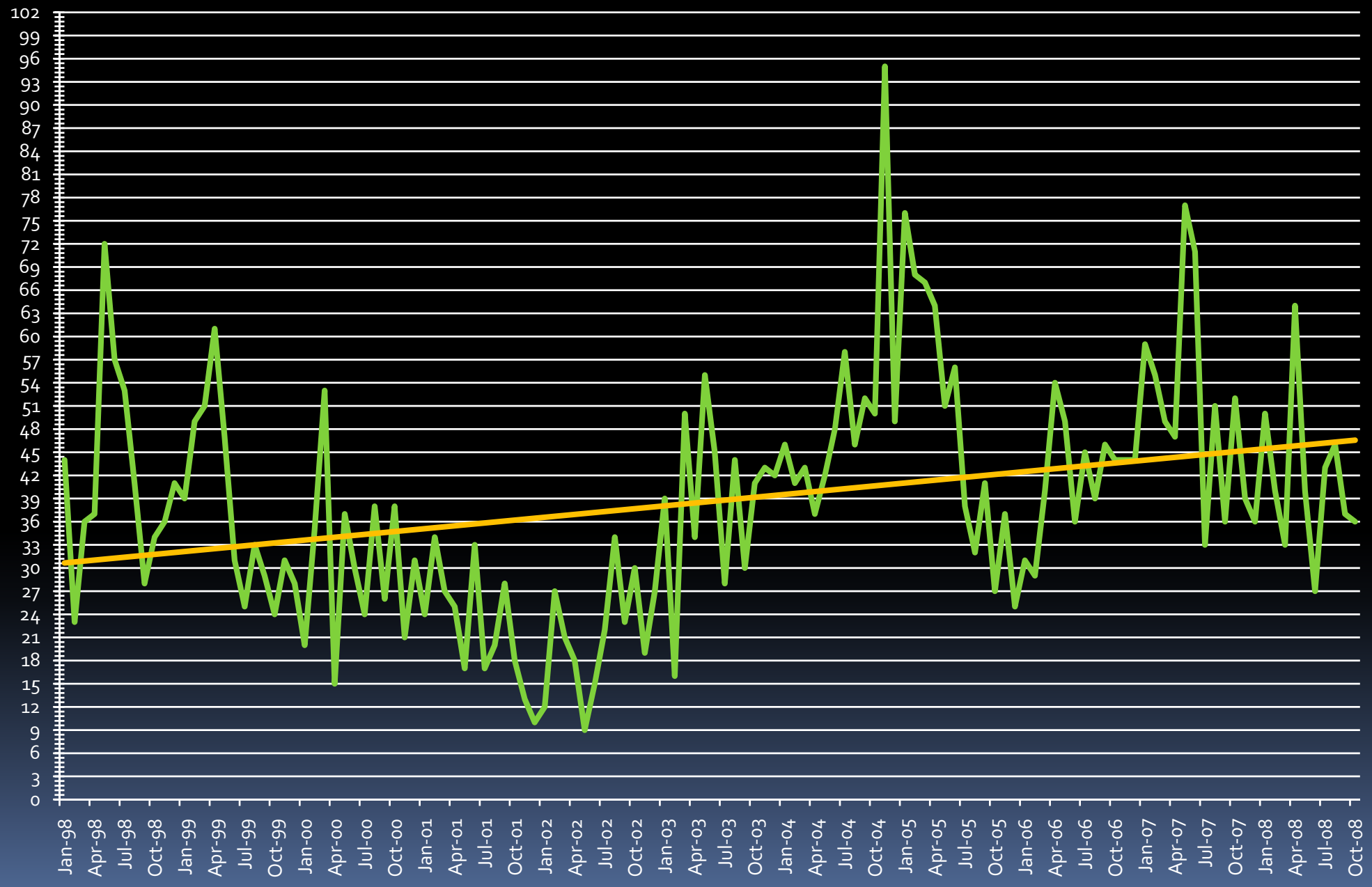
ASR In FDEP's South District

- This presentation is broken into several parts:
- What we have in this district
- Why do we have these facilities
- What progress has been made with these types of facilities
- Future direction

Aquifers are now used for. . .

- Water Supply
- Wastewater Disposal
- Storage of drinking water, reclaimed wastewater, partially treated surface water, storm water, and groundwater to meet a wide variety of seasonal and other water management needs

Applications Received By South District Office 1998 to 2008



Why do we have ASR?

We need ASR because our supply of water is limited to our annual rainfall and recharge to our surface and groundwater resources which result from that rainfall.

Demand and production ability outstrip supply and replenishment.

ASR works. We have demonstrated that the mechanics and hydraulics of ASR systems are successful. ASR is cost effective when compared to surface storage facilities. ASR was viewed as a key tool by water managers. It still is viewed as important. However, ASR has developed some issues.

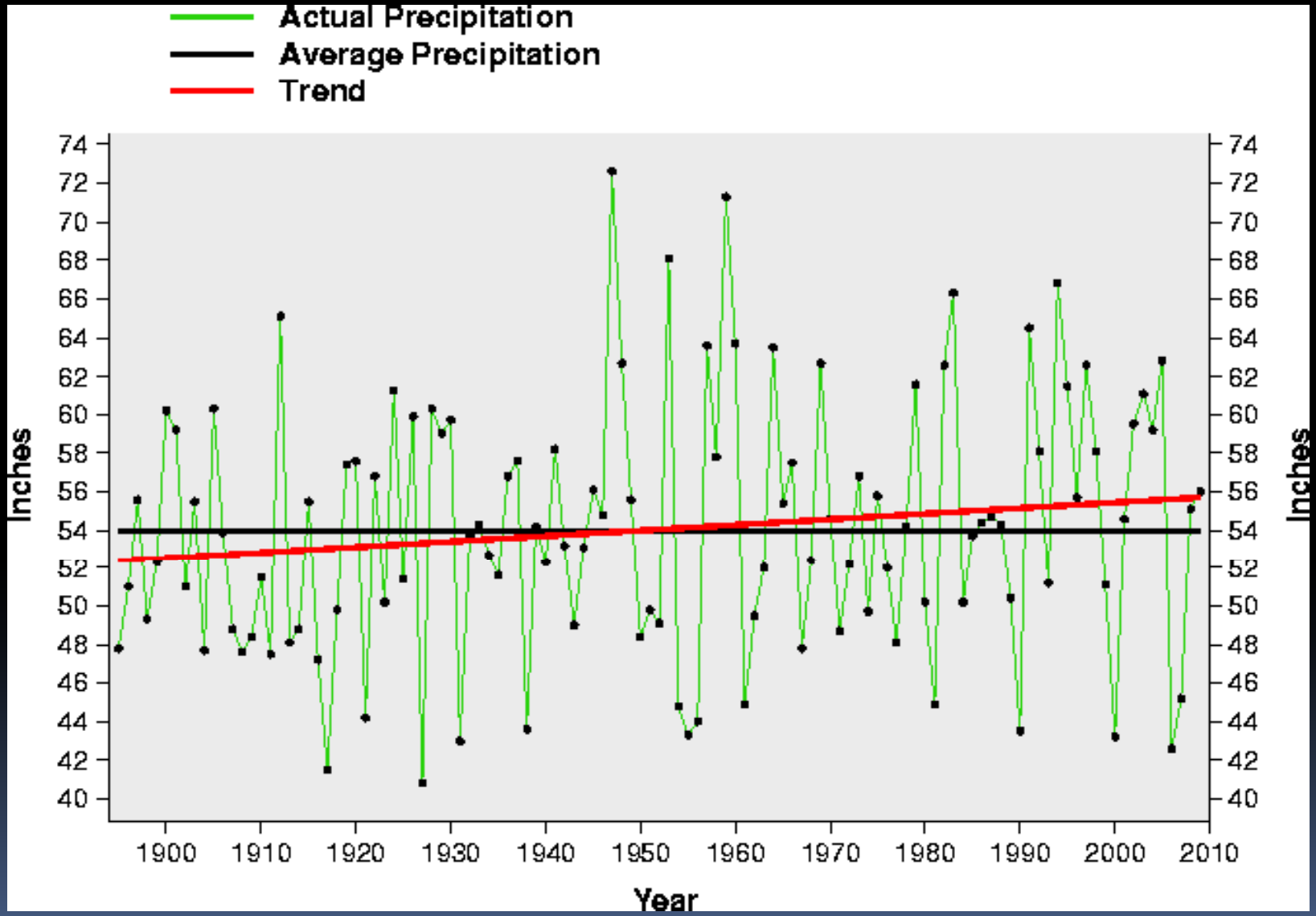
A look at the number of applications received by the District office over the last 10 years illustrates that ASR systems were in high demand at one point in time.

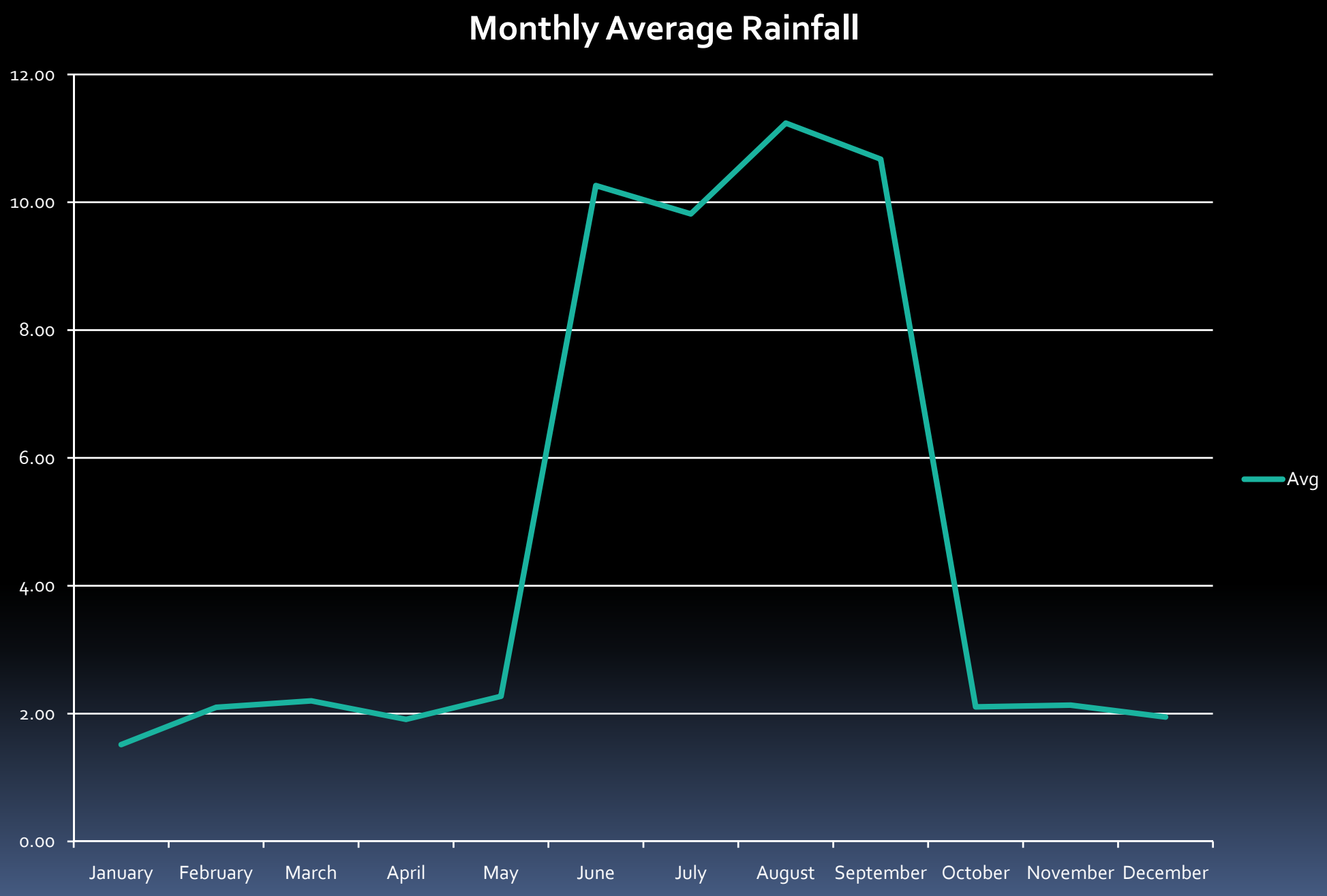
ASR demand peaked between 2005 and 2007. Two items occurred in that timeframe that resulted in a decline in ASR:

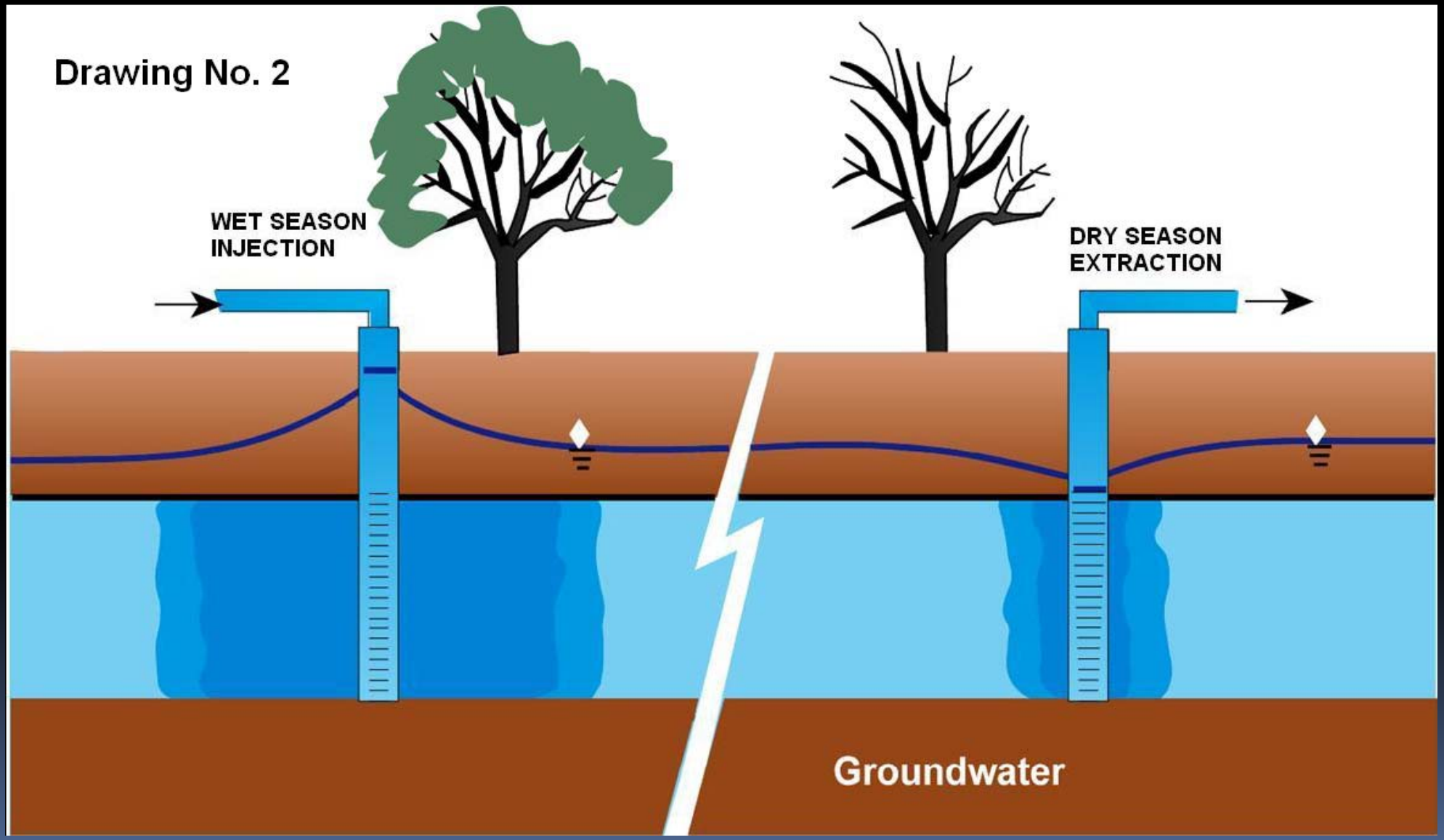
Discovery of geochemical reactions that cause mobilization of Arsenic
Change in federal and state regulation reducing the maximum allowable concentrations of Arsenic in the Underground Sources of Drinking Water, (USDW)

1.0 MG Storage Tank Dimensions are 70’ W X 28’ H

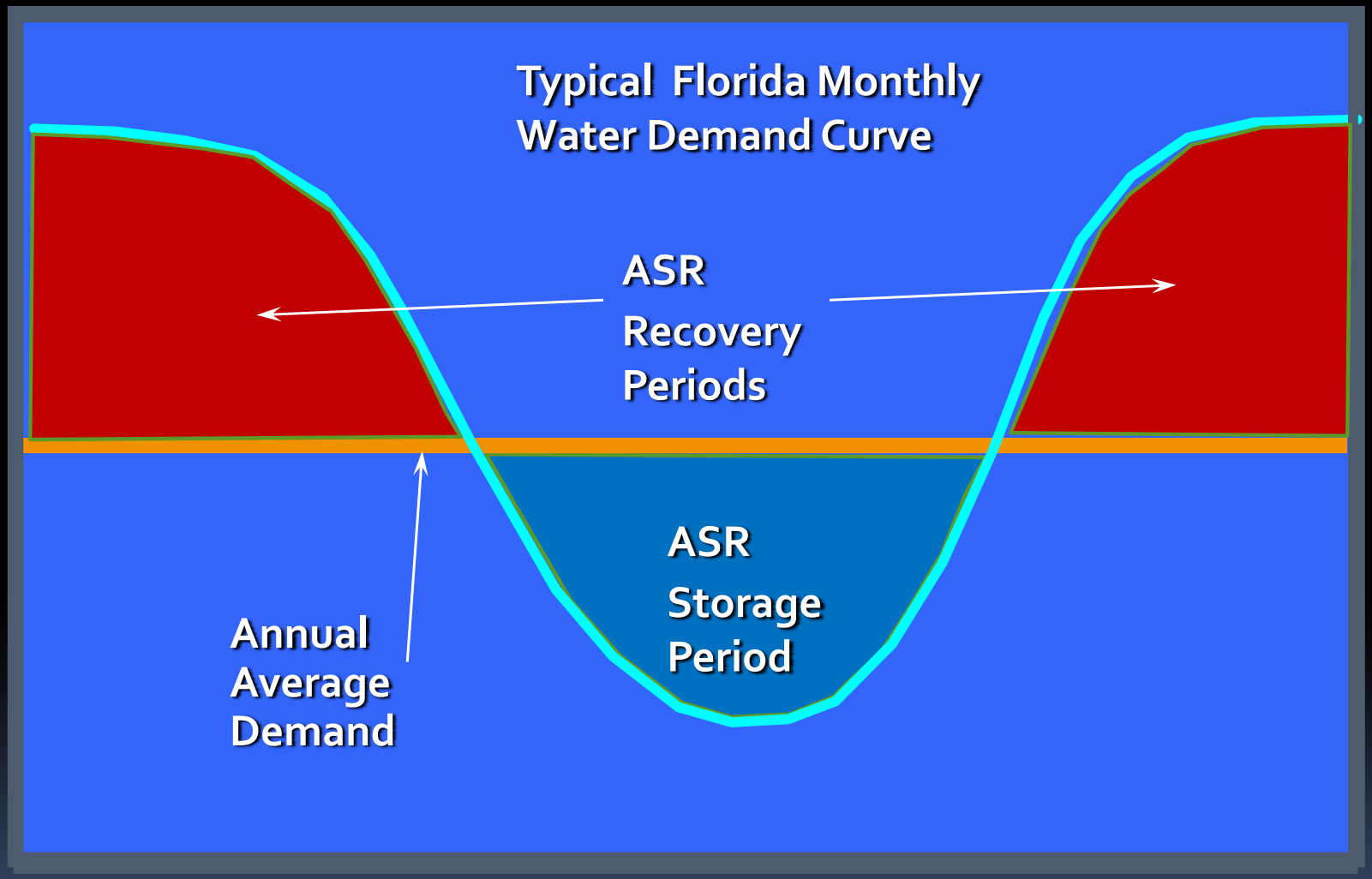
Annual 1895 - 2009 Average = 54.04 Inches
Annual 1895 - 2009 Trend = 0.30 Inches / Decade




Monthly Average Rainfall
12.00
10.00
8.00
6.00
4.00
2.00
0.00
January
February
March
April
May
June
July
August
September
October
November
December
Avg


Drawing No. 2
WET SEASON
INJECTION
DRY SEASON
EXTRACTION
Groundwater

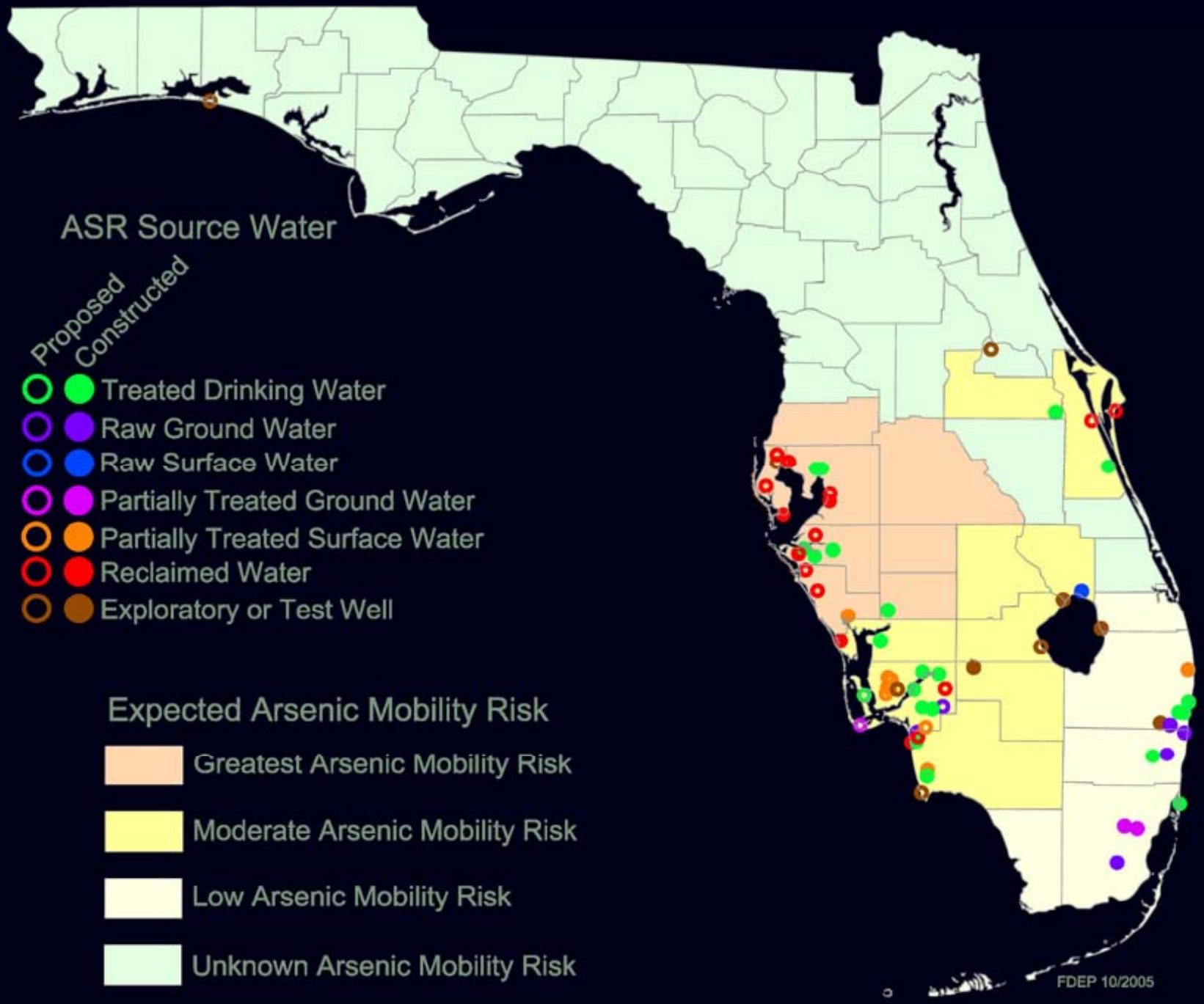
Monthly Seasonal Storage



J F M A M J J A S O N D

Months

AQUIFER STORAGE AND RECOVERY FACILITIES IN FLORIDA



The South District has possibly the second largest number of permitted ASR facilities in the state.

South District has in existence several types of ASR systems:

- Treated drinking water
- Partially treated surface water for recovery to drinking water supply systems
- Reclaimed water
- Treated stormwater
- Non – USDW ASR system

The evolution of ASR in this district has been from storage of drinking water to storage of treated stormwater. This progression is important as it illustrates a possible path to success.

Examination of demand is critical – the better understanding of the demand allows for more appropriate addressing of the quality and quantity of supplies necessary to meet that demand.

Facts About Water

Liters of Water Typically Used to Produce Products in the United States	
1 automobile	400,000
900 kg of paper for bags	32,800
1 kg of cotton	8,800
1 kg of aluminum	8,800
1 kg of beef	7,000
1 kg of rice	5,000
1 kg of steel	2,200
1 liter of gasoline	75

Domestic Water Use (liters)	
showering 5 minutes	95
brushing teeth	10
washing hands	7.5
flushing standard toilet	23
flushing low-flow toilet	6
washing one load of laundry	151
running dishwasher	19
washing dishes by hand	114

Demand is growing largely because the variety of things we need water for is expanding at an ever increasing rate.

Today we use water for things that 100 years ago were beyond the scope of anything other than our imagination

We use water and are able to gather and supply water at rates that 50 years ago existed only in the minds of engineers and scientists.

Today water is used for things that 30 years ago were considered “Far Out”. Those same uses 20 years ago were “Cool”. A decade ago use of water for things considered ordinary today was considered “Awesome”

Today we wonder – “What have we done?”

In short demand has multiplied and today is no longer just a function of population but more a function of technological advances. (First Fundamental Shift) Change in types of demand has lead to a change in how we view the necessary level of quality necessary to meet today’s diverse water demands.

This fundamental shift is resulting in diversification of the types of ASR necessary to assist in meeting overall water demand.

USDW ASR System Challenges

Any ASR constructed within the Underground Source of Drinking Water, USDW, is facing two considerable challenges:

Mobilization of Arsenic and potentially other heavy metals

State and Federal Regulation

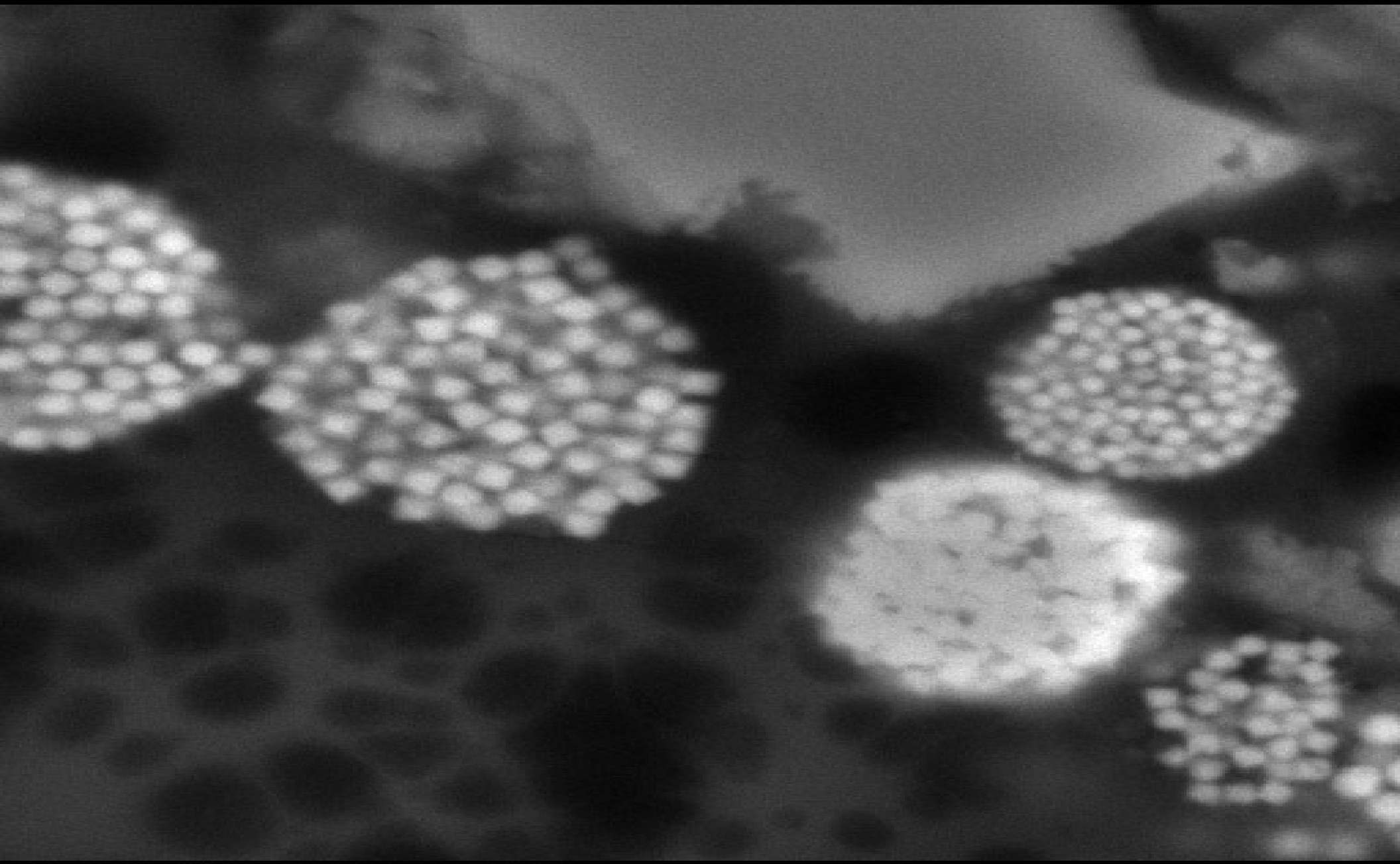
Lesser challenges are:

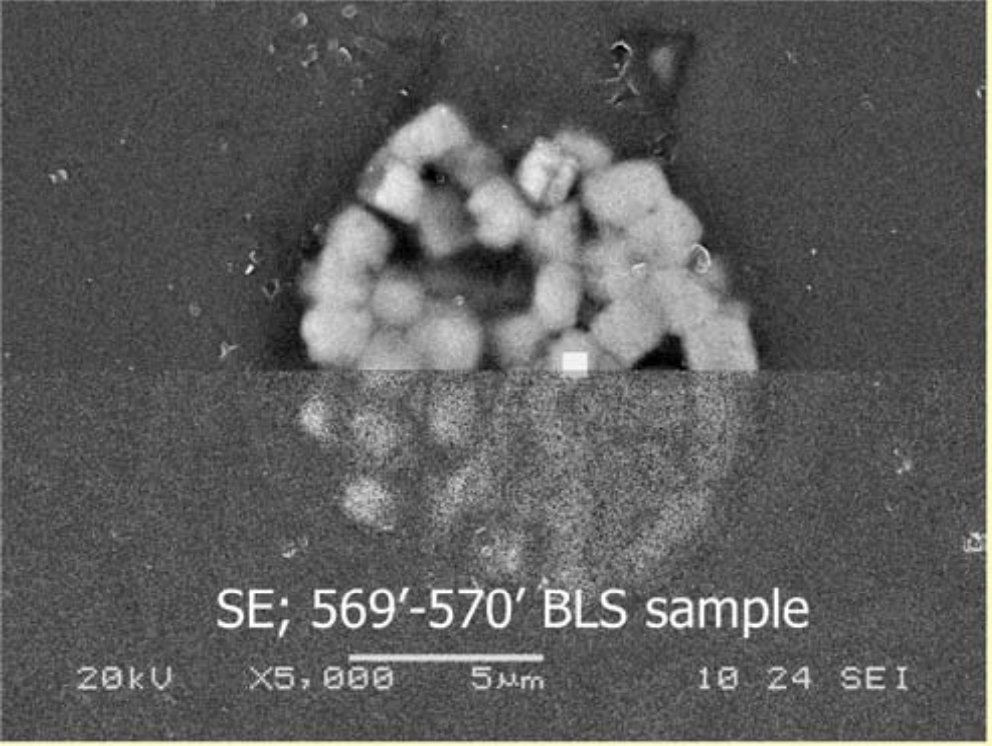
Demand that continues to increase through time

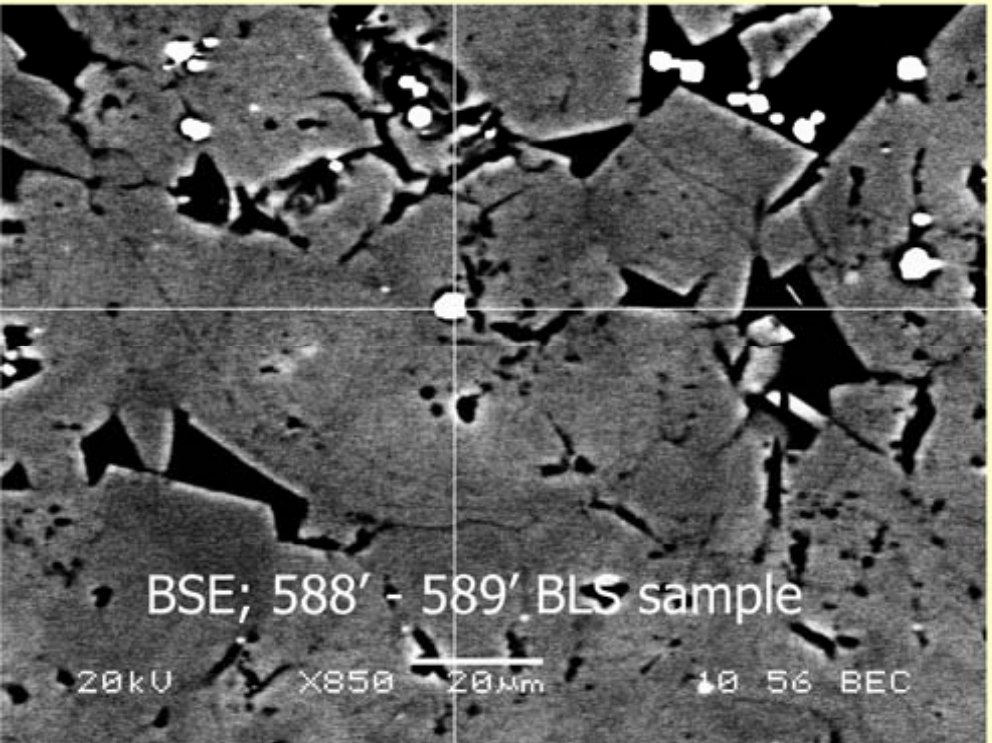
Supply that is finite

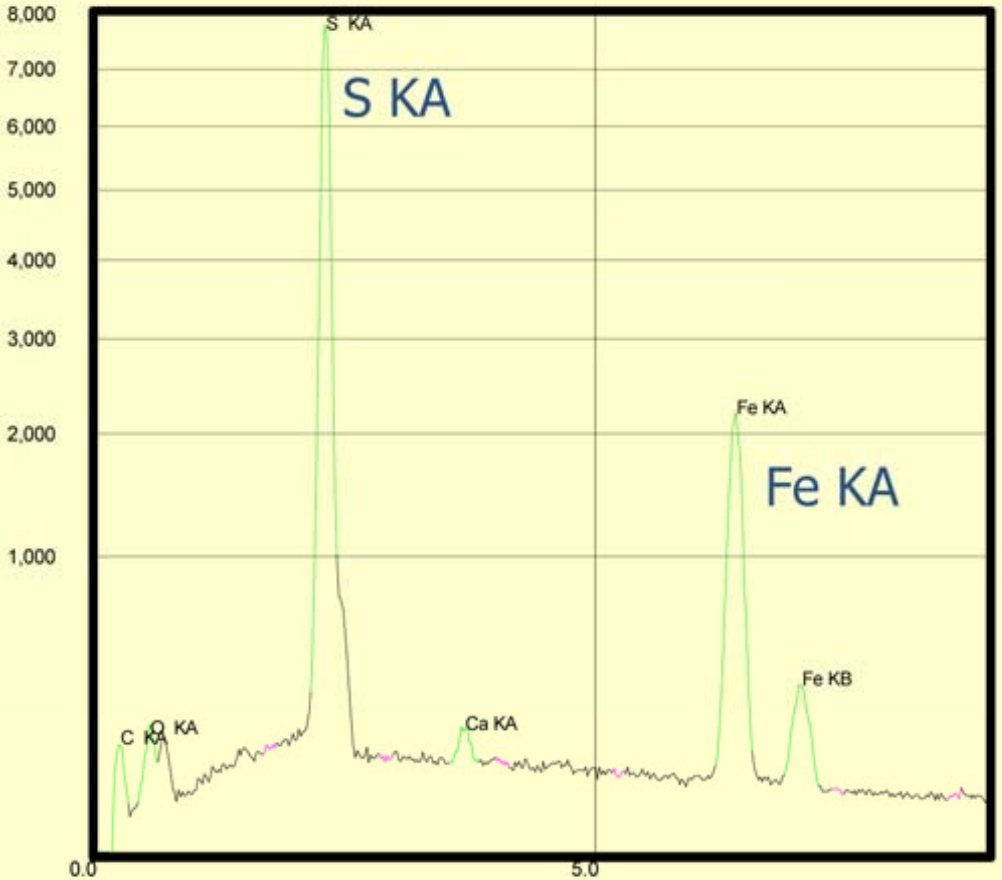
Meet the first formidable adversary:

Mr. Frambodial


Florida Geological Survey SEM/XRAY Lab
20.0 KV, EM Mag 4000X
5um







Pyrite mode of occurrence:

- intergranular (along pore spaces)
- intragranular
- framboidal masses
- low-As (<2wt%)
- up to 10 microns

Frambodial didn’t come to the table all alone……

Some of his friends include:

Complex geochemical reactions that today are still not well understood.

BASIC OXIDATION REACTIONS

- $4FeS_2 + 14\ H_2O + 15O_2 \longrightarrow 4Fe(OH)_3\downarrow + 8H_2SO_4$
- $2FeS_2 + 22\ H_2O + 15\ Cl_2 \longrightarrow 2Fe(OH)_3\downarrow + 4H_2SO_4 + 30\ HCl$
- $H_2SO_4 + 2CaCO_3 \longrightarrow 2Ca^{+2} + 2\ HCO_3^{-1} + SO_4^{-2}$
- $HCl + CaCO_3 \longrightarrow Ca^{+2} + HCO_3^{-1} + Cl^{-1}$

ADDITIONAL REACTIONS

- Additional Chemical Reactions Such As:
- High fraction of Arsenic precipitates with $Fe(OH)_3$ during injection,
- $Fe^{+3} + AsO_4^{-3} \rightarrow FeAsO_4$ Contained in $Fe(OH)_3$
- Then during recovery
- $8Fe(OH)_3 + HS^- \rightarrow 8Fe^{2+} + S0_4^{-2} + 5H_20 + OH^-$
- $4AsO_4^{-3} + HS^- \rightarrow 4AsO_3^{-3} + S0_4^{-2} + H^+$
- Mechanism can account for higher concentrations of Arsenic with increasing fraction of Native Water
- Mechanism can account for lack of Arsenic being observed at many monitoring wells within the fresh water plume.

INITIAL CONCLUSIONS

- Although oxidation of pyrite or related minerals is the likely source of arsenic, simple dissolution model does not fit observed data for most Florida wellfield cases.

- Need to add additional information (Data). Why does Arsenic concentration increase with increasing native water fraction?

- Need to consider additional chemistry – Where is the iron?

Geochemical has a twin…….

Mechanism…….and another sibling…….microbial…..

Mechanisms for As mobilization

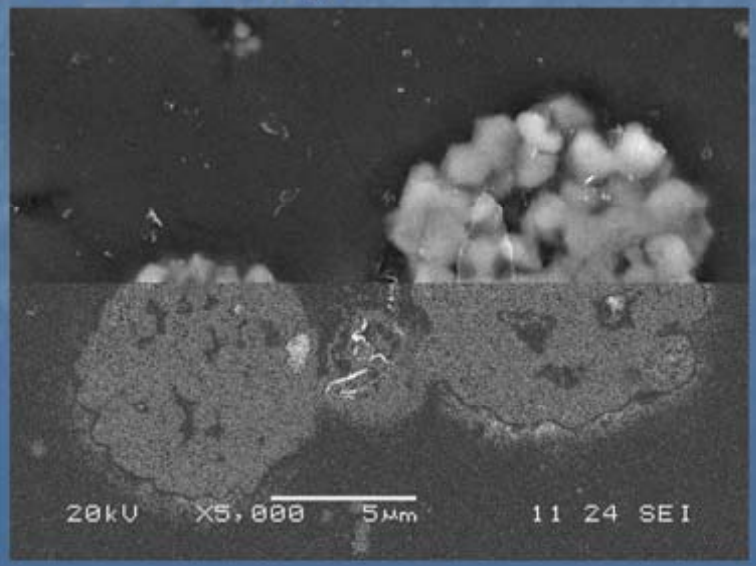
- Oxidation of sulfide minerals (up to 11,200 ppm; Price and Pichler, 2005)
- Reductive dissolution of Fe and Mn hydroxides (As-rich grain/fracture coatings)
- Oxidation - reduction of organic material
- Bicarbonate -> As-carbonate complexes (Kim et al., 2000)
- Microbial transformations (bacteria can increase oxidation rates, change oxidation states)
- Evaporative concentration in shallow ground water
- Geothermal water

$$3.75\ O_2 + FeS_2 + 4HCO_3^- = Fe(OH)_3 + 2SO_4^{-2} + 4CO_2 + .5\ H_20$$

Conclusions at the bench-scale :

- Pyrite is present in Avon Park Fm. dolostones
- Reduction in soluble metals with successive "cycles" observed
- Bulk dissolution of carbonates observed during low-pH "cycle"
- less than 2% of As in rock is mobilized into leachate (source water or DDI)
- Dissolution of arsenian pyrite is indicated, but may not be the only As-bearing phase involved
- Desorption of other metals observed: Mo, Sb, U, V, Ni and others
- Although low-DO conditions were achieved, further bench testing will include reducing agent (e.g., DOC, Ascorbic acid?)

There is a lot we don't know…



Frambodial has other friends as well…….

The Safe Drinking Water Act Section 1421(d)(2)

Underground injection endangers drinking water sources if such injection may result in the presence in underground water which supplies or can reasonably be expected to supply any public water system of any contaminant, and if the presence of such contaminant may result in such system's not complying with any national primary drinking water regulation or may otherwise adversely affect the health of persons.

Federal Regulation 40CFR144.12(a)

No owner or operator shall construct, operate, maintain, convert, plug, abandon, or conduct any other injection activity in a manner that allows the movement of fluid containing any contaminant into underground sources of drinking water, if the presence of that contaminant may cause a violation of any **primary drinking water regulation** under 40 CFR part 142 or may otherwise adversely affect the health of persons. The applicant for a permit shall have the burden of showing that the requirements of this paragraph are met.

UIC Definitions

- **Underground source of drinking water:** An aquifer or portion of an aquifer that
  - Supplies any public water system *or* contains a quantity of ground water sufficient to supply a public water system, *and*
  - Currently supplies drinking water for human consumption, *or*
  - Contains fewer than 10,000 mg/L total dissolved solids *and* is not an exempted aquifer

UIC Definitions

- **Well:** A bored, drilled, or driven shaft, or a dug hole where the depth is greater than the largest surface dimension; or an improved sinkhole; or a subsurface fluid distribution system
- **Underground injection:** Subsurface emplacement of fluids through a well

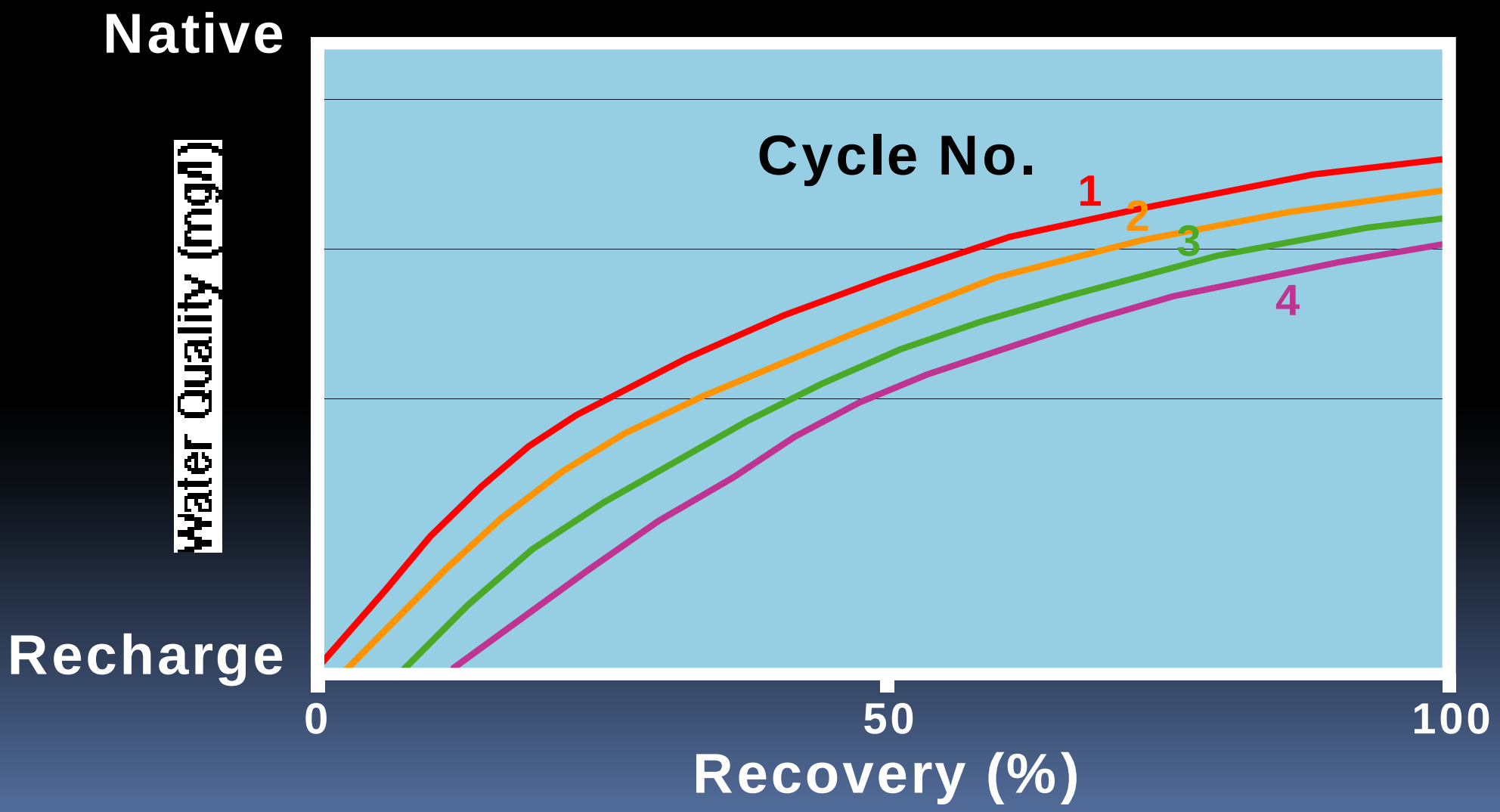
The combined forces have created a situation where ASR in the USDW has become more of a headache than a help to water managers.

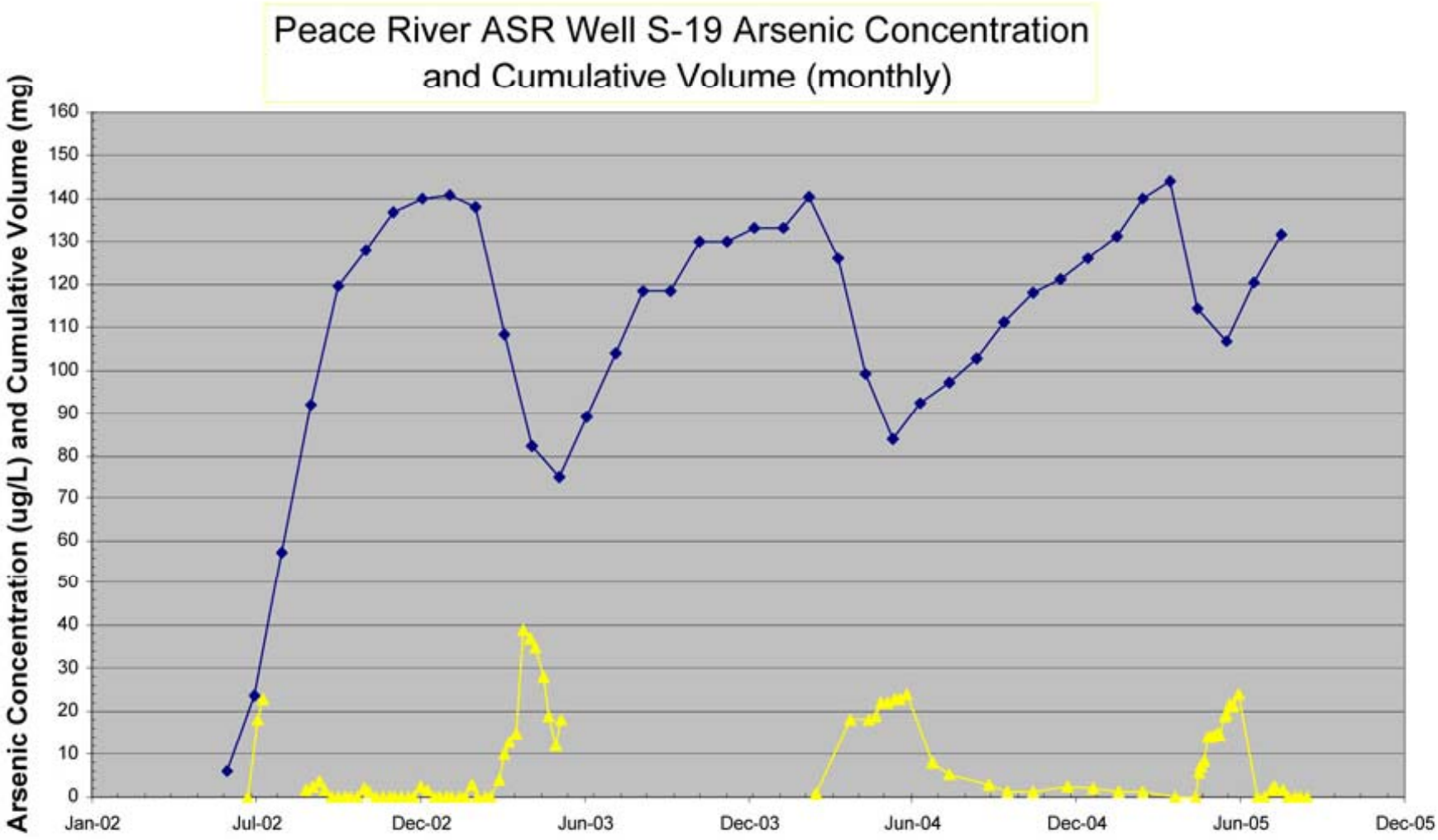
On the plus side there are some things that we do know and can point to as possibly successful longer term:

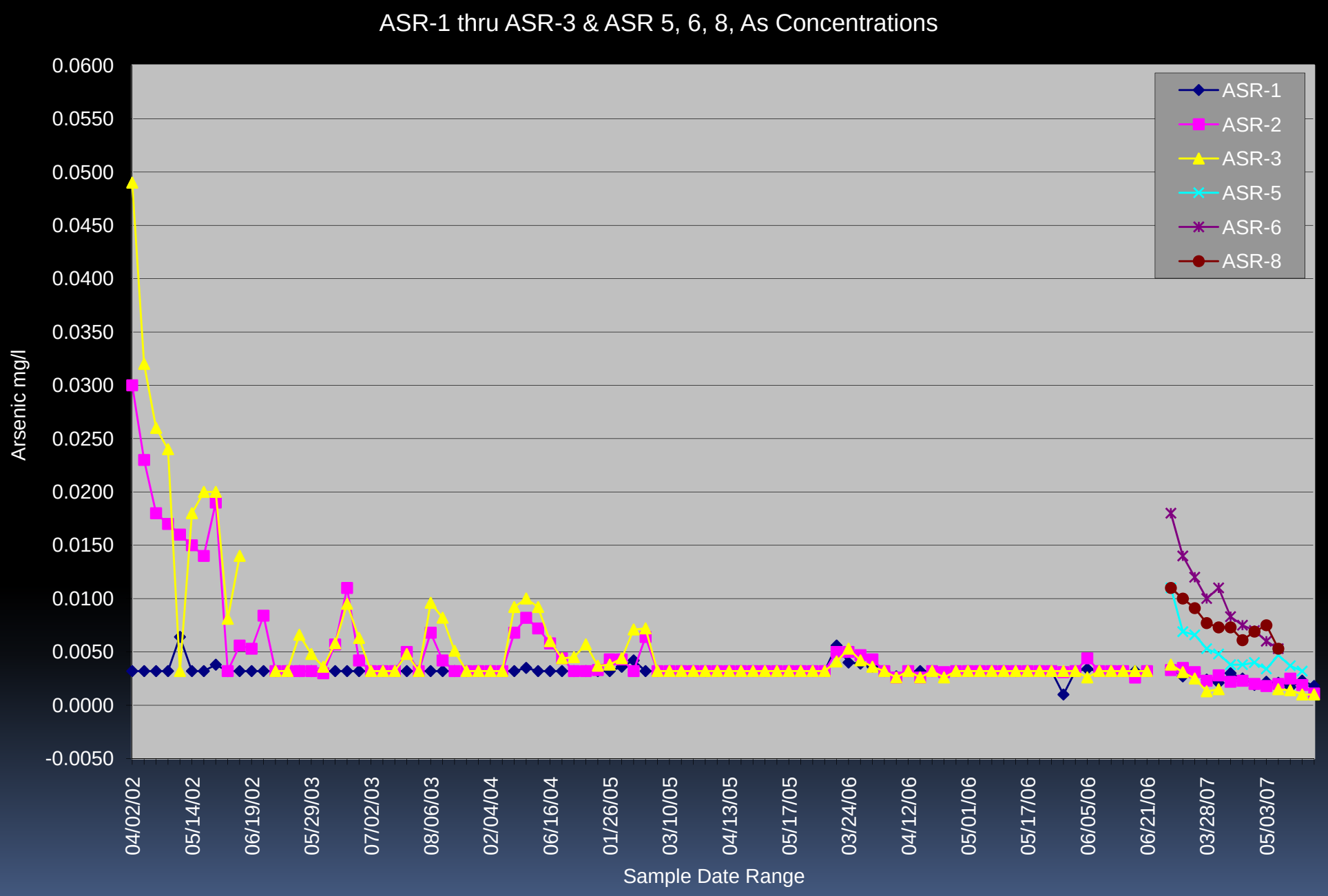
An operating model where consistent injection/recovery result in improvement in water quality particularly with respect to arsenic concentration.

Science is advancing to address the geochemical mechanisms and may result in a part of the solution with respect to the injected water being more compatible with the native formation water

Water Quality Improvement in Successive Cycles




Peace River ASR Well S-19 Arsenic Concentration
and Cumulative Volume (monthly)
Arsenic Concentration (ug/L) and Cumulative Volume (mg)
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
Jan-02
Jul-02
Dec-02
Jun-03
Dec-03
Jun-04
Dec-04
Jun-05
Dec-05


ASR-1 thru ASR-3 & ASR 5, 6, 8, As Concentrations
Arsenic mg/l
0.0600
0.0550
0.0500
0.0450
0.0400
0.0350
0.0300
0.0250
0.0200
0.0150
0.0100
0.0050
0.0000
-0.0050
ASR-1
ASR-2
ASR-3
ASR-5
ASR-6
ASR-8
04/02/02
05/14/02
06/19/02
05/29/03
07/02/03
08/06/03
02/04/04
06/16/04
01/26/05
03/10/05
04/13/05
05/17/05
03/24/06
04/12/06
05/01/06
05/17/06
06/05/06
06/21/06
03/28/07
05/03/07
Sample Date Range

State regulation is advancing as well:

FDEP has developed an ASR policy which is intended to allow compliant operation of USDW ASR systems while continuing testing and development of technologies to address the Arsenic mobilization issues

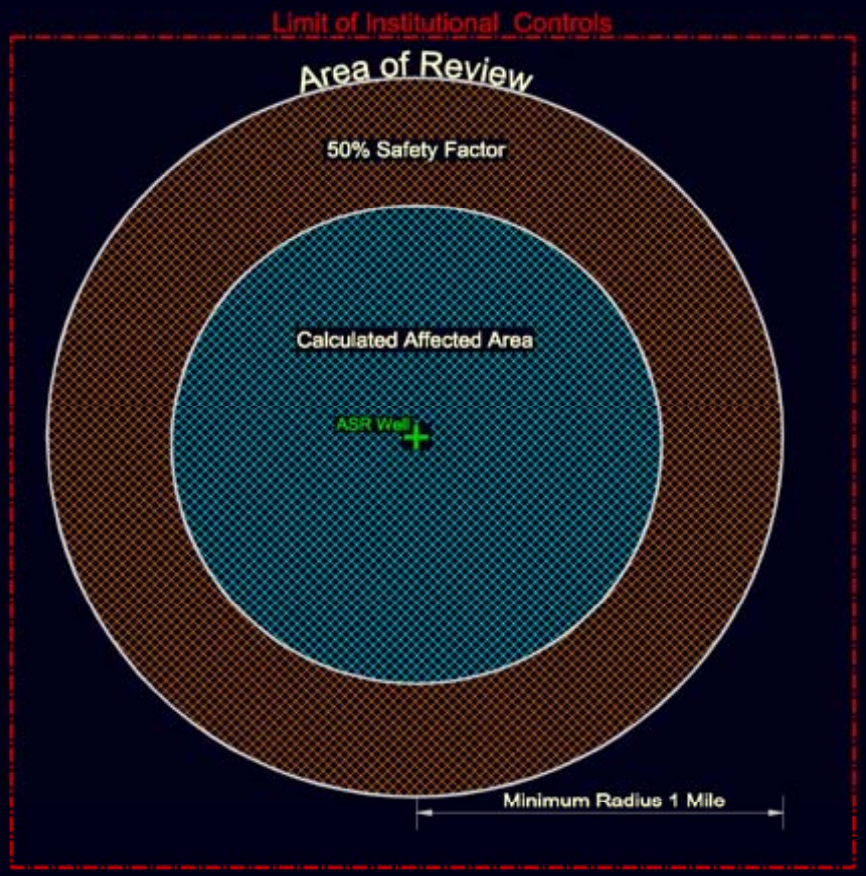
The policy is based around issuance of permits and Administrative Orders. The Orders allow operation of an ASR system without penalization for water quality exceedances while testing to determine a solution that will allow the USDW ASR system in question to meet the water quality standards consistently through time. However, if after a period of time allowed by the permits and Orders, the system cannot achieve compliance consistently, then the system may be subject to further agency action to address water quality issues.

Items that the FDEP is working with in these permits and Orders are:

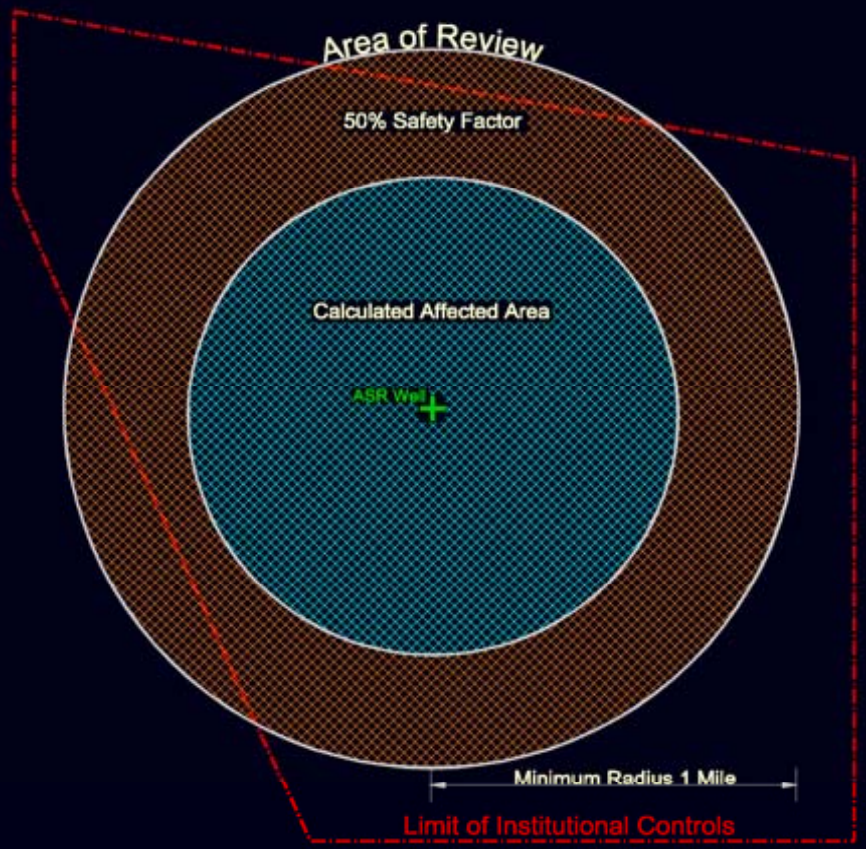
Target Storage Volume (TSV)

- Each ASR well has a TSV estimated from well hydraulics, test results, recharge supply variability and water demand characteristics.
- Once the TSV is reached, recovery efficiency should be 100% or other appropriate level for that specific site. TSVs should be matched to the system projected needs for future volume considerations.
- This concept is important because one of the major items requested by the regulated entities is institutional control.
- An example of how institutional control works follows this slide.

Institutional Controls



Off Site Exceedance Allowed
(Entire area of review is within limits of the ordinance)



Off Site Exceedance Not Allowed
(Area of review exceeds the limits of the ordinance)

Some items shown in the example may not be applicable:

There may adjustments to the radius required, the example lists one mile.

The safety factor may be adjusted as well, the example lists 50 %

Odd shaped areas of control will likely not exist as the area of control would be radially outward from the well or central to the wellfield.

This type of institutional control has been included in two sets of Administrative Orders and several permits

The key to utilization of the institutional control is control of the stored volume. For obvious reasons the stored volume should not exceed the area of control.

How do we measure ASR success?

Recovery Efficiency

- the volume recovered as a percentage of the volume stored in each cycle.
- typically 100% after a few cycles of equal volume.
- relies upon formation of a buffer zone around each ASR well.

Recoverability

- do we recover the volume that we need, at an acceptable rate and quality, at reasonable cost?
- no measurement units
- less than 100% recovery efficiency may be acceptable at many sites.

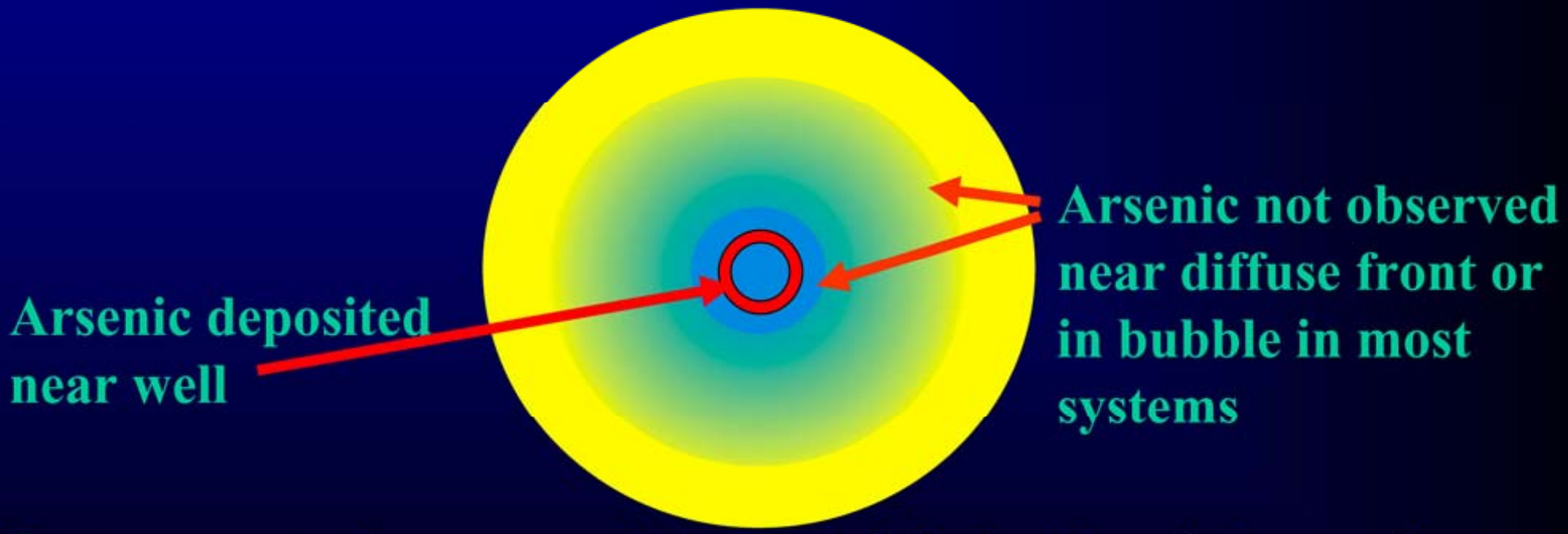
The example provided previously and one additional that we will discuss in a few slides from now tell us that recovery efficiency must be well managed to control the arsenic concentrations measured in the recovered water.

What we have seen is recovery to approximately 100 % is appropriate. Recovery beyond 100 % of water injected in total results in an increase in Arsenic concentrations measured in the recovered water.

This observation leads to another thesis related to what is happening in the aquifer system:

SUGGESTED IMPLICATIONS

Revised vision of Arsenic distribution (Near wellbore rather than diffuse front . A non-linear time, space perspective)



Interpretation consistent with lack of Arsenic being observed in monitoring wells

The idea that the area of concern may be limited to a close proximity to the wellbore is an important idea that should absolutely be determined to be true or false.

The way to make that determination is through monitoring and that would require installation of additional monitor wells within an existing system.

If this thesis can be proven to be accurate – then many regulatory hurdles may be able to be overcome. If we can state with a reasonable degree of certainity that the area of concern is limited to a general radius around the well or wellfield then the institutional control mechanism may be all that is necessary to provide an acceptable level of protection.

Given the information we have discussed today in terms of the USDW ASR situation, it is apparent that other alternative methods of storage must be considered going forward.

Fortunately there is an example of what is proving to be a potential winning solution for water that serves demand purposes other than potable consumption:

The saline aquifer ASR or “G-IV Solution”

I mentioned earlier that there was one Non-USDW reclaimed water ASR system in the district. That system is the Englewood Water District ASR. This unique situation was discovered by accident.

The Englewood ASR was not intended to be a salt water ASR system. However, during construction the base of the USDW was discovered at 129 feet bls.

The system was completed and more or less left languishing while water was injected but not recovered with a great deal of efficiency.

After a period of time – the system was viewed as a short cut to a Class I well and the FDEP essentially required EWD to begin consistent recovery of injected water.

A startling discovery occurred:

David Pyne is absolutely correct about the function of Storage Volumes……

Table 5
ASR Water Year Recovery Efficiency

	Water Year	Recharge (mg)	Recovery (mg)	Recovery Efficiency (%)	Cummulative Storage Volume (mg)
	2001	18.680	0.000	0.0%	18.680
	2002	145.102	13.781	9.5%	150.001
	2003	255.803	12.742	5.0%	393.062
	2004	144.441	0.175	0.1%	537.328
	2005	116.271	15.957	13.7%	637.642
	2006	116.725	64.673	55.4%	689.694
	2007	49.793	79.373	159.4%	660.114
	2008	93.013	34.957	37.6%	718.170
	2009*	7.917	60.224	760.7%	666.245
Totals:		947.745	281.882	29.7%	666.245

Recovery Efficiency since WY06: 89.4%

Recovery Efficiency since WY07: 115.8%

* Through June 2009.

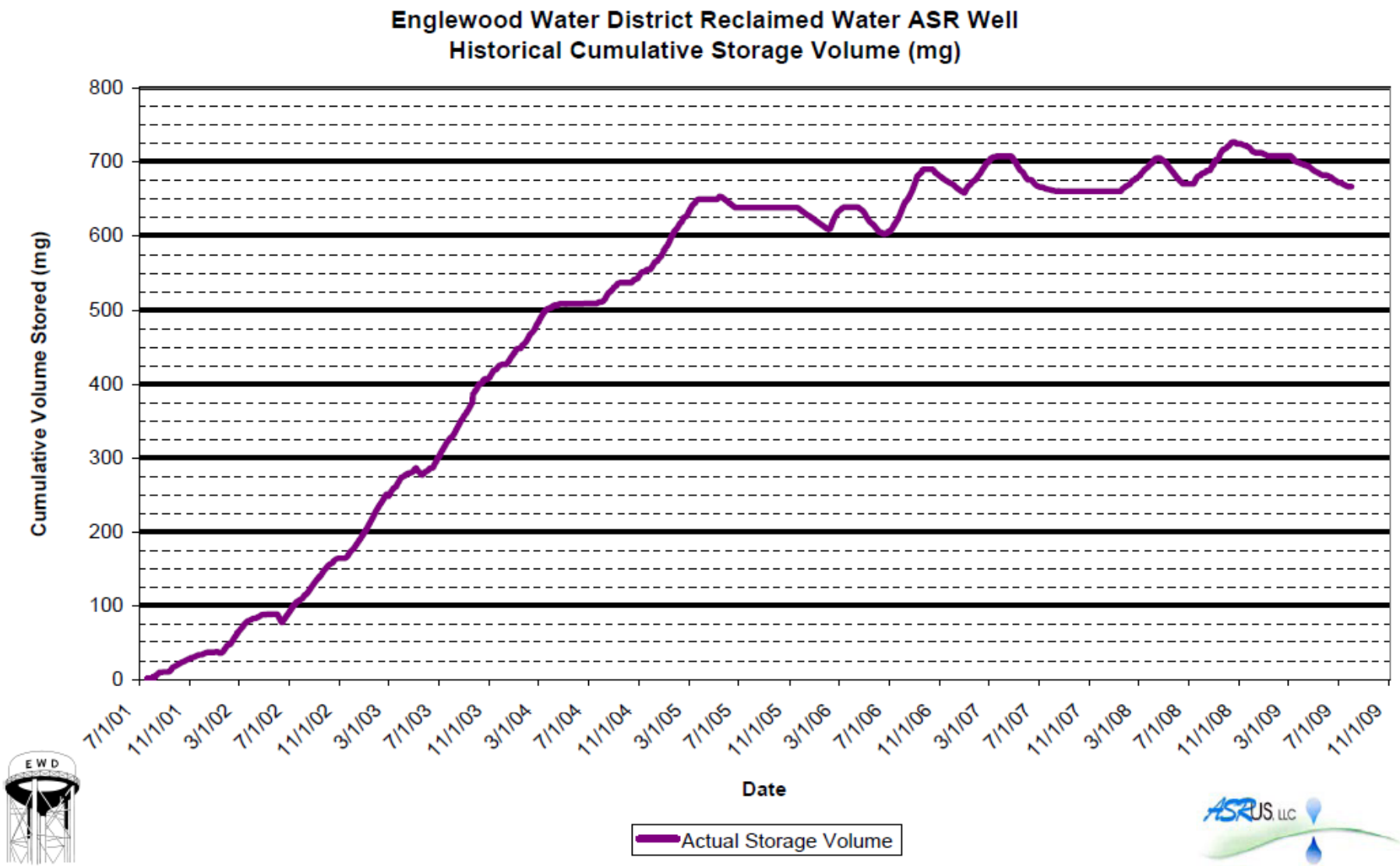

Englewood Water District Reclaimed Water ASR Well
Historical Cumulative Storage Volume (mg)
Cumulative Volume Stored (mg)
800
700
600
500
400
300
200
100
0
7/1/01
11/1/01
3/1/02
7/1/02
11/1/02
3/1/03
7/1/03
11/1/03
3/1/04
7/1/04
11/1/04
3/1/05
7/1/05
11/1/05
3/1/06
7/1/06
11/1/06
3/1/07
7/1/07
11/1/07
3/1/08
7/1/08
11/1/08
3/1/09
7/1/09
11/1/09
Date
Actual Storage Volume
EWD
ASR US LLC

Figure 1

A sufficiently sized and properly managed storage volume can result in impressive recovery efficiency, even in adverse conditions.

When the EWD storage volume reached between 500 and 600 million gallons recovery efficiency improved tremendously.

EWD has recently achieved 100 % plus recovery in the water year 2009 – 2010.

Guess What Happened Then……..

Mr. Frambodial and his friends showed up…….

TABLE 4 - Englewood Water District Reclaimed Water ASR Laboratory Water Quality - July 2009

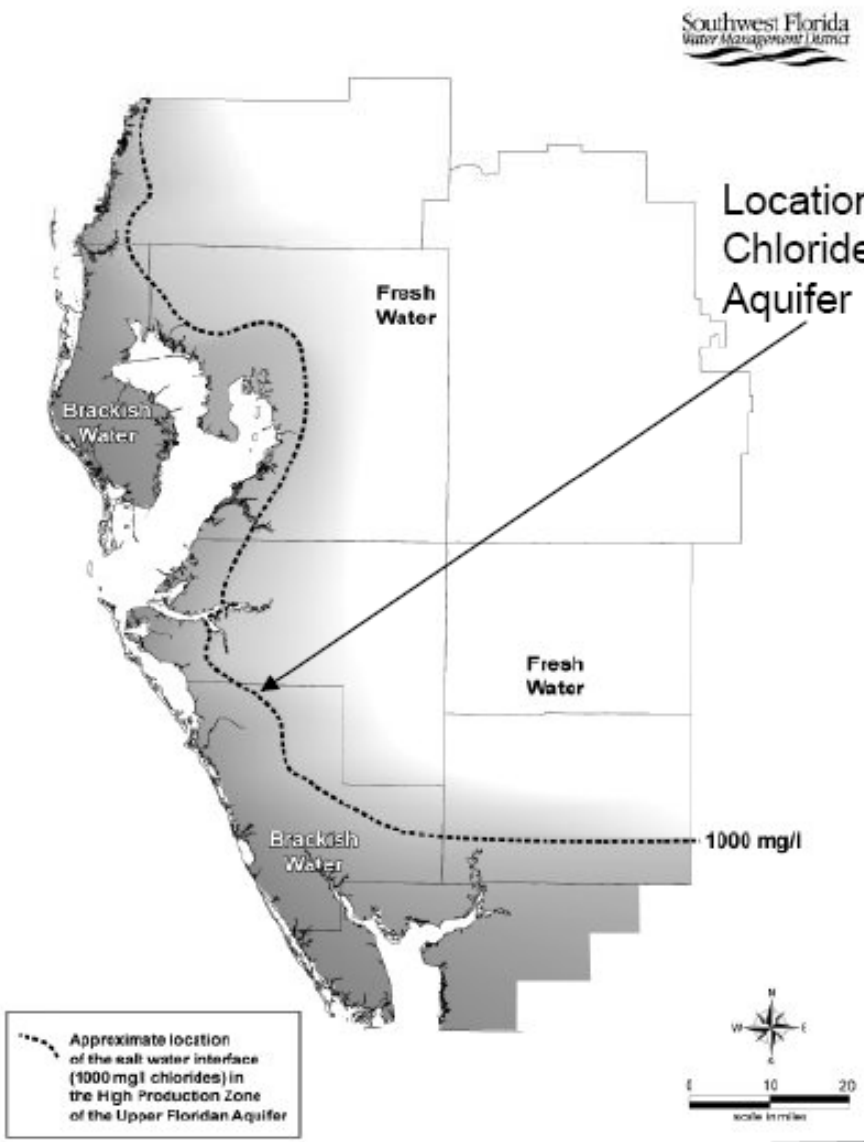
Monitoring Location	39957.00	OR	CR	TA	As	Cl	SO4	TDS	Fe	THMs	TSS	TC	FC	CBOD	CON	GA
		Odor	Color	Total Alkalinity	Arsenic	Chloride	Sulfate	Total Dissolved Solids	Total Iron	Total Trihalomethanes	Total Suspended Solids	Total Coliform	Fecal Coliform	Carbonaceous Biochemical Oxygen Demand	Conductivity	Gross Alpha
		TON	PCU	mg/L	ug/L	mg/L	mg/L	mg/L	ug/L	ug/L	mg/L	#/100mL	#/100mL	mg/L	umhos/cm	pCi/L
TPW-1	7/1/09										1.7		<1	<2		
	7/2/09										1.7		<1			
	7/3/09															
	7/4/09															
	7/5/09															
	7/6/09															
	7/7/09															
	7/8/09										2.2		<1	<2		
	7/9/09				7.43											
	7/10/09		25			1,800		3,510			1.4	<1	<1		5,890	
	7/11/09										1.4		<1			
	7/12/09										2.1		<1			
	7/13/09										1.4		<1			
	7/14/09	2	30	164	10.2	1,855	234	3,800	217	<0.50	1.9	<1	<1		5,990	
	7/15/09										1.2		<1	<2		
	7/16/09															
	7/17/09										2.5		<1			
	7/18/09										1.8		<1			
	7/19/09										2.4		<1			
	7/20/09										1.8		<1			
	7/21/09										1.2		<1			
	7/22/09		25		10.4	1,915		3,920			1.4	<1	<1	<2	5,940	
	7/23/09										1.8		<1			4.5+/-0.7
	7/24/09															
	7/25/09															
	7/26/09															
	7/27/09															
	7/28/09															
	7/29/09															
	7/30/1009															
	7/31/09															
SMW-1	7/9/09															
	7/14/09	>100	15	148	<1.32	3,800	274	8,367	<29			<1	<1		10,780	
	7/22/09															
SZMW-1	7/9/09															
	7/14/09	16	10	158	<1.32	8,300	1048	15,533	70.4	<0.50		<1	<1		23,100	
	7/22/09															
IMW-1	7/9/09															
	7/14/09	>100	10	136	<1.32	4,600	572	9,433	<29			<1	<1		12,740	
	7/22/09															

Since the EWD ASR is not operating within the USDW, the FDEP's concern was not one of the ASR is out of compliance, but rather assurance must be provided that the recovered water during its end use does not cause a pollution incident contravening rules contained in Chapters 62-610 and 62-520, F.A.C.

The Federal Endangerment issue was not a factor, the state policy for USDW ASR was not a factor. Only appropriate handling of the recovered water and its distribution were factors.

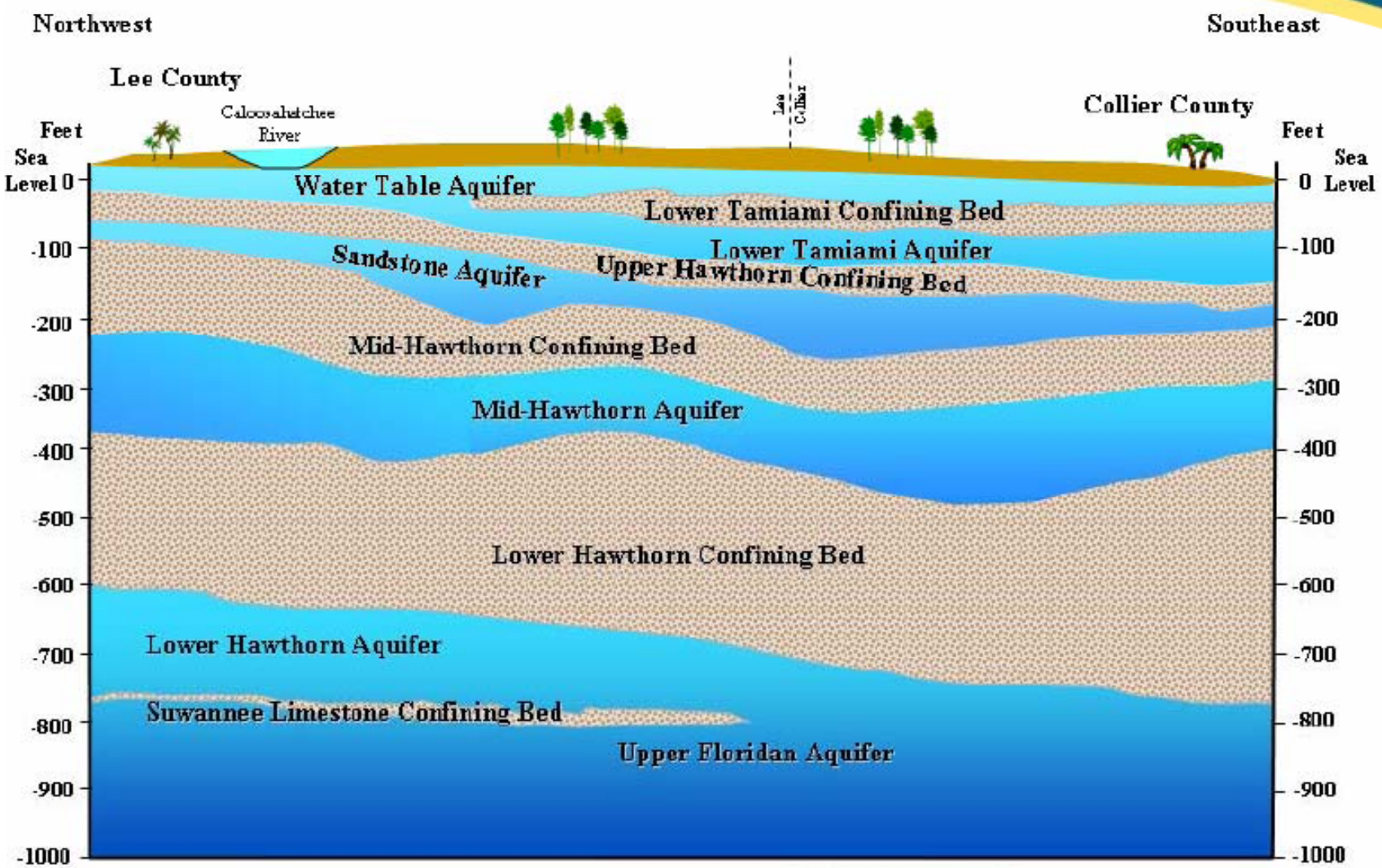
What this means is that for waters intended for specific non-potable end use in coastal areas of the state, a Non – USDW ASR may be the appropriate solution for water managers.

Real Effects of Saltwater Intrusion



Location of 1,000 mg/L Chlorides in Upper Floridan Aquifer

Drinking Water

EPA MCL = 250 mg/L chlorides

Florida Geologic Cross Section