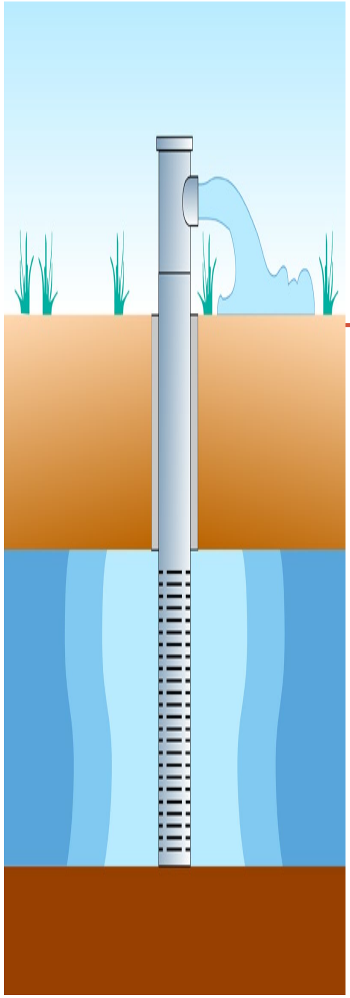

Aquifer Storage Recovery (ASR): Efficient and Cost-Effective Applications to Achieve Florida's Water Management Goals

University of Florida Water Institute
2020 Water Symposium

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ASR SYSTEMS

SOME ASR OPPORTUNITIES FOR FLORIDA

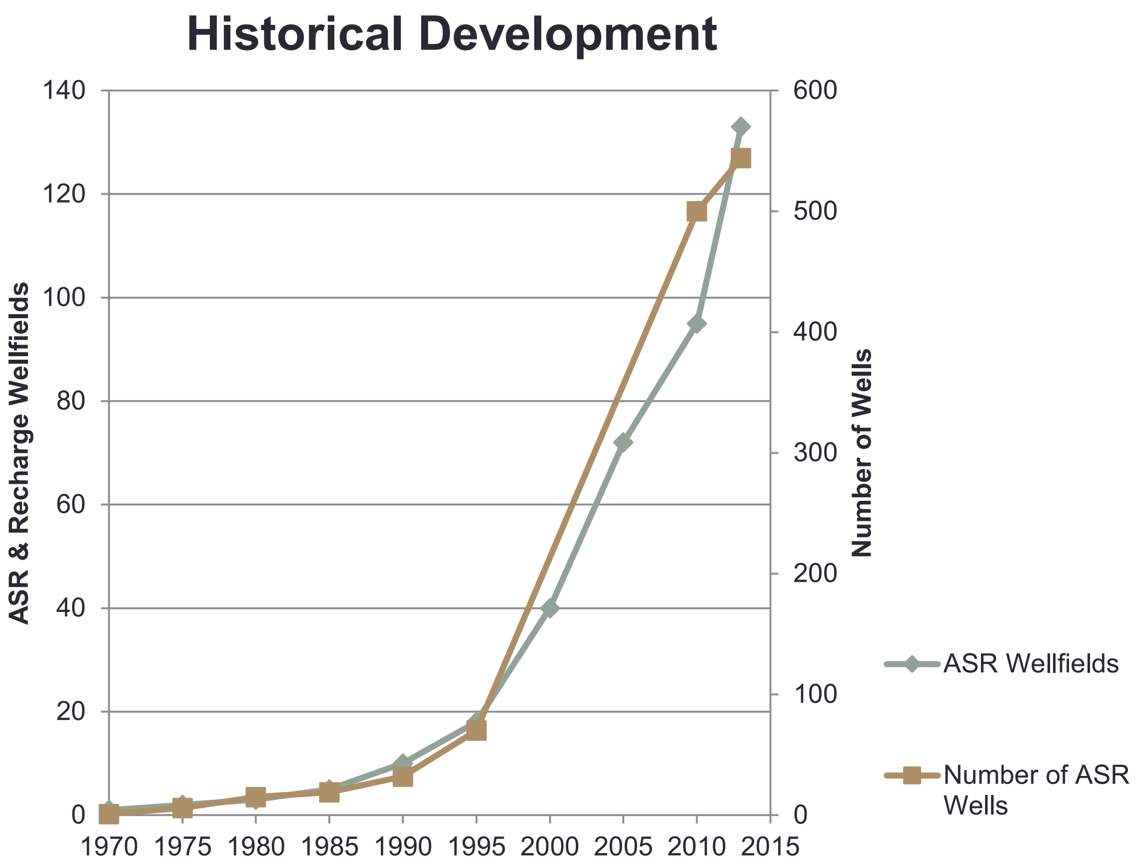
- ASR UPDATE
- FLORIDA ASR OPPORTUNITIES
  - ASR WELLFIELD CONCEPTUAL DESIGN FOR LAKE OKEECHOBEE
  - LAKE OKEECHOBEE OPERATIONS MODEL
  - NUTRIENT (N,P,C) REMOVAL
  - LEC SALTWATER INTRUSION
  - C-43 RESERVOIR
  - APALACHICOLA WATER WARS
  - PUBLIC WATER SUPPLY
- Q&A

Manatee County, Florida's First ASR Well, 1983

ACEC Grand Award, 1984

ASR Development in the U.S. has been rapid during the past 30 years

- 30 different types of ASR applications
- Many different types of water sources for aquifer recharge
- Storage in many different types of aquifers and lithologic settings



February 2020: About 25 States; Over 125 ASR Wellfields; Over 500 ASR wells

	Wellfields	Wells
Florida	22	70
New Jersey	24	27
California	18	68
Arizona	13	51
Oregon	11	37
South Carolina	8	41
Colorado	6	45
Nevada	5	91
Iowa	4	4
Texas	4	43
Washington	3	7
Idaho	2	7
North Carolina	2	2
Delaware	2	2
VA, NM, SD, UT, ME, MN, KS, MS	1 each	9

Global implementation of ASR since 1985 to achieve water supply sustainability and reliability

- United States
- Australia
- India
- Israel
- Canada
- England
- Netherlands
- Spain
- South Africa
- Namibia
- United Arab Emirates
- Kuwait
- Bangladesh
- And others in development

Adelaide, Australia ASR Well

A broad range of water sources and storage zones is utilized for ASR

- Water sources for ASR storage
  - Drinking water
  - Reclaimed water
  - Seasonally-available stormwater
  - Groundwater from overlying, underlying or nearby aquifers
  - Rainwater
- Storage zones
  - Fresh, brackish and saline aquifers
  - Confined, semi-confined and unconfined aquifers
  - Sand, clayey sand, gravel, sandstone, limestone, dolomite, basalt, conglomerates, glacial deposits
  - Vertical "stacking" of storage zones

Chandler, AZ

Tumbleweed ASR Wellfield

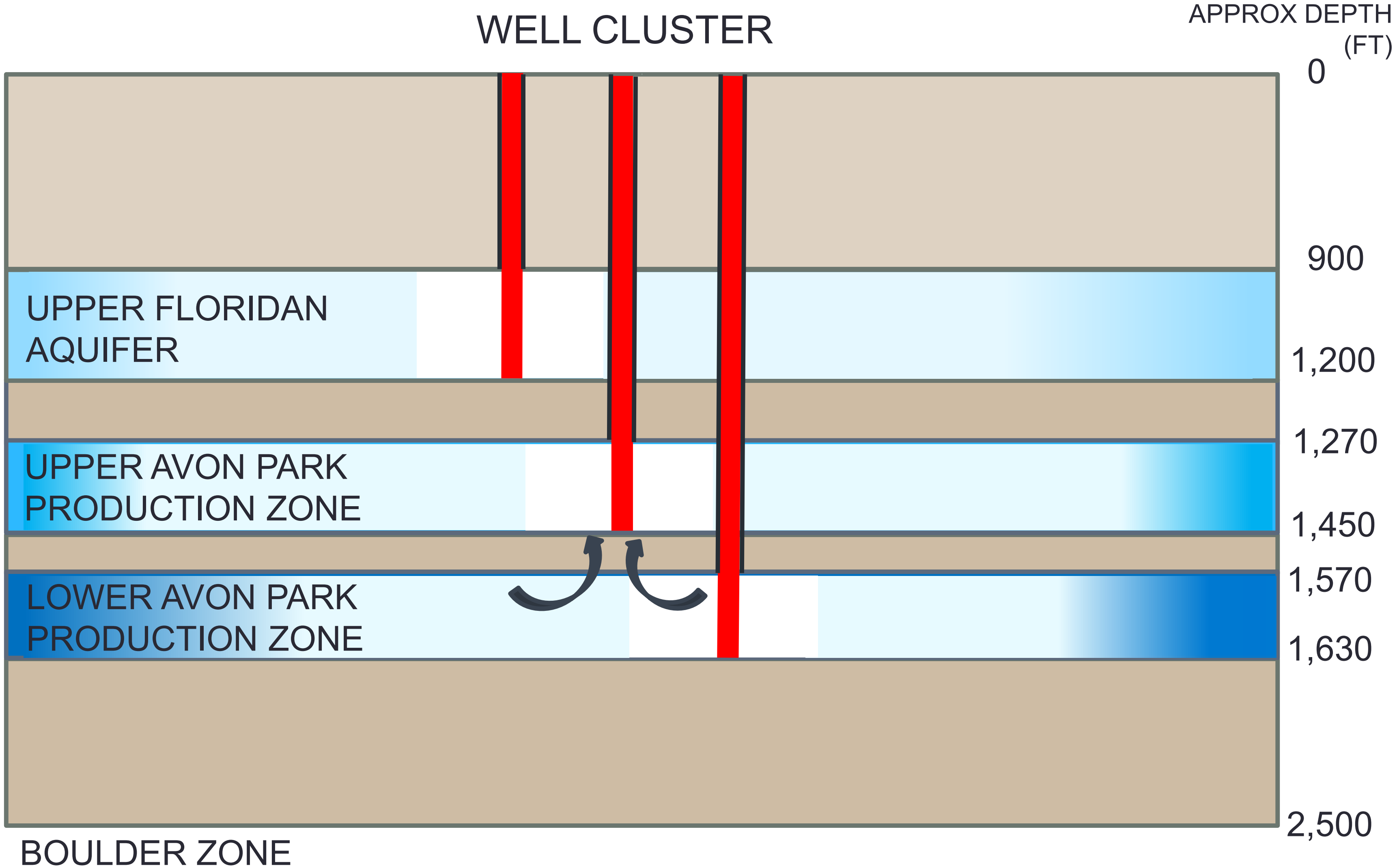
Storing Reclaimed Water for Aquifer Recharge

About 30 different ASR applications to date

- Seasonal storage
- Long-term storage, or “water banking”
- Emergency storage (pipeline breaks, earthquakes, floods, hurricanes, etc.)
- Disinfection byproduct attenuation (TTHMs, HAAs)
- Raise groundwater levels
- Reduce subsidence
- Maintain distribution system pressure
- Maintain distribution system flow
- Improve water quality
- Prevent saltwater intrusion
- Reduce environmental effects of streamflow diversions
- Agricultural water supply
- Nutrient reduction in agricultural runoff
- Enhance conventional wellfield production
- Defer expansion of water facilities
- Compensate for salinity barrier seepage losses
- Reclaimed water storage for reuse
- Nitrogen reduction (Organic, NH_3, NO_3, NO_2)
- Phosphorus reduction
- Carbon sequestration
- Bacteria and virus attenuation
- Stabilize aggressive water
- Hydraulic control of contaminant plumes
- Diurnal storage
- Fish hatchery water temperature control
- Industrial process water temperature control
- Airport runway air temperature cooling
- Aquifer thermal energy storage (ATES)
- Restoration of aquatic ecosystems
- Confirm surface water rights through demonstrated ASR storage

Most applicable for Florida

"Stacking:" ASR Conceptual Design at Kissimmee Lake Okeechobee



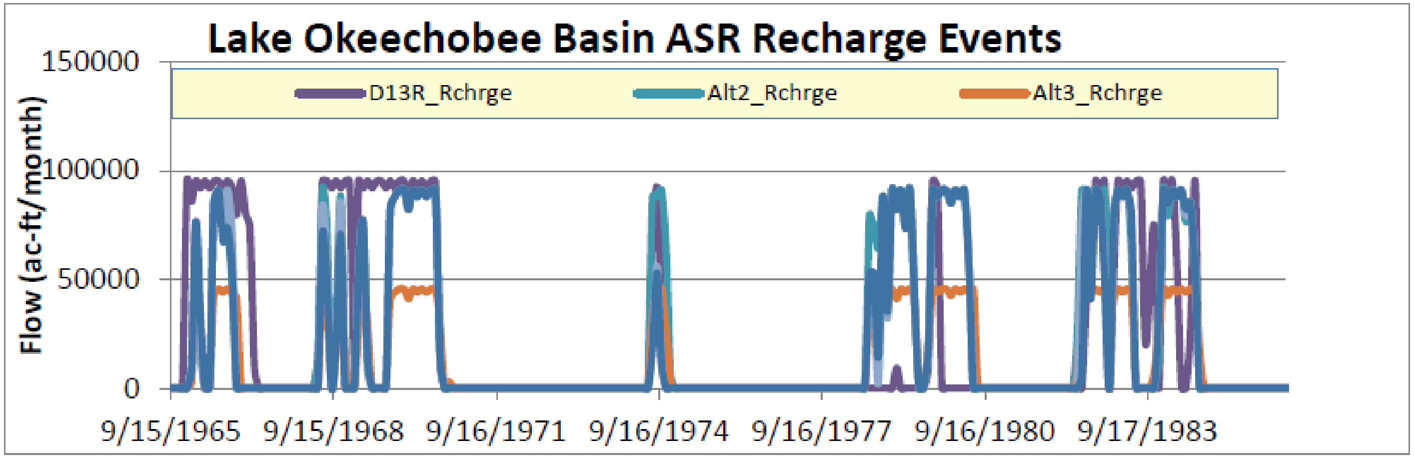
ASR Wellfield Conceptual Design for Lake Okeechobee

- Stacking water vertically in two or three intervals at the same location can be cost-effective
- Cluster of three separate wells at each site, one in each interval
  1. Full thickness of **Upper Floridan Aquifer (UFA)**, around 900 to 1,200 ft
     - Fresh or relatively low TDS
     - Limited hydraulic capacity
  2. **Upper, productive interval at top of Avon Park Production Zone (APPZ)**
     - Used to be called "Middle Floridan Aquifer" around 1,270 to 1,450 ft
     - Upper and lower confinement
     - TDS generally under 3,000 mg/l
     - Very productive
  3. **Base interval of APPZ** (around 1,570 to 1,630 ft)
     - TDS around 6,000 mg/l
     - Very highly productive
     - May not be a very good ASR storage interval
     - "Deep well injection zone" for high flows during flood events, instead of Boulder Zone at 3,000 ft
     - Upward migration of fresh water from Interval 3 into Interval 2 would recharge overlying storage interval during extended ASR recovery periods

ASR Wellfield Conceptual Design Should be Integrated with Surface Reservoir Storage Volume

- Typical Surface Reservoir
  - Per 1,000 acres, 17 ft deep = **17,000 AF**
- ASR Well Cluster
  - Per 3 wells on 5 acres (15+ MGD, 17,000+ AFY)
  - Approximately 600 ft of aquifer thickness
  - Assumed bulk porosity of 30% for karst limestone aquifer
  - Per 1,000 acres of overlying land surface area, **180,000+ AF**
  - Probably at least 10 years required to achieve Target Storage Volume
- **Combined surface reservoir and ASR storage = 197,000+ AF**
- Effective integration of the two storage systems can enable operating L.O. at a lower elevation, providing greater available volume for flood detention storage

Lake Okeechobee Operations Model



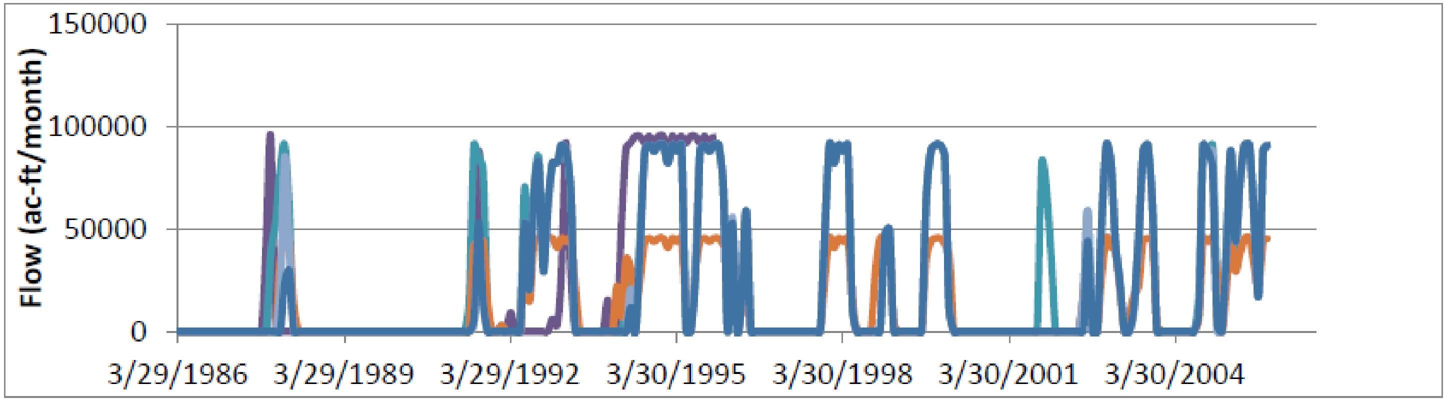


Figure 8-6 -- Lake Okeechobee basin recharge events as predicted using SFWMM (D13R) and LOOPS.

Lake Okeechobee Operations Model

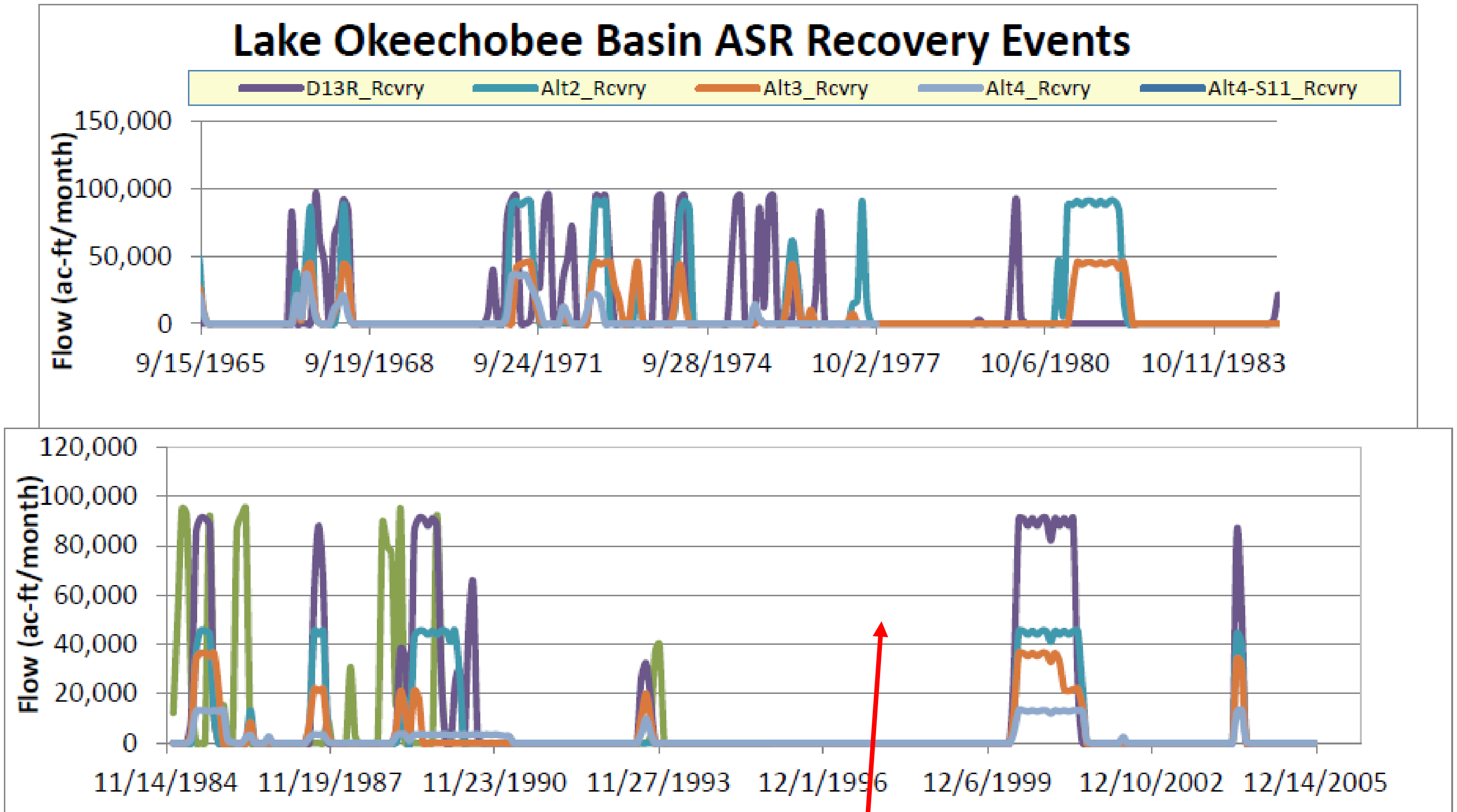


Figure 8-7 -- Lake Okeechobee basin recovery events as predicted using SFWMM (D13R) and LOOPS.

Why no ASR recovery during worst drought on record (1998) ???

Lake Okeechobee Operations Model

- What are the operation rules assumed for the LOOPS D13R simulation model that presumably is the basis for evaluating ASR operations? Was this the basis for 1.65 BGD of ASR capacity from 333 ASR wells?
- Are these rules still appropriate considering what we now know about ASR? Is ASR storage and surface reservoir storage effectively integrated in the model?
- LOEM (Environmental Model) is based upon end-of-recovery water quality data from cycle testing, which is close to native groundwater. That is not representative of how ASR should be operated.
- *Consider re-running ASR Regional Study, Table 7-4, Scenario 11 with updated assumptions regarding recovery efficiency and ASR wellfield operations.*

ASR Regional Study, Table 7-4, Scenario 11

Table 7-4 -- Scenario 11 Design.

Recovery efficiency is the ratio of available extraction volume to injected water volume; Extraction percentage is an additional reduction of extraction rates to meet the Artesian Pressure Protection Area rules.

Basin	Proposed ASR System	UFA (5mgd capacity)			APPZ (5 MGD capacity)			BZ (10 MGD capacity)		Total No. Wells	Target No. Wells (at 5 mgd)
		# Wells	Recovery Efficiency (percent)	Extraction Percentage (percent)	# Wells	Recovery Efficiency (percent)	Extraction Percentage (percent)	# Wells	Recovery Efficiency (percent)		
Caloosahatchee Basin	Moore Haven	4	70	100	0			6	0	27	44
	River Bend	3	70	100	1	30	100	2	0		
	Flaghole	2	70	100	0			9	0		
	Basin Total	9			1			17			
Lake Okeechobee Basin	Nicodemus Slough	0			10	30	100	0		139	200
	C-41 Canal	0			0			5	0		
	C-40 Canal	2	70	100	0			4	0		
	North Lake Okeechobee	8	70	25	2	30	100	5	0		
	Kissimmee R/ Paradise Run	15	70	25	0			30	0		
	Taylor Creek	0			10	30	50	5	0		
	L-63N	0			9	30	50	3	0		
	Lakeside Ranch	4	70	0	0			8	0		
	Port Mayaca	18	70	0	0			1	0		
	Basin Total	47			31			61			
L-8		6	70	100	0			2	0	8	10
C-51		12	70	100	2	30	100	10	0	24	34
Central Palm Beach		10	70	100	3	30	100	1	0	14	15
Site 1 (Hillsboro)		10	40	100	0			10	0	20	30
Total		94			37			101		232	333

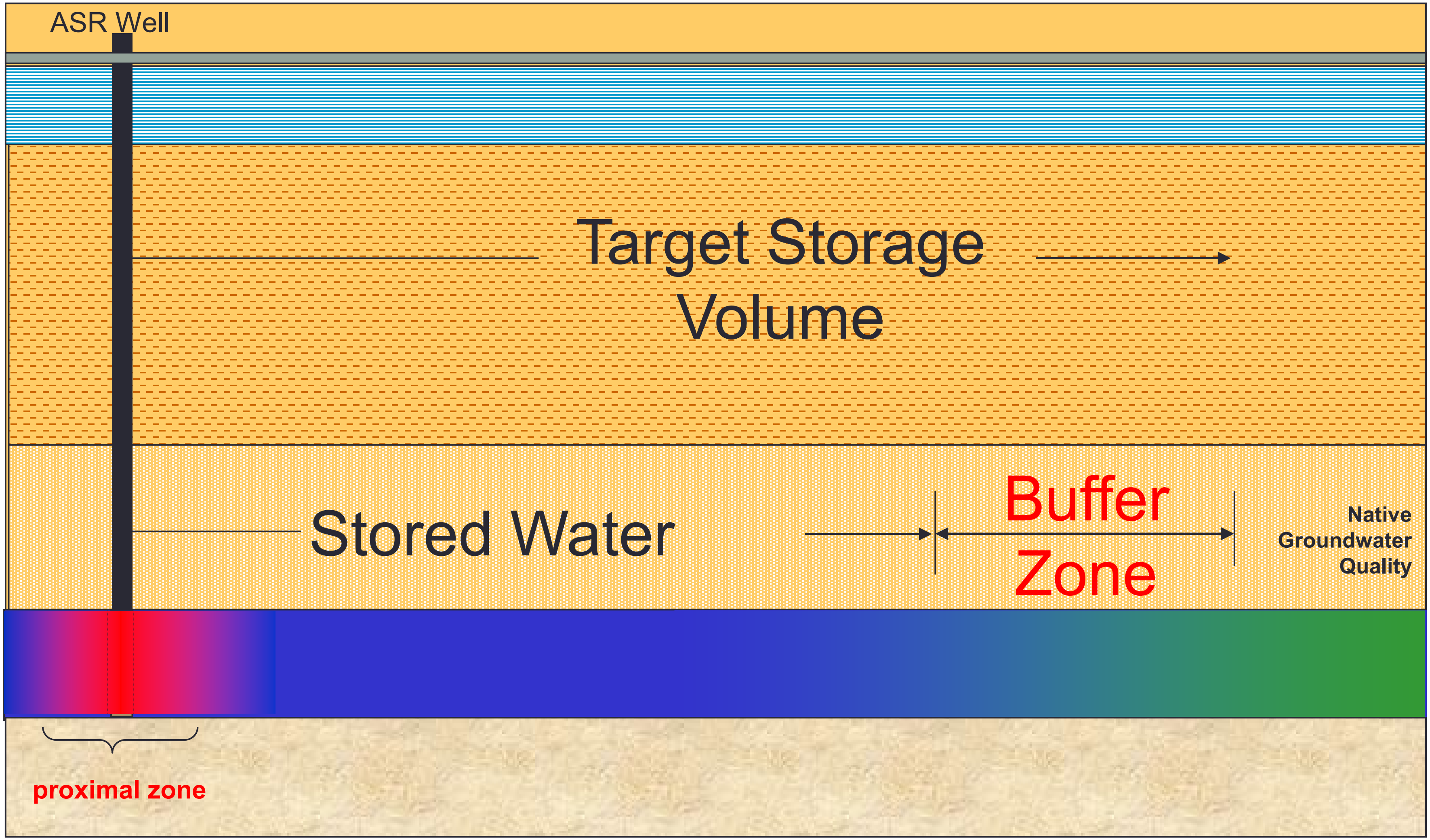
Using the LOOPS model, evaluate…

- Period of record for simulation
- Longest duration of continuous recharge
- Longest duration of continuous recovery
- Recharge flow rate goals
- Recovery flow rate goals
- Target Storage Volume (TSV)
- Time required to achieve TSV
- Suggested revisions to operating rules
- A range of system reliability goals
  - 100%, 99%, 95%, 90%, etc.
  - Units of days, months, years for evaluating reliability

Marathon FL – First ASR well to successfully store drinking water in a seawater aquifer

This is the output from a typical ASR Operation Simulation Model. Consider conducting such an updated analysis for Lake Okeechobee.

Target Storage Volume (TSV) is the sum of the stored water volume to be recovered, plus the buffer zone volume.



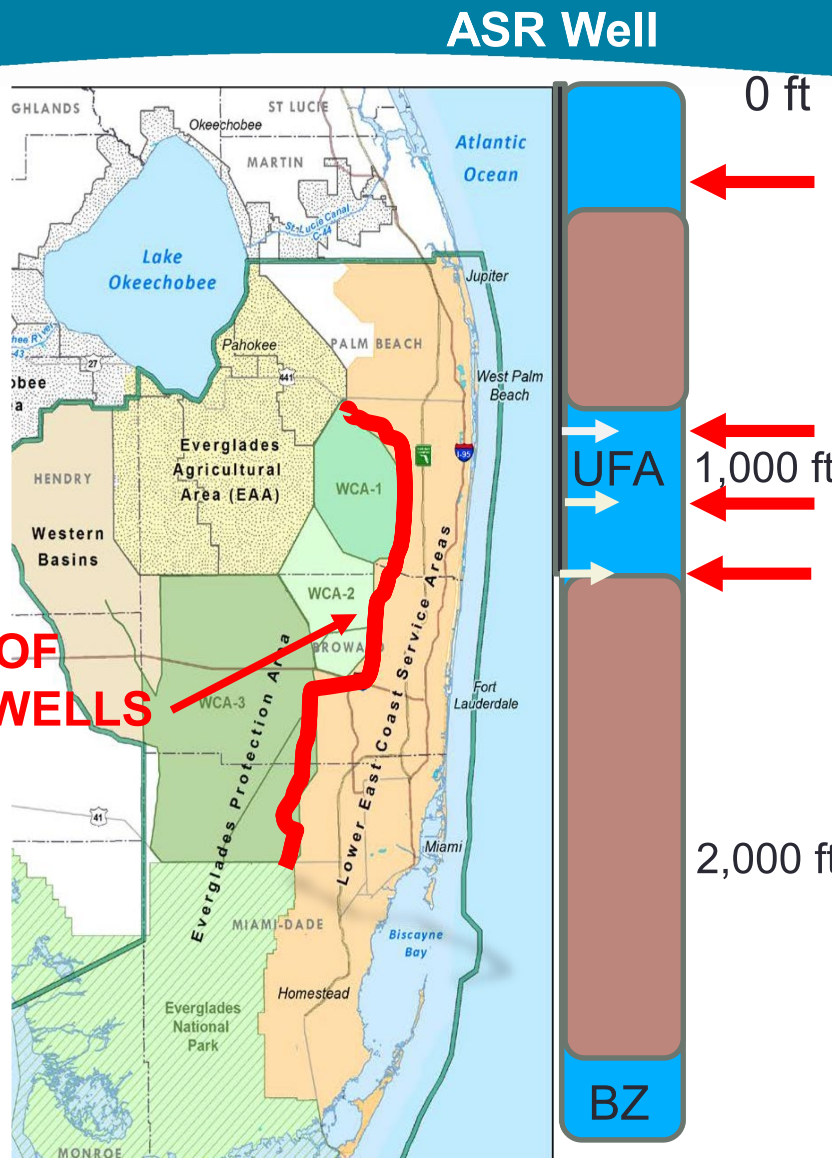
Nutrient Reduction

- CERP ASR site studies (Kissimmee, Hillsboro sites) confirmed prior experience indicating about 90% P-reduction during ASR storage, probably due to geochemical and microbial reactions.
- Approximately 40% rapid reduction, increasing to 90% over approximately one year.
- ASR storage could augment reduction of P-loadings to the Everglades achieved within the STA's.
- Significant N-reduction also achieved
- TOC/DOC reduction (Carbon Sequestration)

West Palm Beach, Florida
ASR Well – 8 MGD Capacity
Largest ASR Well in the World

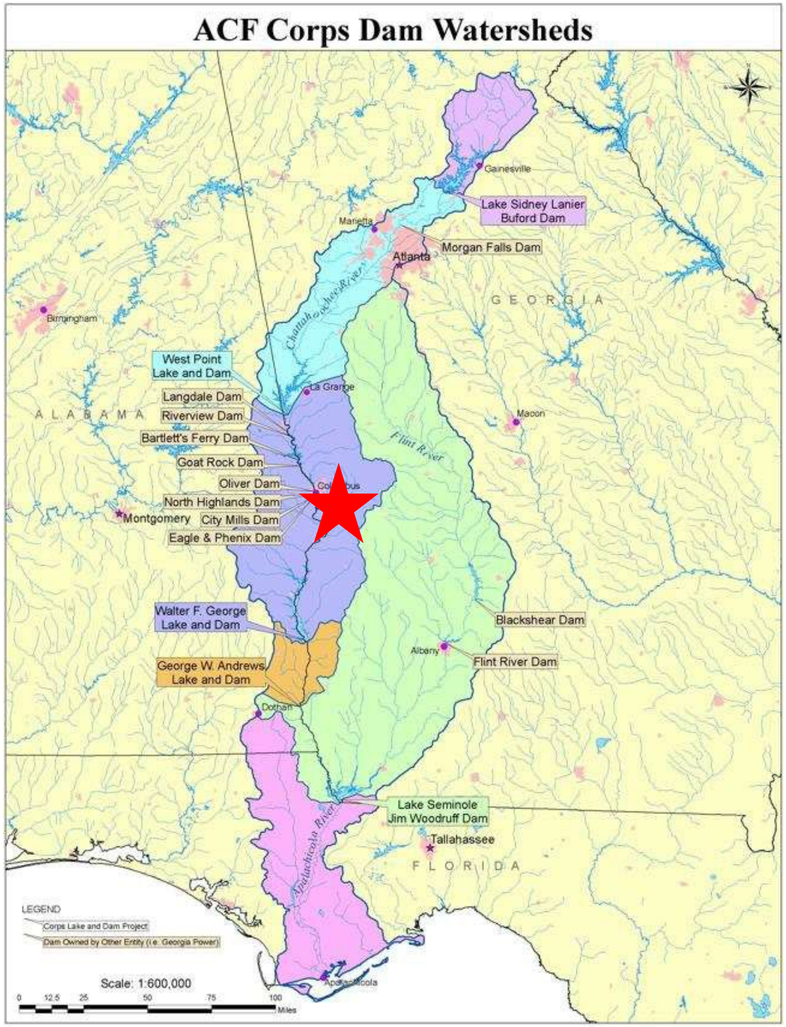
Lower East Coast ASR Reservoir

- LEC Surficial and Biscayne Aquifer production of fresh water is capped by SFWMD to prevent saltwater intrusion.
- Production to meet growth is coming from RO treatment of brackish water from the Upper Floridan aquifer
- Recharge to the Upper Floridan aquifer is with seawater from offshore, not far away.
- Suggested ASR Strategy:
  - Line of ASR wells for recharge of seasonally-plentiful surface water along west boundary of LEC, into the UFA, with partial recovery to WCA-1, 2, 3
  - Replace produced brackish water with fresh water beneath the LEC, not with seawater. Form a salinity barrier.

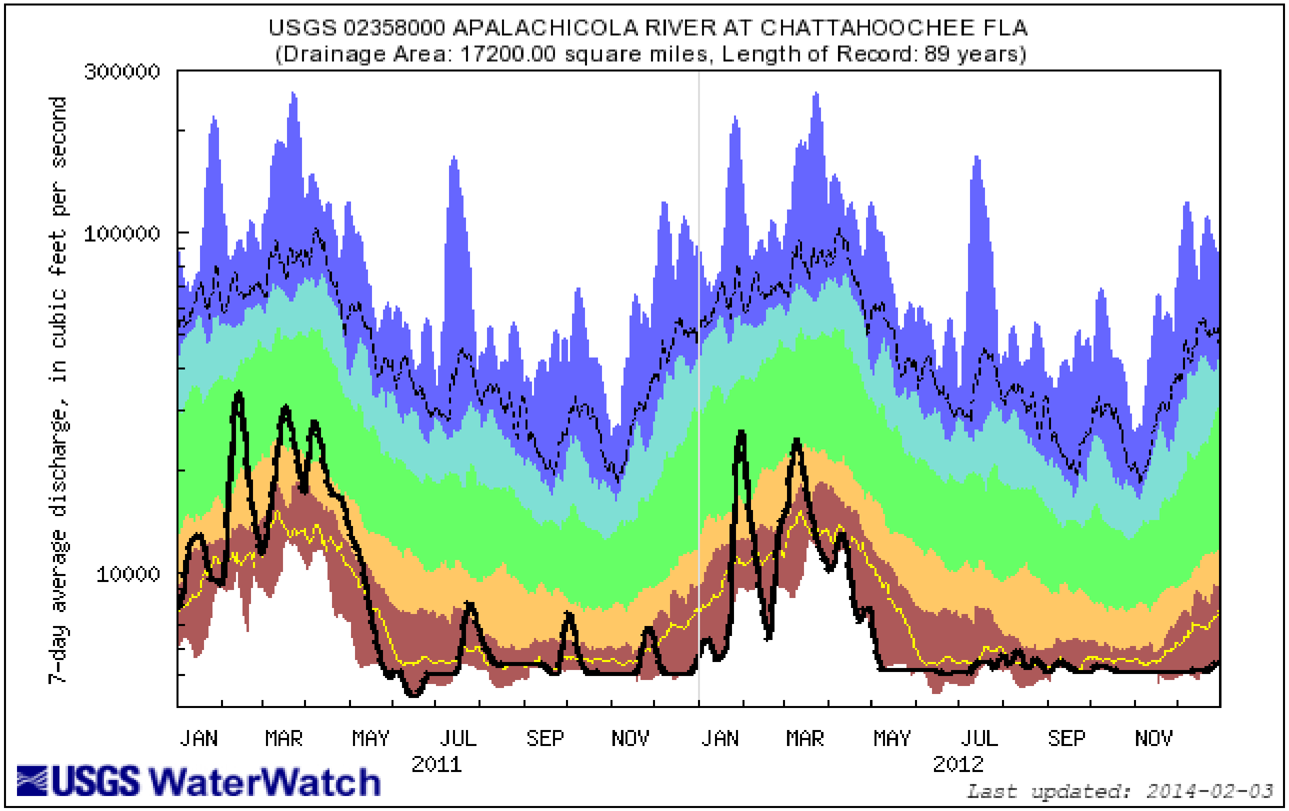


Apalachicola-Chattahoochee-Flint (ACF) river basins have limited storage in surface reservoirs

- 3 Large USACE Reservoirs plus several small dams. 1.2 million-acre feet (MAF) of active storage, of which about 2/3 is in Lake Lanier, north of Atlanta
- USACE current reservoir operation to meet navigation and recreation target flows/ levels
- Proposed ASR wellfield ★ would add >1.8 MAF of storage underground, augmenting flows by >250 MGD (400 CFS) during droughts, 7 months per year, for three straight years. Potential additional ASR wellfields.
- USACE could re-regulate reservoirs to effectively integrate ASR, further increasing flow augmentation during droughts



Apalachicola River flows - 2012



Explanation - Percentile classes

lowest-10th percentile	5	10-24	25-75	76-90	95	90th percentile -highest	Flow
Much below Normal		Below normal	Normal	Above normal	Much above normal		

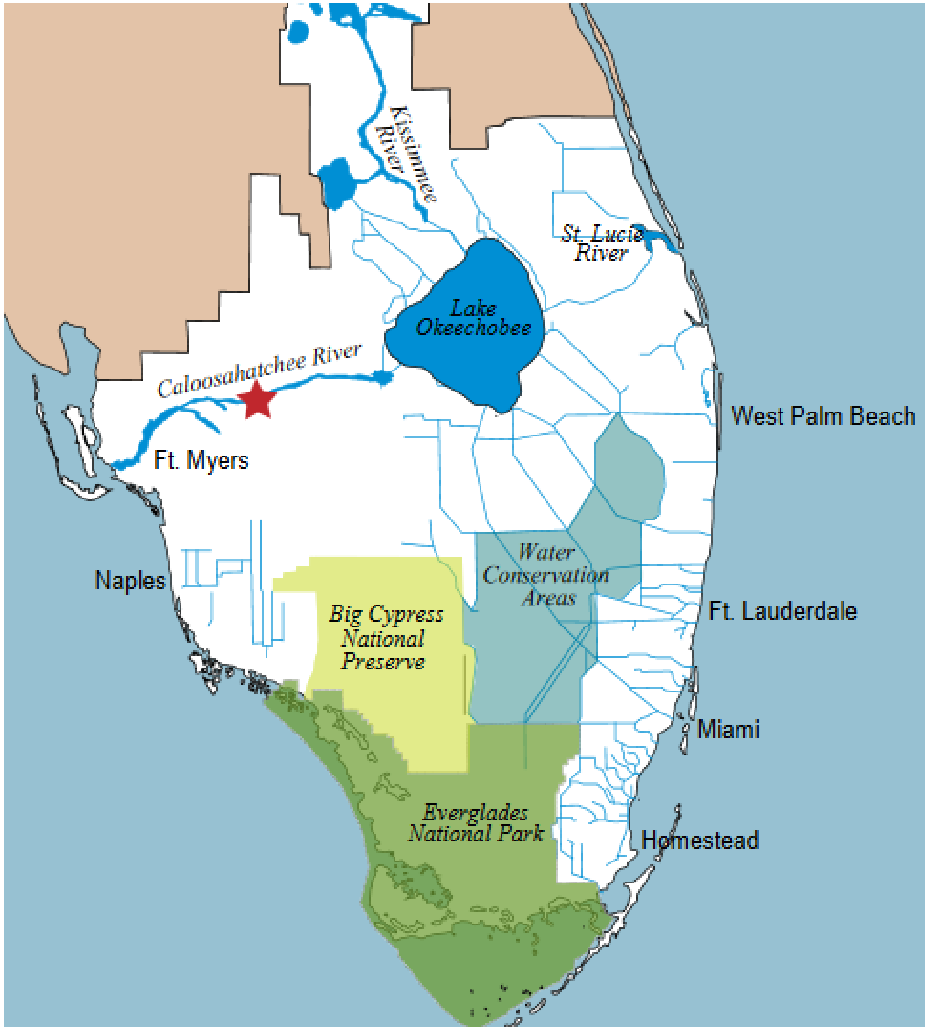
ASR supplemental flow during droughts estimated at > 700 cfs

USACE surface reservoir re-regulation to effectively integrate with ASR operations would augment this drought supplemental supply

C-43 Reservoir

- A proposed ASR wellfield at this site was removed from consideration based on early test drilling that found unexpected, thick sand deposits, not karst limestone.
  - Planned 44 ASR wells; 220 MGD capacity; 5 MGD/well
- A majority of ASR wellfields nationwide are operating in thick sand deposits, many with high yields in a range of up to 5 MGD per well.
- Increased water storage at this location, effectively integrating surface reservoir storage, ASR storage and L.O. operations, would provide considerable benefits.
- *Reevaluate the data from early test well drilling, in light of current ASR experience in sand aquifers, providing an updated conceptual ASR wellfield design and cost estimate for this site.*

C-43 Reservoir



- 10,500 acres
- 170,000 acre ft surface reservoir
- 1,500 cfs pump station to fill reservoir
- $585 M (2014) estimated construction cost
- Possible ASR component to augment dry weather flows and reduce peak flow releases to tide

ASR FOR PUBLIC WATER SUPPLY South Island Public Service District, Hilton Head Island SC

- Site is six feet below hurricane coastal surge elevation of 13 ft msl. "Pad" is at 17 ft msl.
- Operate treatment facilities to meet slightly more than average demands, providing for maintenance periods and times of inadequate supply
- Meet maximum day demands from ASR wells; peak hour demands from elevated and ground storage tanks
- **Reduce capital costs by typically more than 50%**

Palmetto Bay ASR well
South Island Public Service District
Hilton Head Island, SC

Looking back…and to the future

- Four National Award-winning ASR projects from American Council of Engineering Companies (ACEC):
  - Manatee County, Florida 1984
  - City of Kerrville, Texas 1992
  - City of Oak Creek, Wisconsin 2001
  - City of Woodland, California 2019

Woodland CA _ ASR Well 29

- Four ASR projects of particular interest:

Westlands Water District, CA (Ag ASR)
Oxnard, CA (IPR ASR)
Lake Okeechobee, FL
Qatar

ASR Book, Second Edition

www.asrforum.com