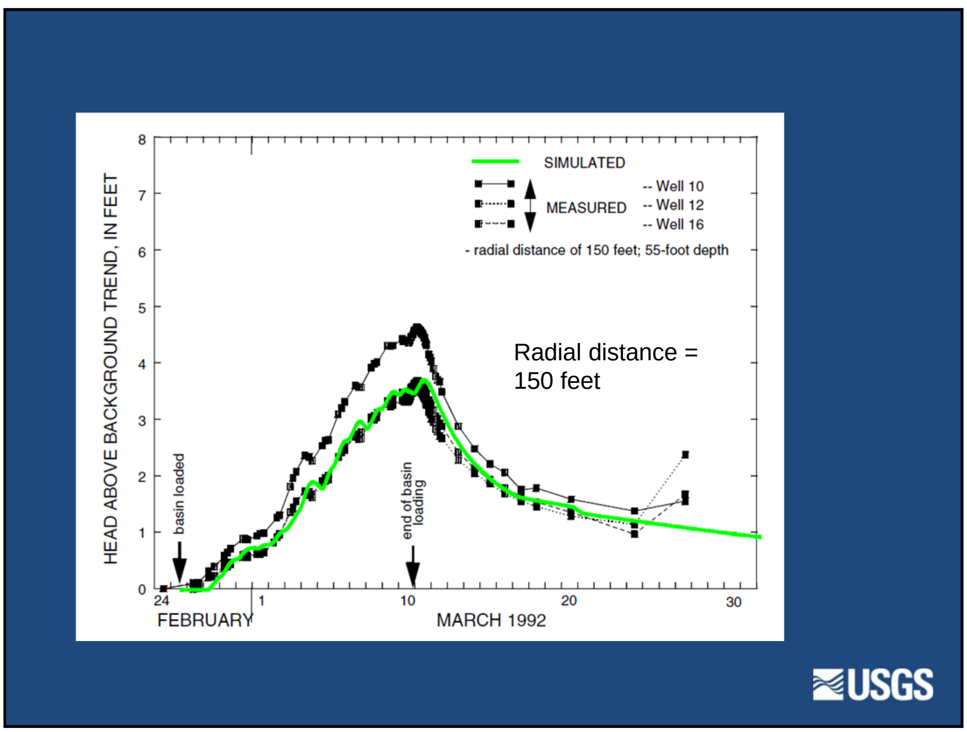


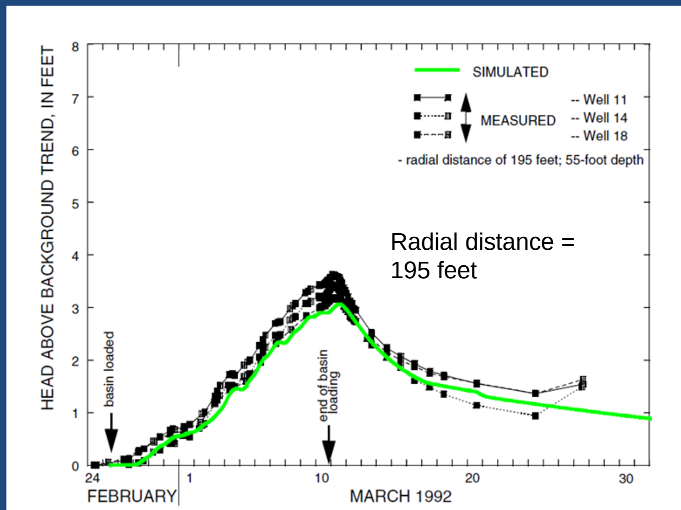


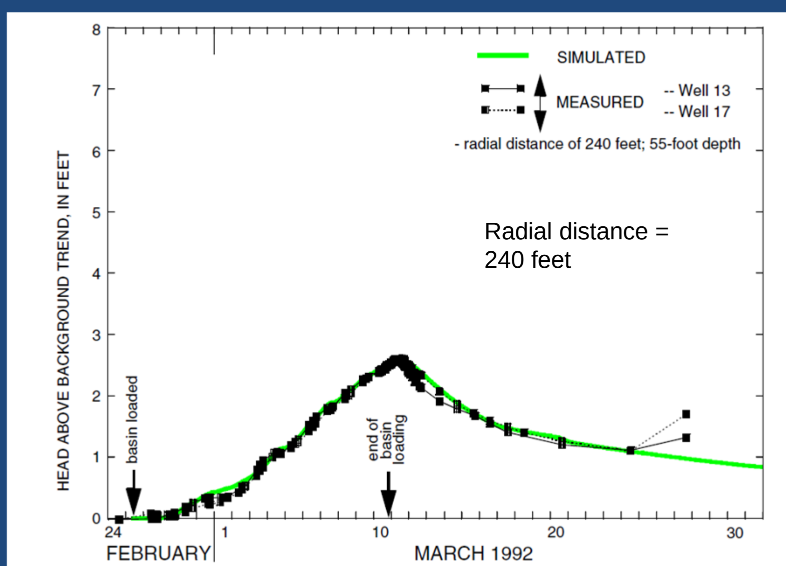

SIMULATED
MEASURED
Well 6 - radial distance of 24 feet; 75-foot depth
Depth = 75 feet;
near basin center
HEAD ABOVE BACKGROUND TREND, IN FEET
basin loaded
end of basin loading
FEBRUARY
MARCH 1992
USGS


SIMULATED
MEASURED
Well 7 - radial distance of 29 feet; 89-foot depth
Depth = 89 feet;
near basin center
HEAD ABOVE BACKGROUND TREND, IN FEET
basin loaded
end of basin loading
FEBRUARY
MARCH 1992
USGS

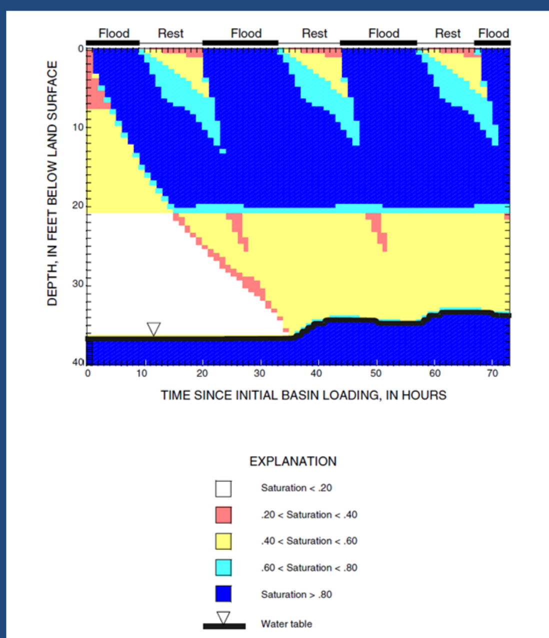

HEAD ABOVE BACKGROUND TREND, IN FEET
SIMULATED
MEASURED
Well 1 - radial distance of 125 feet; 55-foot depth
Radial distance =
125 feet
basin loaded
end of basin loading
24
1
10
20
30
FEBRUARY
MARCH 1992
USGS


HEAD ABOVE BACKGROUND TREND, IN FEET
SIMULATED
MEASURED
-- Well 10
-- Well 12
-- Well 16
- radial distance of 150 feet; 55-foot depth
Radial distance =
150 feet
basin loaded
end of basin loading
24
1
10
20
30
FEBRUARY
MARCH 1992
USGS


HEAD ABOVE BACKGROUND TREND, IN FEET
SIMULATED
MEASURED
-- Well 11
-- Well 14
-- Well 18
- radial distance of 195 feet; 55-foot depth
Radial distance =
195 feet
basin loaded
end of basin loading
FEBRUARY
MARCH 1992


HEAD ABOVE BACKGROUND TREND, IN FEET
SIMULATED
MEASURED
-- Well 13
-- Well 17
- radial distance of 240 feet; 55-foot depth
Radial distance =
240 feet
basin loaded
end of basin loading
FEBRUARY
MARCH 1992

Apply model in "forward" sense to further describe the flow system



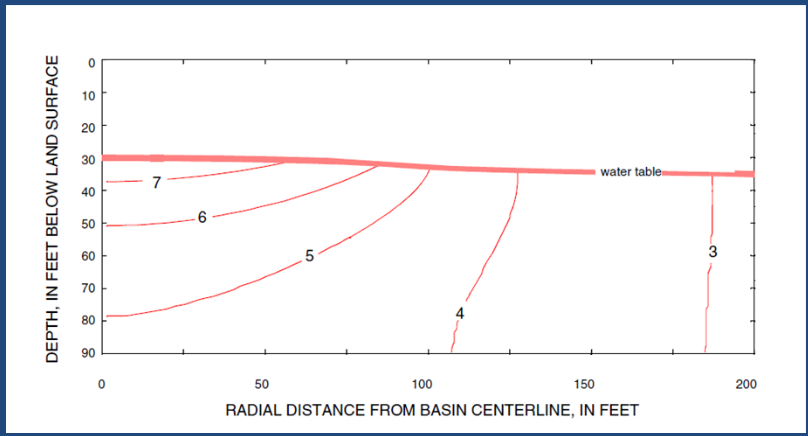
Simulations provide view of subsurface moisture status with depth and time

Important in analysis of oxygen availability for nutrient analysis and percolation controls.

USGS

Simulated mounding after 15 days of loading

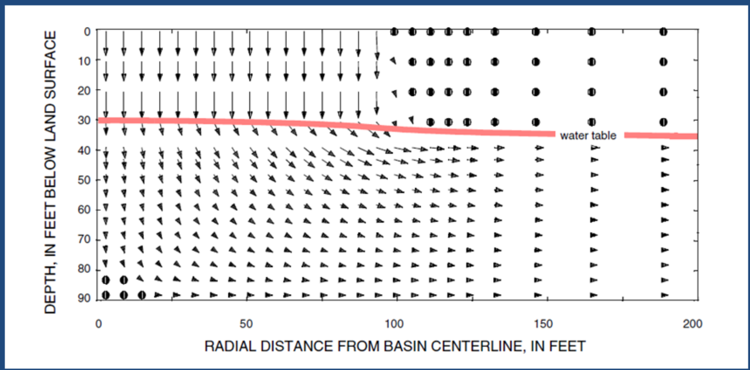
Model allows better definition of water table



USGS

Simulated pore water velocity after 15 days of loading

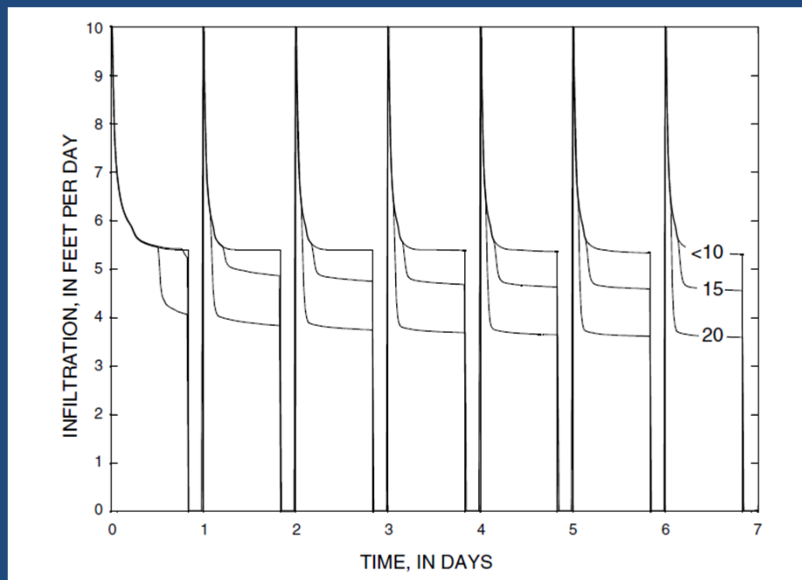
Model allows tracking of subsurface water



USGS

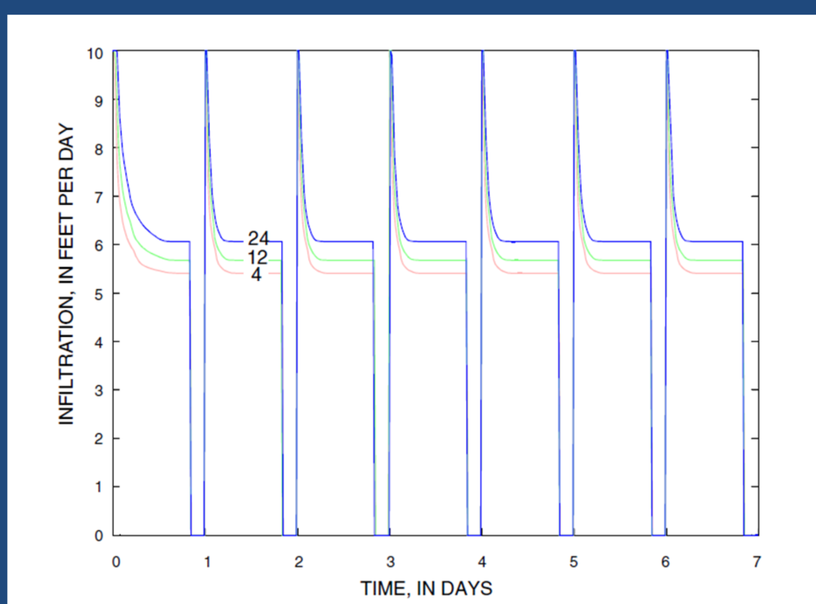
Impact of background water table rises on basin infiltration

USGS

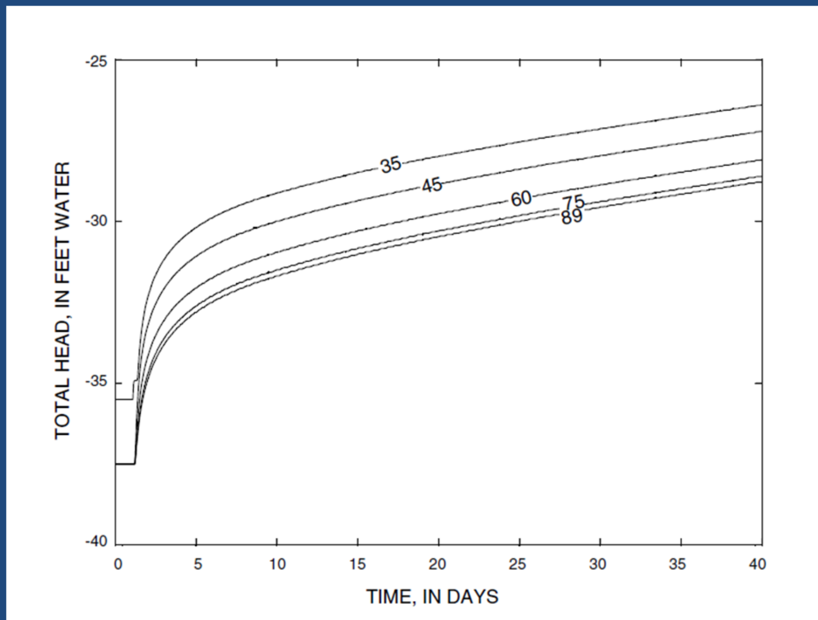


Impact of basin inundation depth (inches) on infiltration rate

USGS



Impact of continuous 40-day basin loading on water table mounding



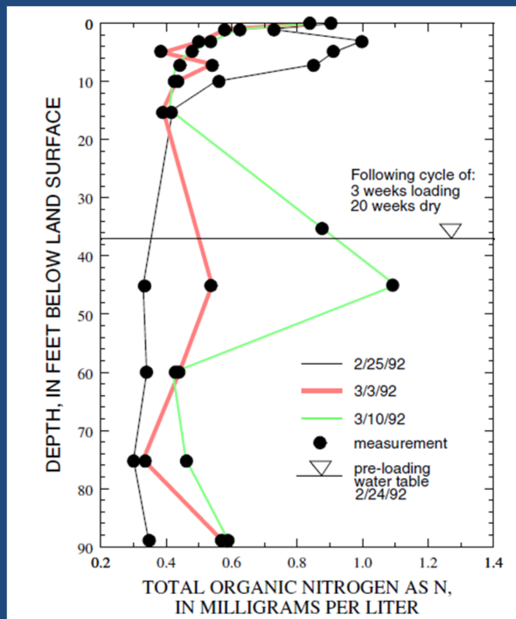
Nutrient evolution

Vertical water sampling near center of basin

Multiple wells beneath water table (35, 45, 60, 75 and 89 ft)

KVA Analytical shield point samplers w/tube to surface for multiple points in shallow subsurface (1, 3, 5, 7, 10 and 15 ft depths) – rely on positive pressure

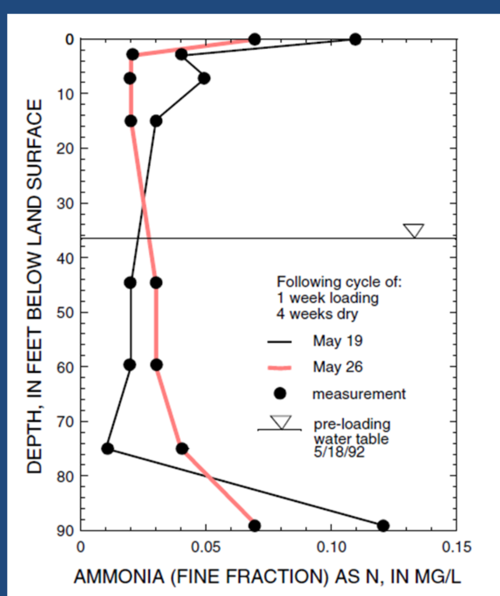
Two loading events were sampled:
(1) 3 weeks loading followed by 20 weeks dry
(2) 1 week loading followed by 4 weeks dry



Observations

1. **Filtering** of organic N above water table
2. **Accumulation** of organic N below water table during loading (slacking water pore velocities)

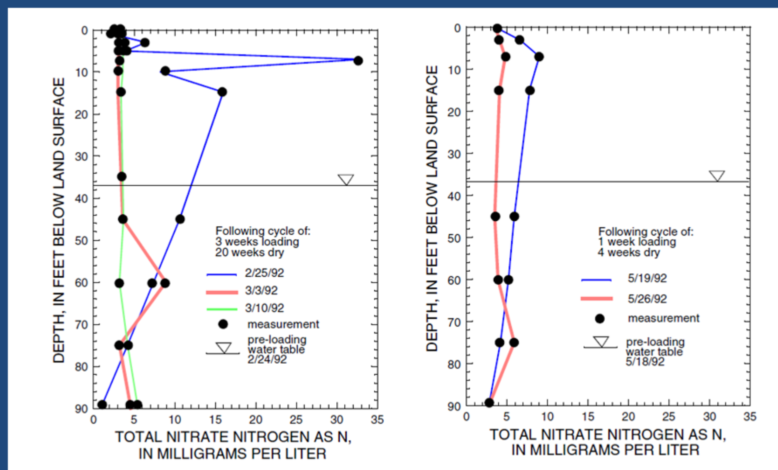
USGS



Observations

1. **Adsorption** of ammonium above water table
2. **Reduction** of nitrate to ammonium (DNRA) at base of aquifer ?

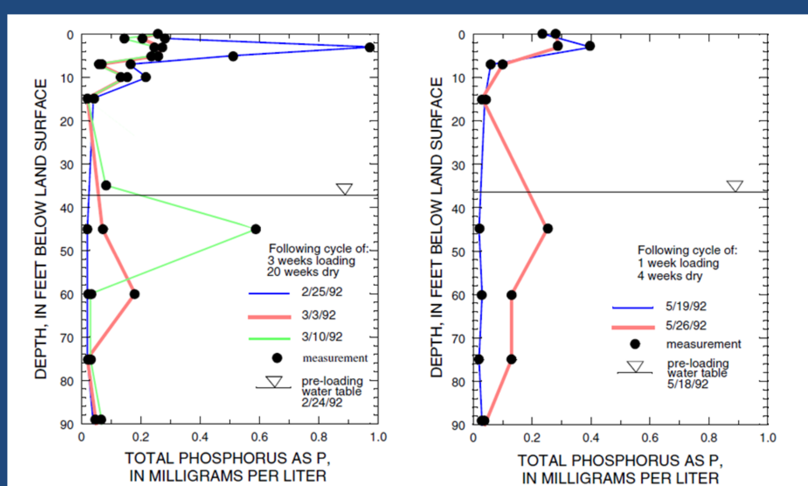
USGS



Observations

1. Mineralization of accumulated organic N / NH4 – in unsaturated zone organic N just below water table
2. Elevated nitrates most pronounced with longer basin loading intervals

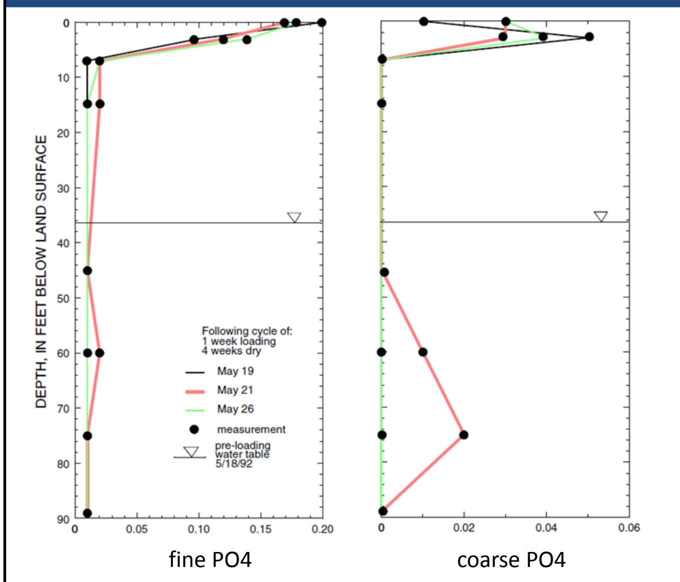
USGS



Observations

1. **Filtering** of phosphorus above water table
2. **Accumulation** of phosphorus below water table during loading (slacking water pore velocities)
3. First day spikes of phosphorus at 3 feet

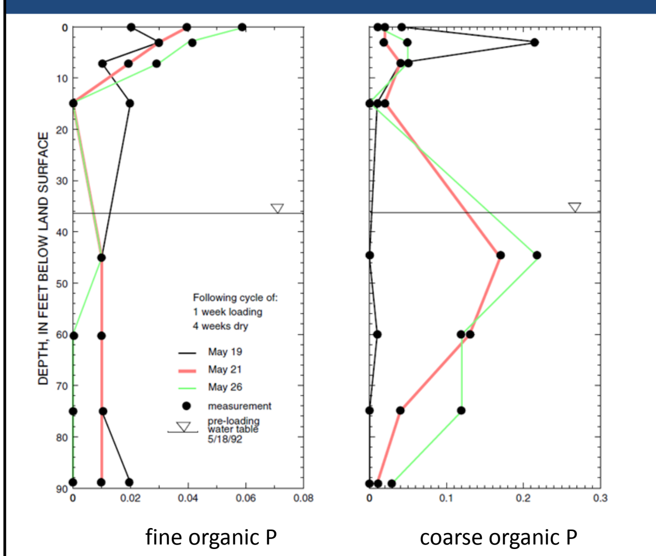
USGS



Observation

1. **Adsorption** of fine-fraction PO4 in shallow subsurface by oxides of iron and aluminum -90% removal

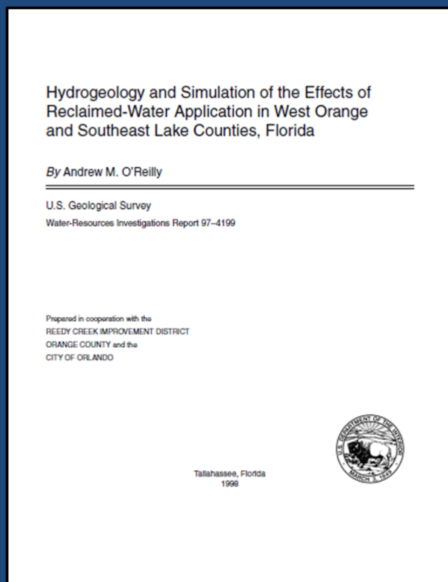
USGS



Observations

1. **Accumulation** of organic P below water table during loading (slacking water pore velocities)
2. Mineralization and precipitation during rest periods – oversaturated with respect to several calcium phosphate minerals.

USGS


Hydrogeology and Simulation of the Effects of Reclaimed-Water Application in West Orange and Southeast Lake Counties, Florida

By Andrew M. O'Reilly

U.S. Geological Survey
Water-Resources Investigations Report 97–4199

Prepared in cooperation with the
REEDY CREEK IMPROVEMENT DISTRICT
ORANGE COUNTY and the
CITY OF ORLANDO

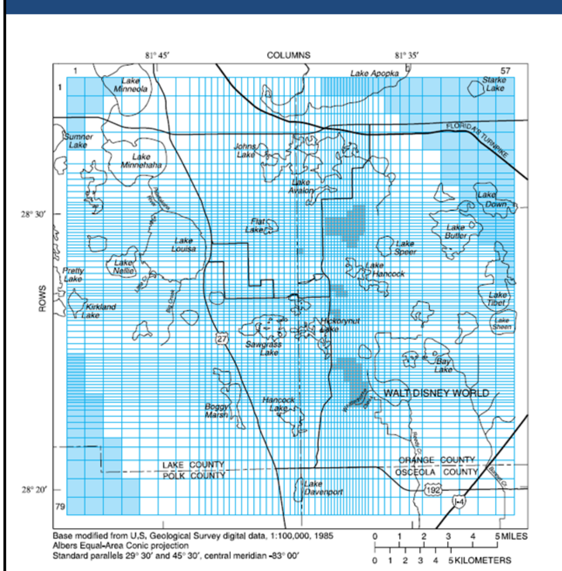
Tallahassee, Florida
1998

Hydrogeology and Simulation of the Effects of Reclaimed-Water Application in West Orange and Southeast Lake Counties, Florida
USGS WRIR 97-4199

1) Definition of regional flow system via flow model
2) Application of model to scenario questions?

USGS

Regional scale flow evaluation

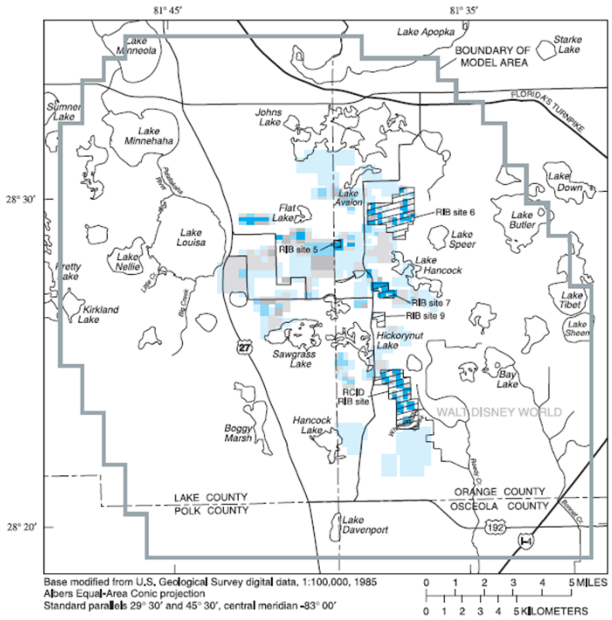


USGS MODFLOW saturated subsurface flow model

Cartesian grid

Steady-state - average 1995

USGS

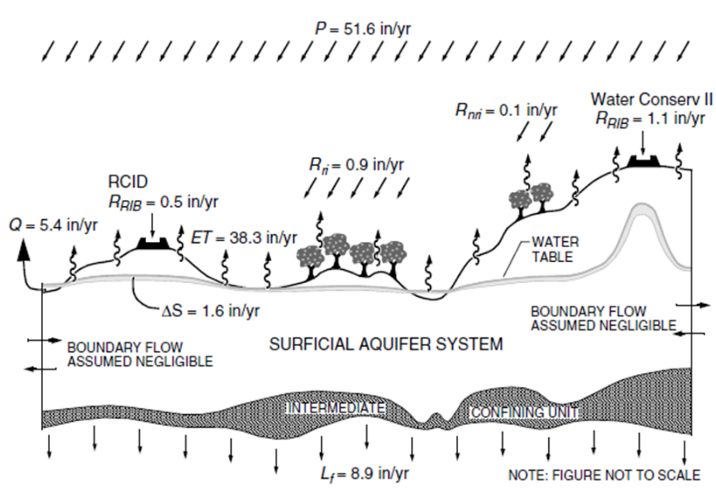


Areas of RIB and irrigation disposal of treated wastewater

CONSERVII ~ 28 MGD to RIBS & AG

RCID ~ 6 MGD to RIBS

Area water budget



Characterization of Hydraulic Properties

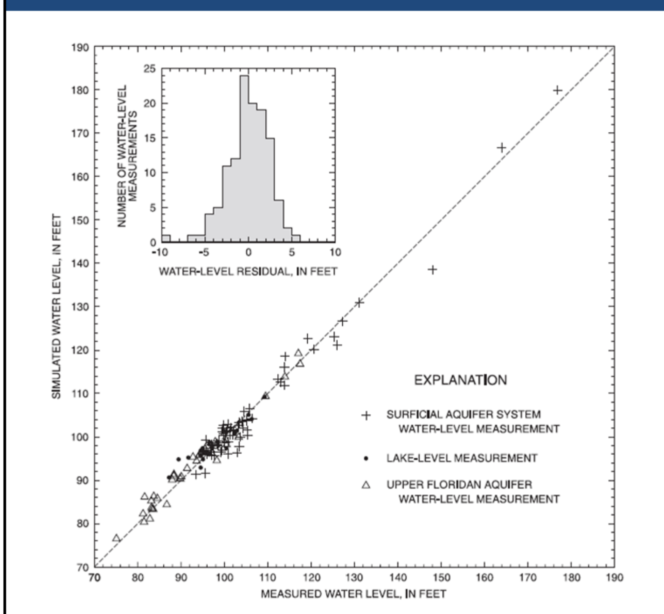
Mapping of hydrogeologic layers
- Base of Surficial Aquifer
- Thickness of Intermediate Confining Unit
- Thickness of Florida aquifer – upper and lower
- Thickness of Middle Semi-Confining Unit

Compilation of Florida Aquifer transmissivity aquifer test data and surficial aquifer slug test data (often questionable) and results of previous regional flow models

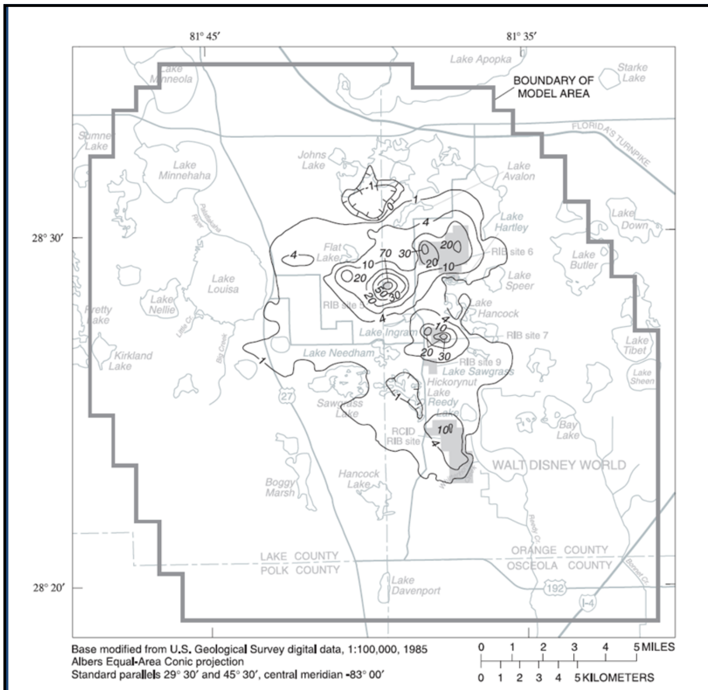
Transmissivity = K times thickness
Leakance = K divided by thickness

Still many questions ….

Data-driven zonation and automated parameter estimation (MODOPTIM) used for ICU leakance and Floridan transmissivity. – i.e., best match observed water levels



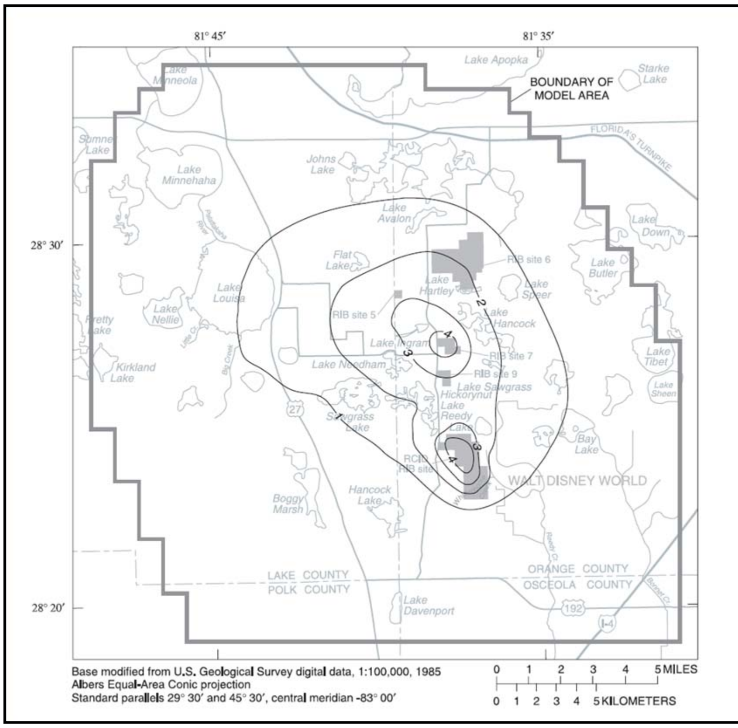
Good simulation of mean observed 1995 water levels in surficial and Floridan aquifers, and in lakes.



Impact of disposal of reclaimed water on water levels in the surficial aquifer (1995)

Max observed 40 foot increase in WL at 1995 rates

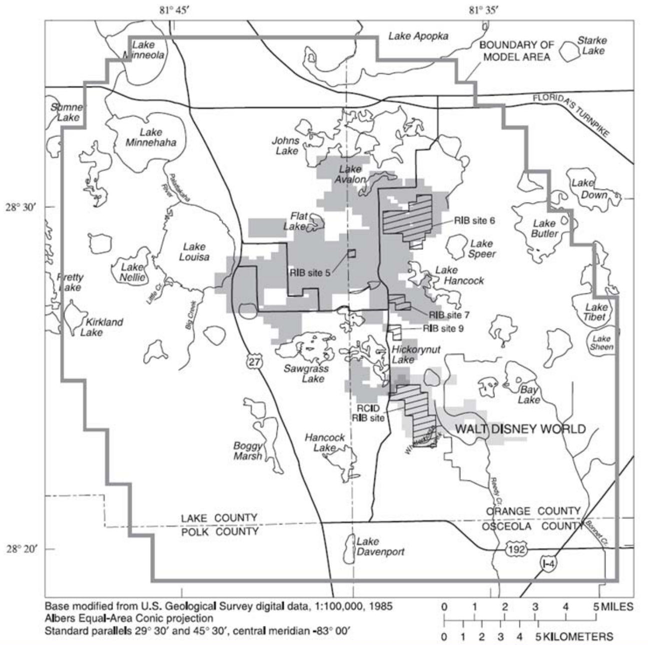
USGS



Impact of disposal of reclaimed water on water levels in the potable Upper Floridan aquifer (1995)

Max < 5 foot increase in pot surface at 1995 rates

USGS



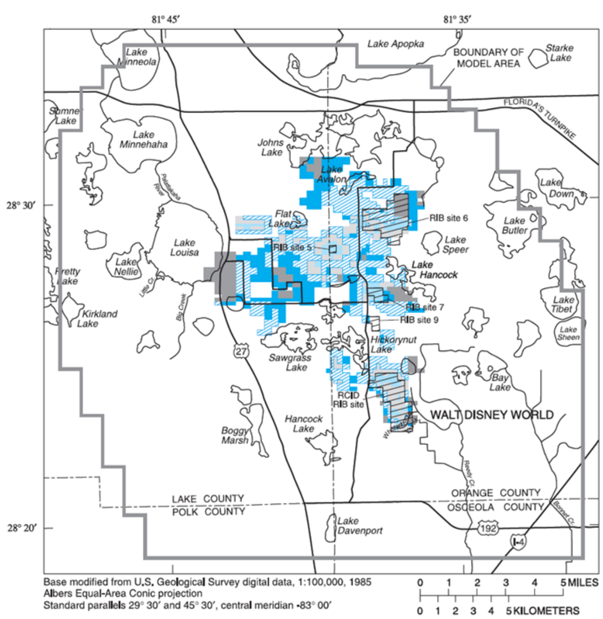
Areas where reclaimed water is simulated as present in surficial aquifer in 1995

USGS MODPATH package

Particle tracking

No dispersion

USGS



Simulated traveltime of water from water table to Upper Floridan aquifer

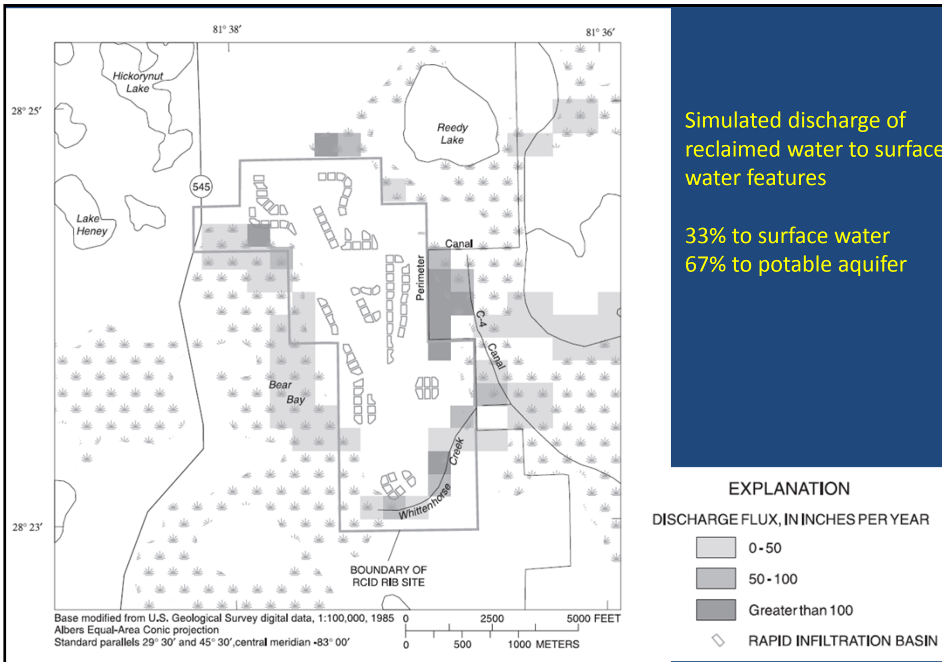
Effective porosity assumed of 0.40

EXPLANATION

TRAVELTIME, IN YEARS

- 0-5
- 5-10
- 10-25
- 25-50
- Greater than 50

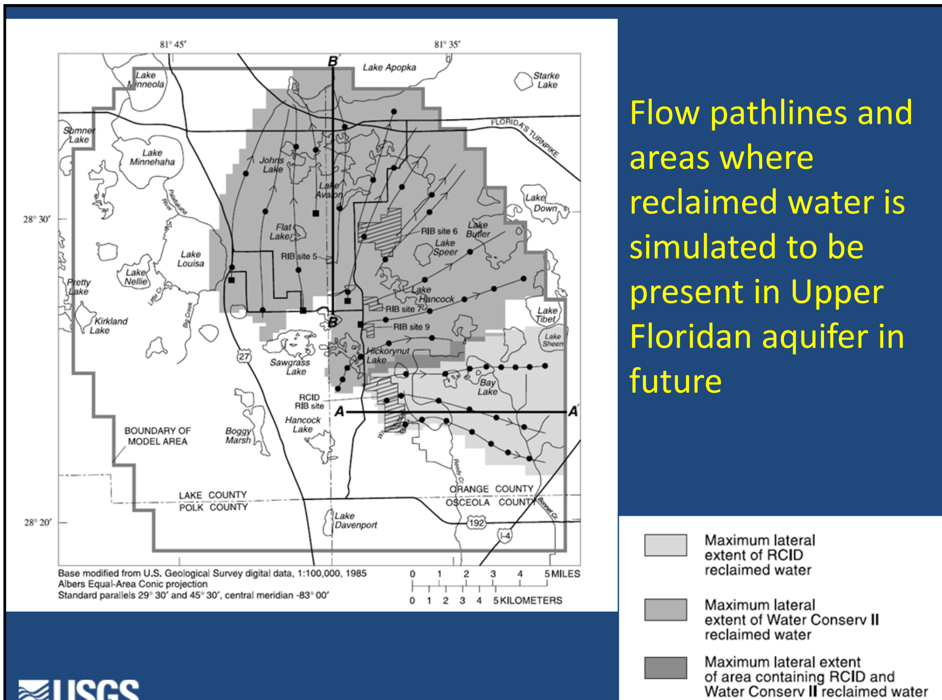
USGS



Simulated discharge of reclaimed water to surface water features

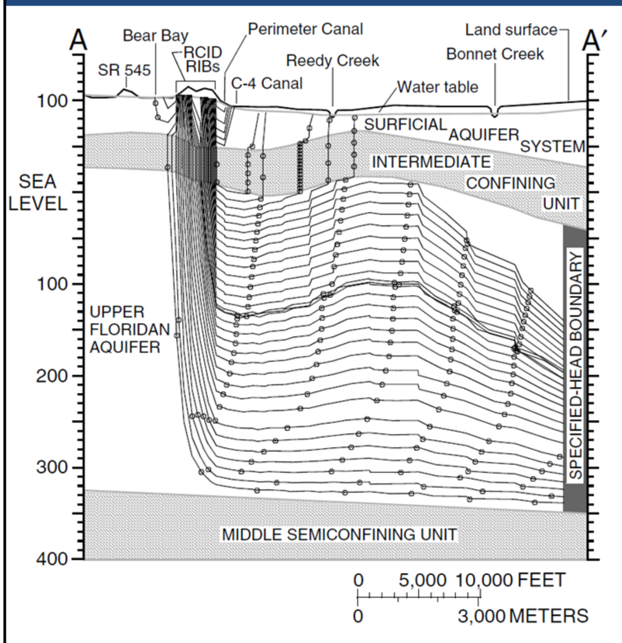
33% to surface water
67% to potable aquifer

USGS



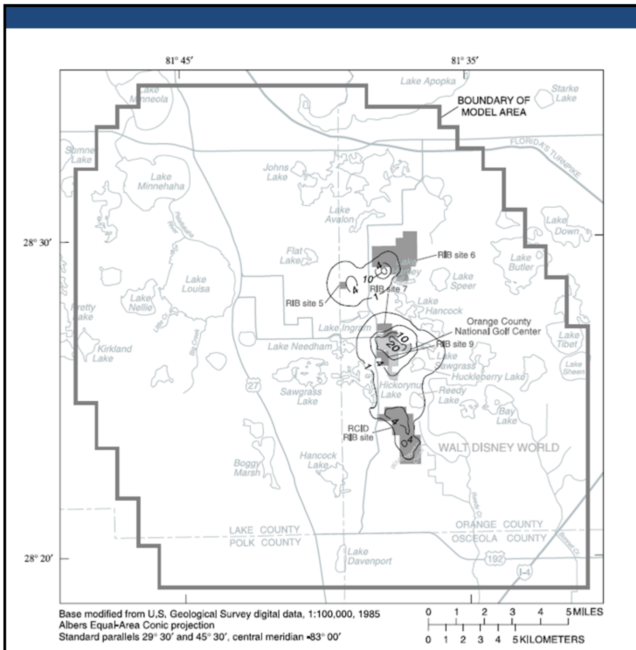
Flow pathlines and areas where reclaimed water is simulated to be present in Upper Floridan aquifer in future

USGS



Cross-sectional view -simulated pathlines of reclaimed water beneath RCID RIBS

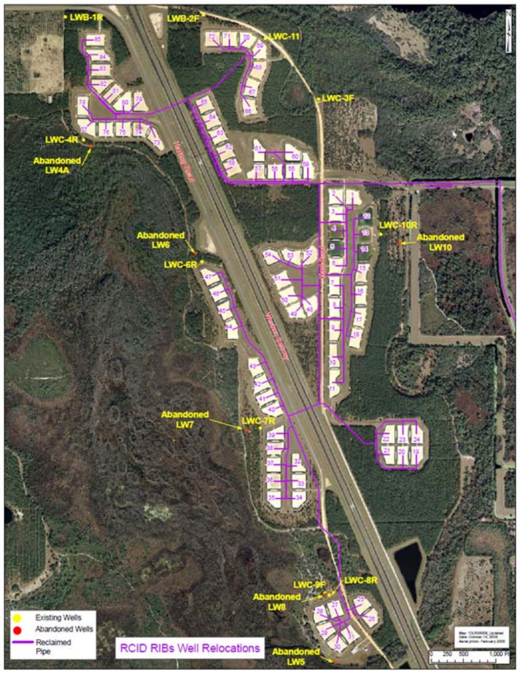
USGS



Simulated scenario projections

Projected water level increase with future scenario of water application

USGS

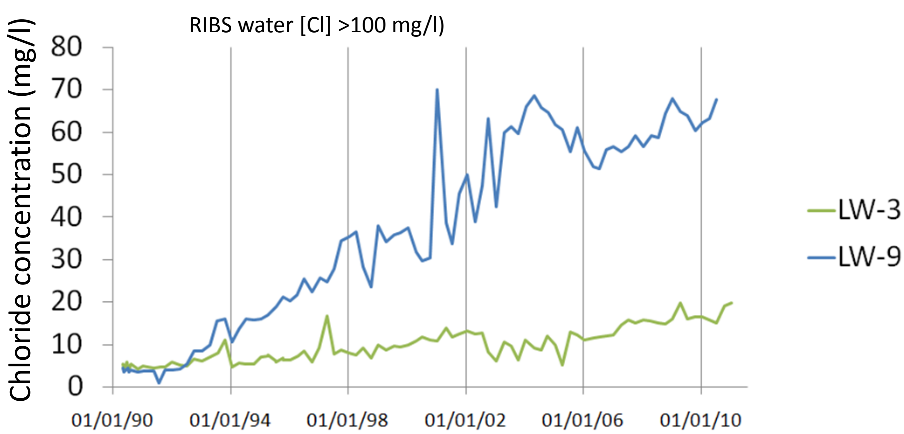


Impact of RIBS loading on potable water aquifer – Some observations from historical data

USGS

Clear indication of RIBS water in potable aquifer (UFA)

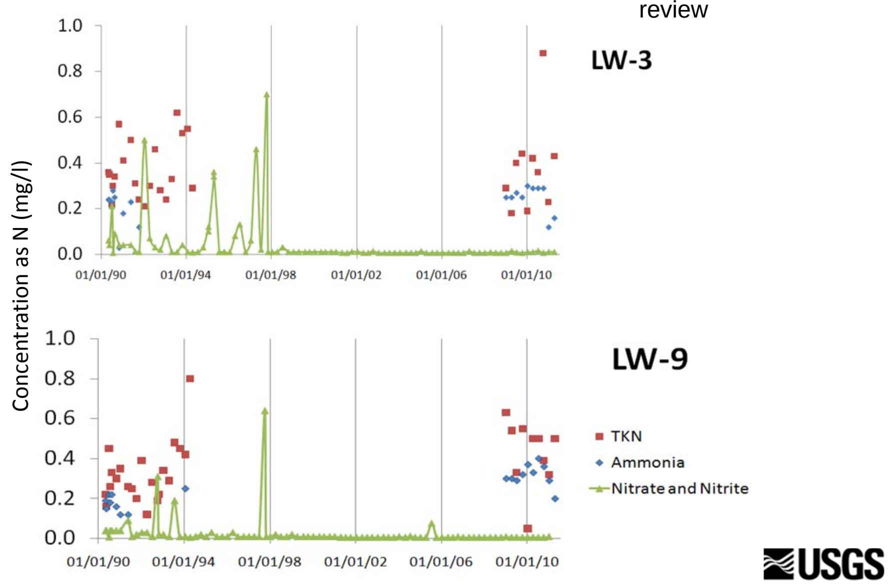
Provisional data – not subject to USGS review



USGS

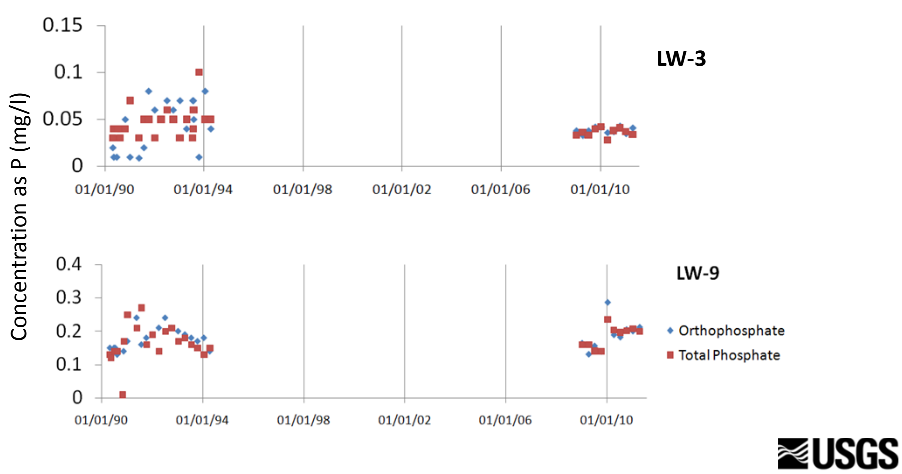
Nitrogen concentrations

Provisional data – not subject to USGS review

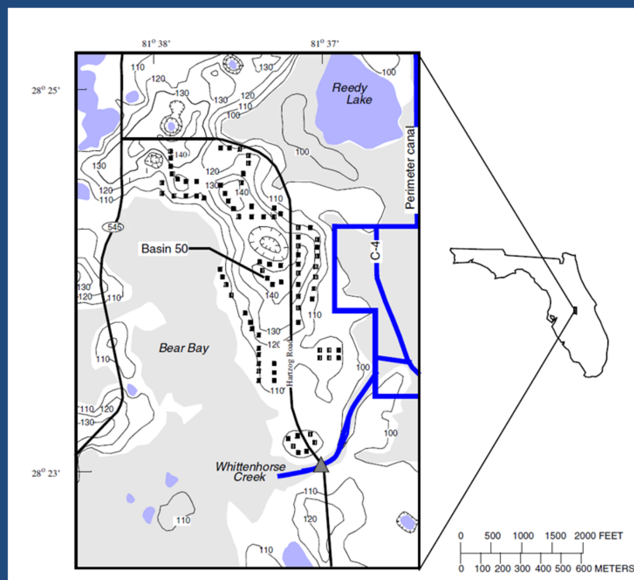


Phosphorus concentrations

Provisional data – not subject to USGS review

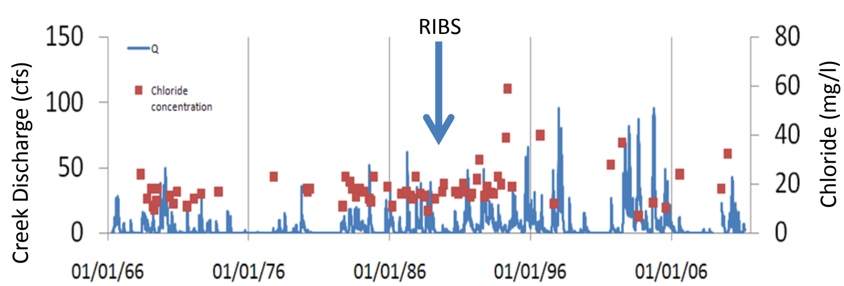


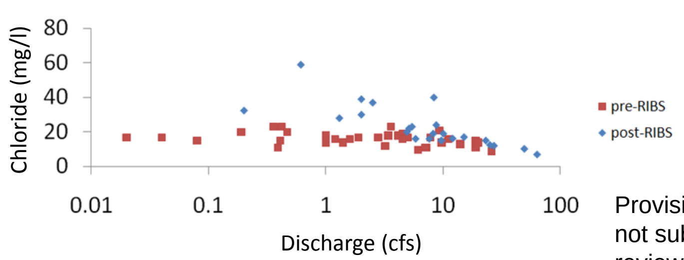
Impact of RIBS on adjacent wetland



USGS

RIBS water is reaching Whittenhorse Creek



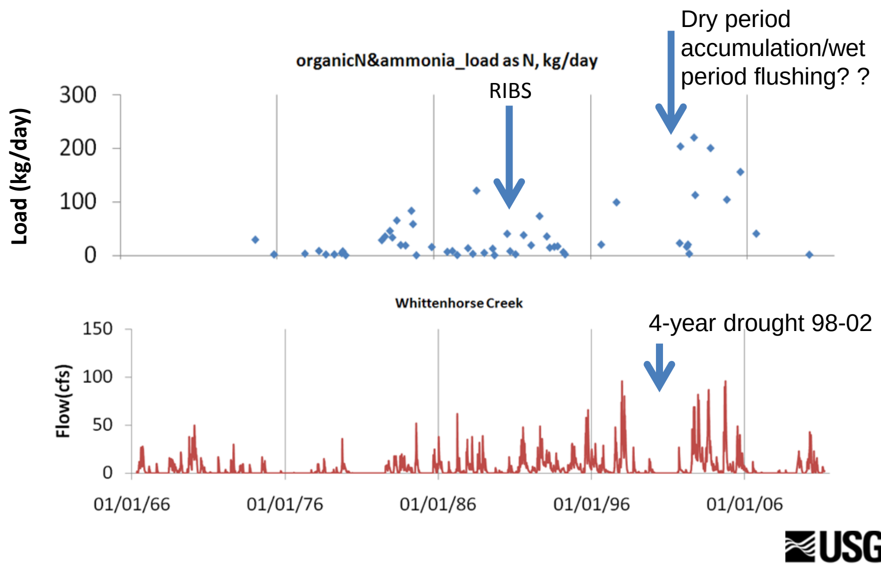


Provisional data – not subject to USGS review

USGS

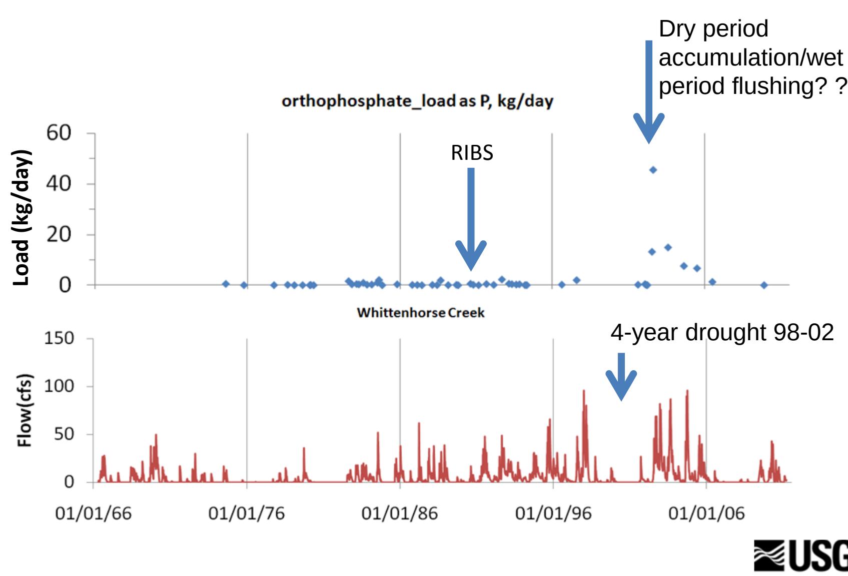
Provisional data –
not subject to USGS
review

Nitrogen load exiting from wetland adjacent to RIBS



Provisional data –
not subject to USGS
review

Phosphorus load exiting from wetland adjacent to RIBS



Summary

Water reuse at RCID has proven to be a viable Alternate Water Supply, reducing demand on potable water aquifer

RIBS have performed well

- Disposal rates have not been limited by water table mounding or surface crusting over 20 years of operation

- Nutrient concentrations in underlying potable water aquifer show no increase following the initiation of RIB operation

- Possible dry period accumulation/wet period flushing in adjacent wetland

- About 66% of RIBS disposals are thought to have recharged the potable water aquifer – the remainder discharged in the adjacent wetland/canals.

USGS