A Review of Nitrogen Loading and Treatment Performance Recommendations for OWTS in the Wekiva Study Area

FDOH Technical Review & Advisory Panel Meeting

February 15, 2006

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HAZEN AND SAWYER
Environmental Engineers & Scientists

Purpose and Scope

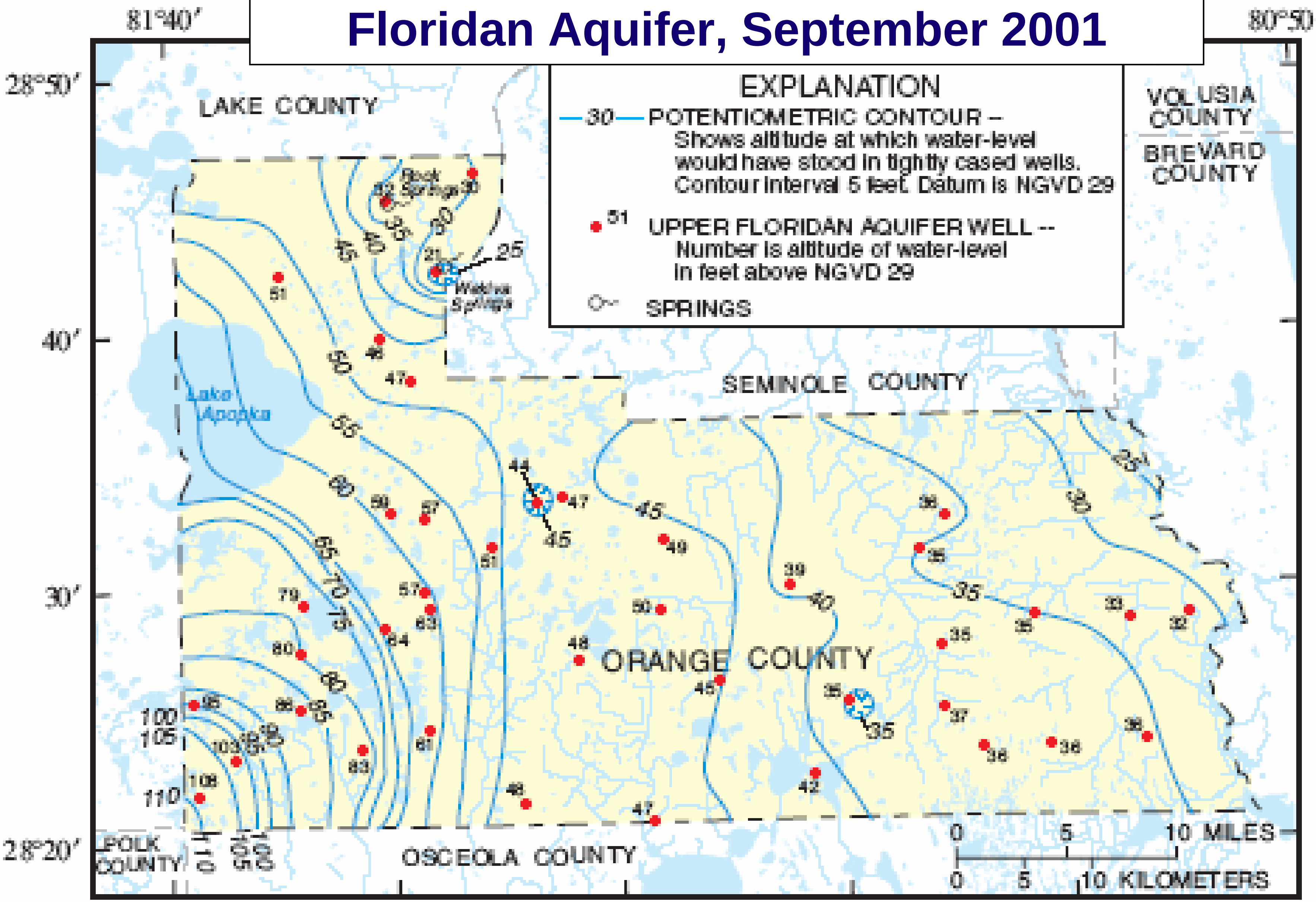
- Retained by stakeholders through FHBA
- **Purpose:** To gain understanding of the significance of N loading from OWTS
- **Scope:** Review data, make assessment of OWTS impacts relative to other sources and FDOH recommended OWTS actions

Hydrogeology of the Wekiva Area

SYSTEM	SERIES		STRATIGRAPHIC UNIT	LITHOLOGY	HYDROGEOLOGIC UNIT		APPROXIMATE THICKNESS (feet)
QUATERNARY	RECENT		UNDIFFERENTIATED DEPOSITS	Quartz sand, unconsolidated, locally can contain clay, chert shell, and limestone lenses.	SURFICIAL AQUIFER SYSTEM		LESS THAN* 50 - 200
	PLEISTOCENE						
TERTIARY	PLIOCENE						
	MIOCENE		HAWTHORN GROUP	Clay, green-gray color with phosphatic pebbles, silt, locally can contain sand and carbonate units.	INTERMEDIATE CONFINING UNIT		10 - GREATER THAN 200
	EOCENE	UPPER	OCALA LIMESTONE	Limestone, white, tan, or cream, fossiliferous, soft to hard, locally dolomitic, highly porous.	FLORIDAN AQUIFER SYSTEM	UPPER FLORIDAN AQUIFER	300 - 400
		MIDDLE	AVON PARK FORMATION	Limestone, light brown to brown porous, fossiliferous, locally dolomitic and carbonaceous; intergranular gypsum and anhydrite; brown, crystalline dolomite.		MIDDLE SEMICONFINING UNIT / MIDDLE CONFINING UNIT	400 - 700
		LOWER	OLDSMAR FORMATION	Limestone, white to light brown, porous, fossiliferous, interbedded with dolomite, minor amounts of gypsum present.		LOWER FLORIDAN AQUIFER	1,000 - 1,300
	PALEOCENE		CEDAR KEYS FORMATION	Dolomite, light gray, with significant amounts of gypsum and anhydrite.	SUB-FLORIDAN CONFINING UNIT		POORLY KNOWN

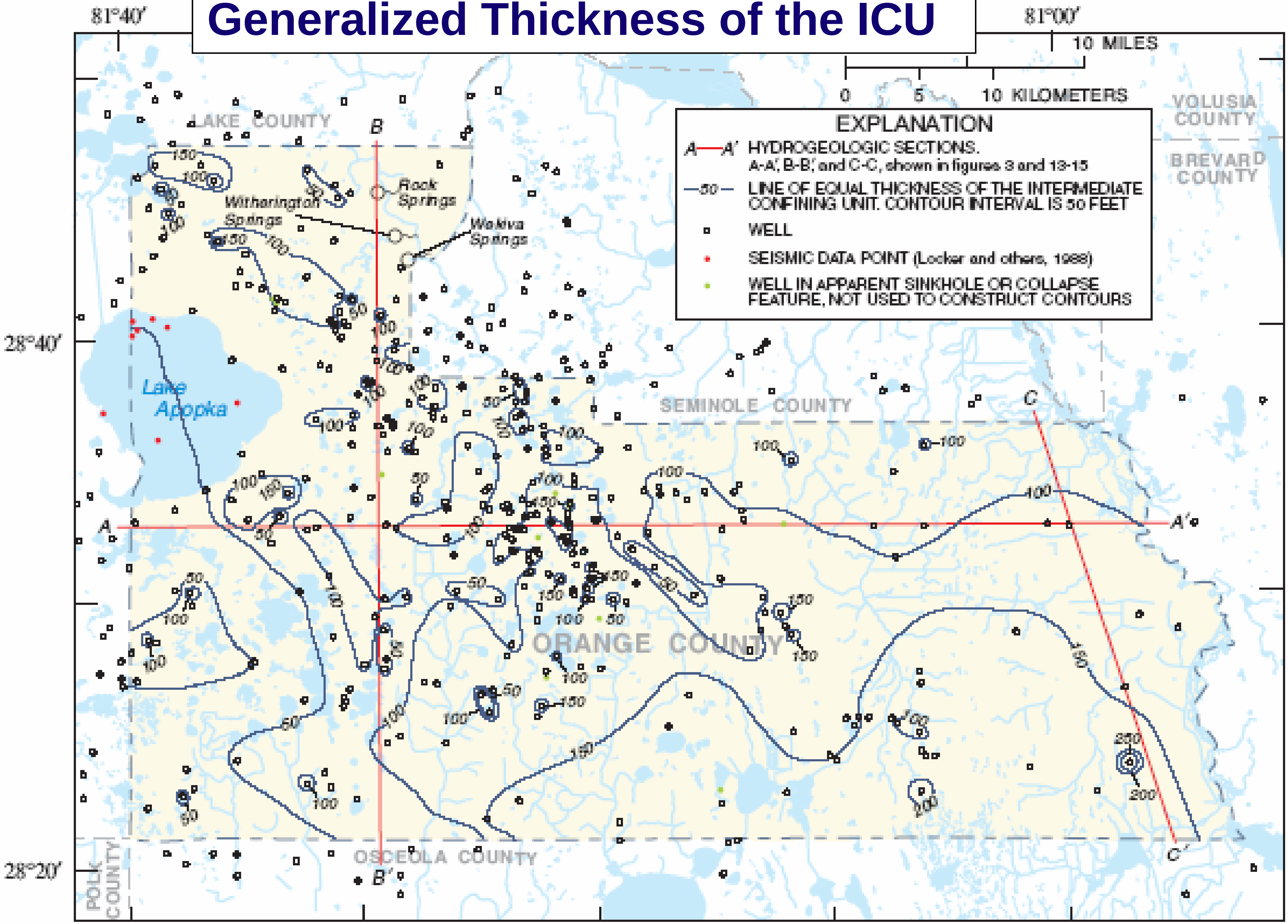
*Thickness includes saturated and unsaturated undifferentiated sedimentary deposits overlying the intermediate confining unit.

Potentiometric Surface of the Upper Floridan Aquifer, September 2001

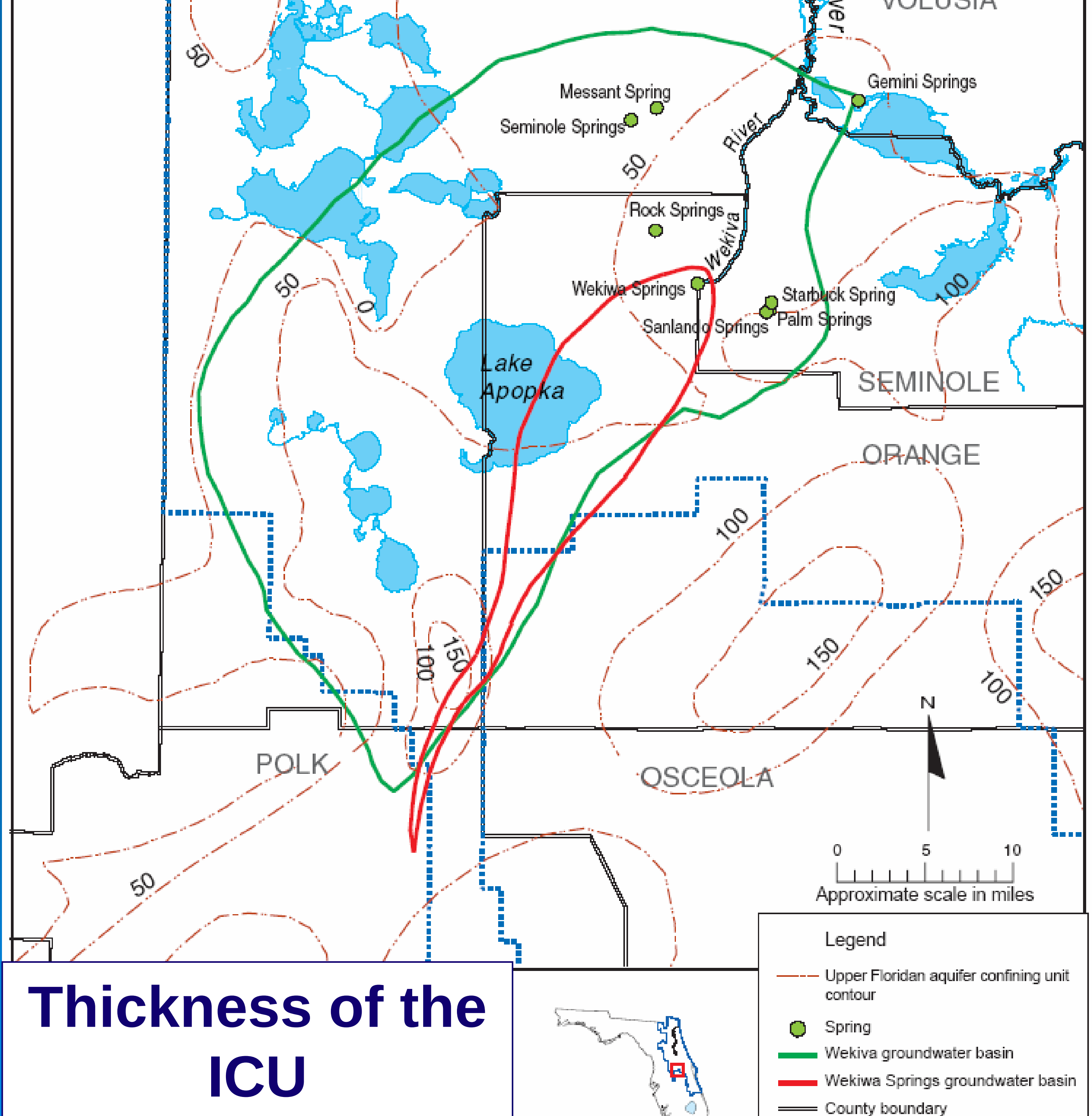


Base modified from U.S. Geological Survey digital data; 1:100,000, 1985
Albers Equal-Area Conic projection
Standard parallels 29°30′ and 45°30′, central meridian -83°00′

Generalized Thickness of the ICU

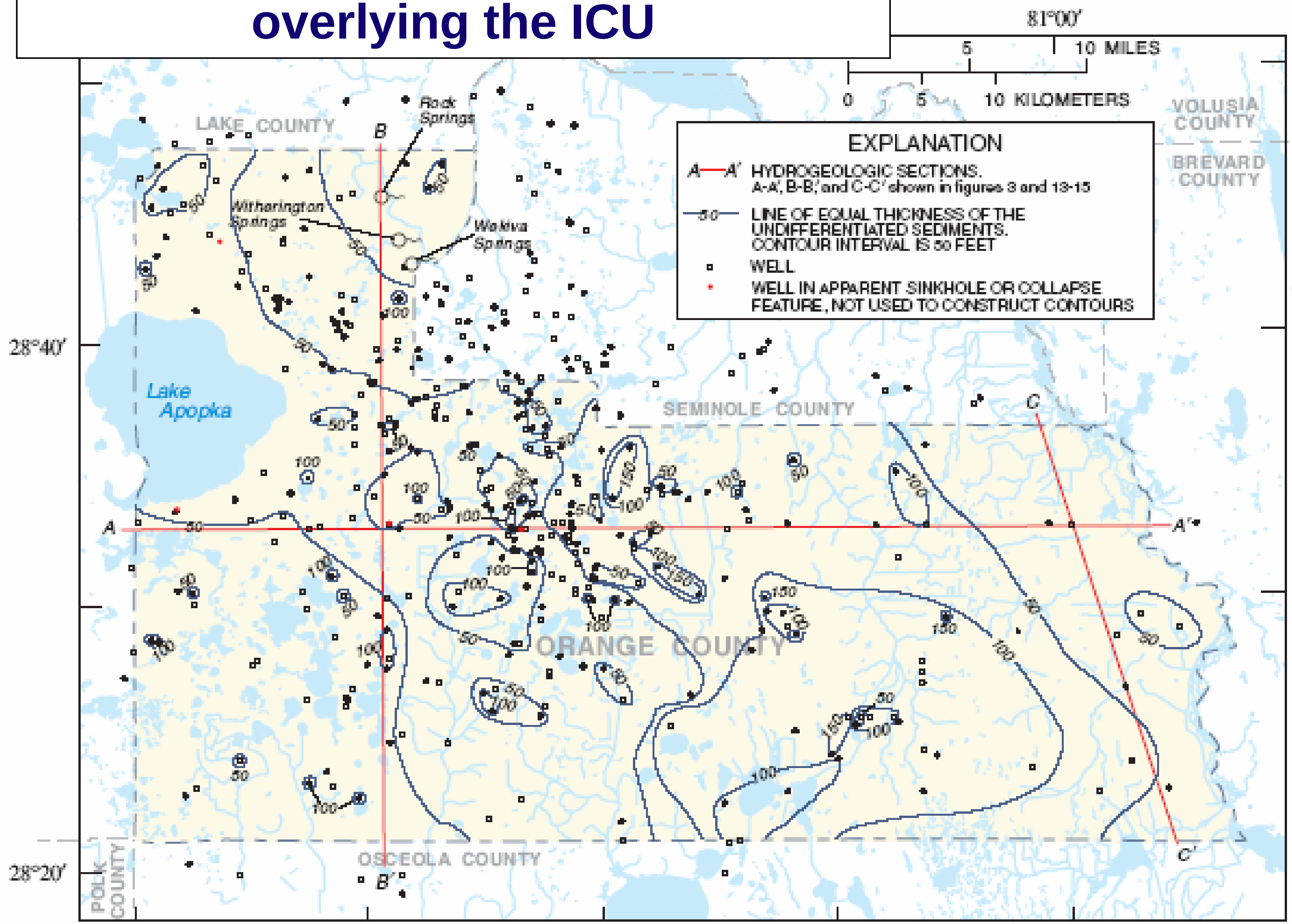


Sources of data: geophysical and geological information from the U.S. Geological survey
St. Johns River Water Management District, and Florida Geological Survey

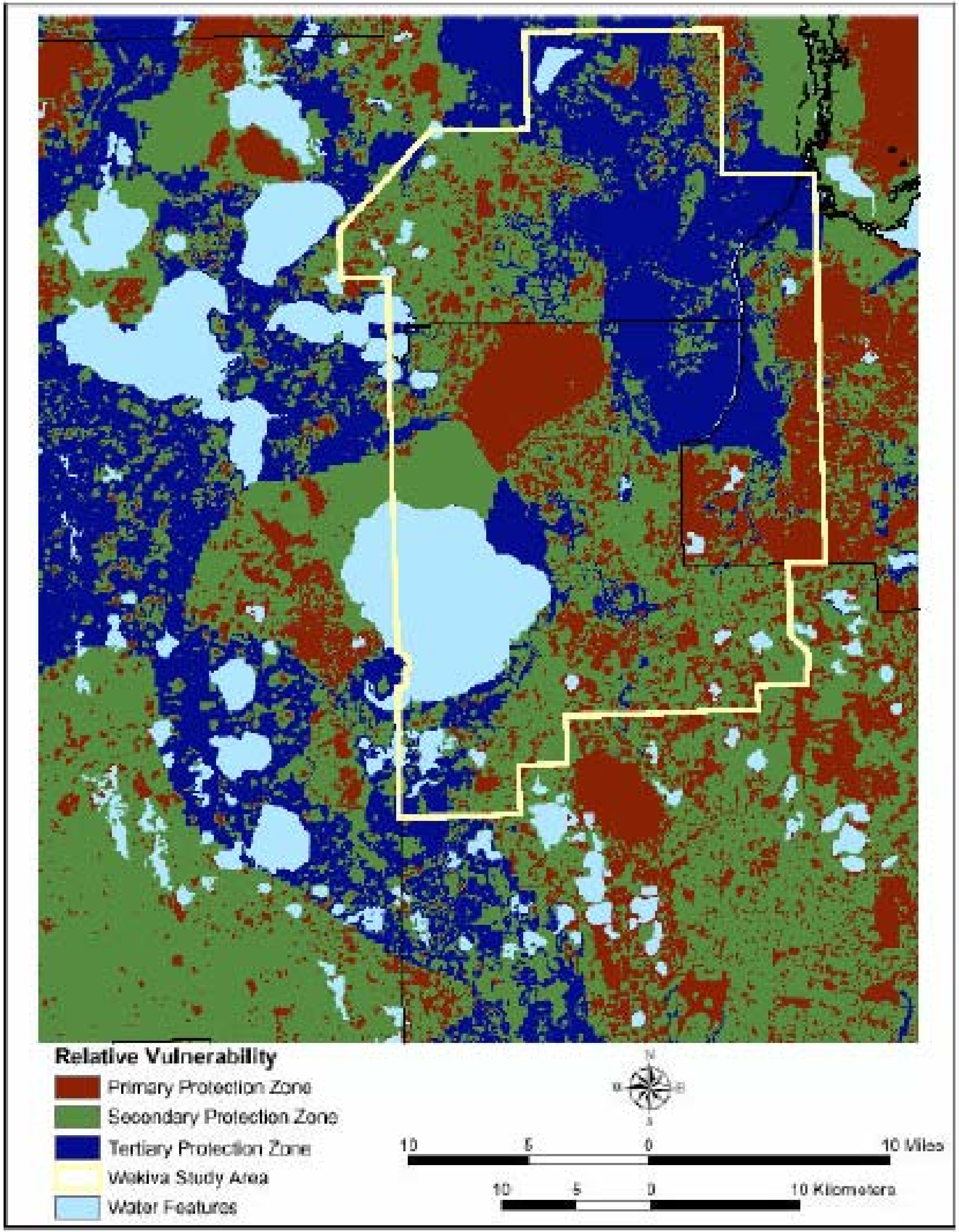


Thickness of the ICU

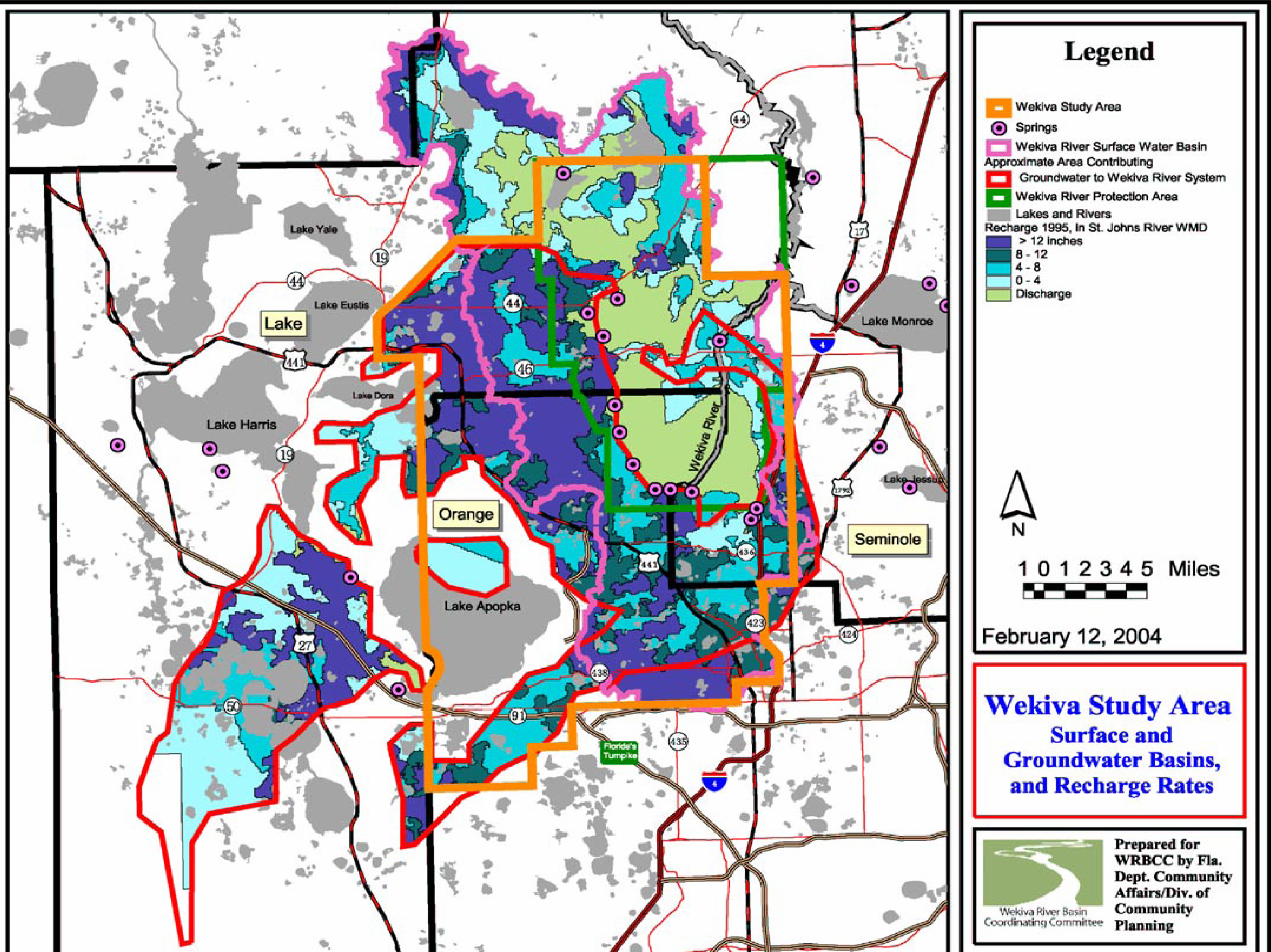
Thickness of surficial sediments overlying the ICU



Sources of data: geophysical and geological information from the U.S. Geological survey, St. Johns River Water Management District, and Florida Geological Survey

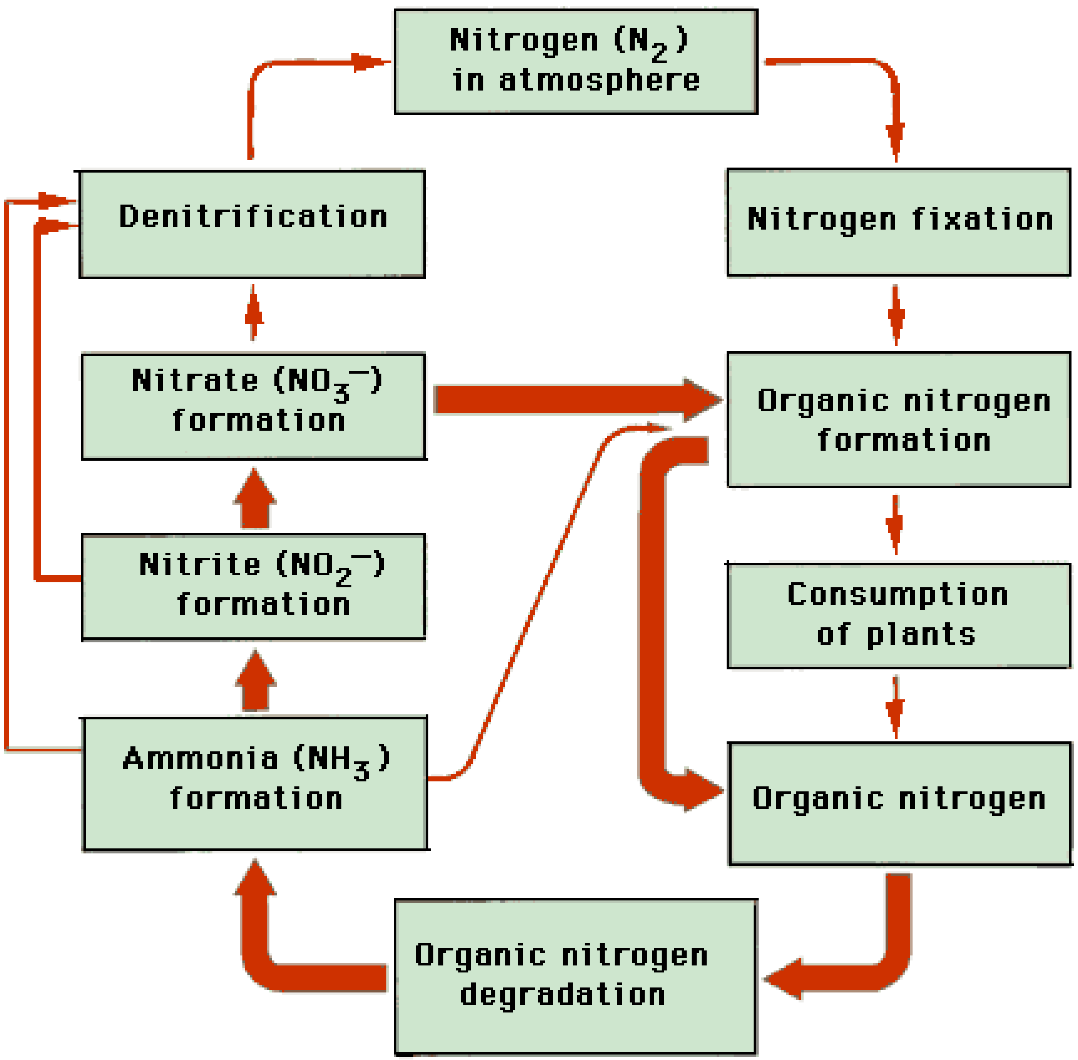


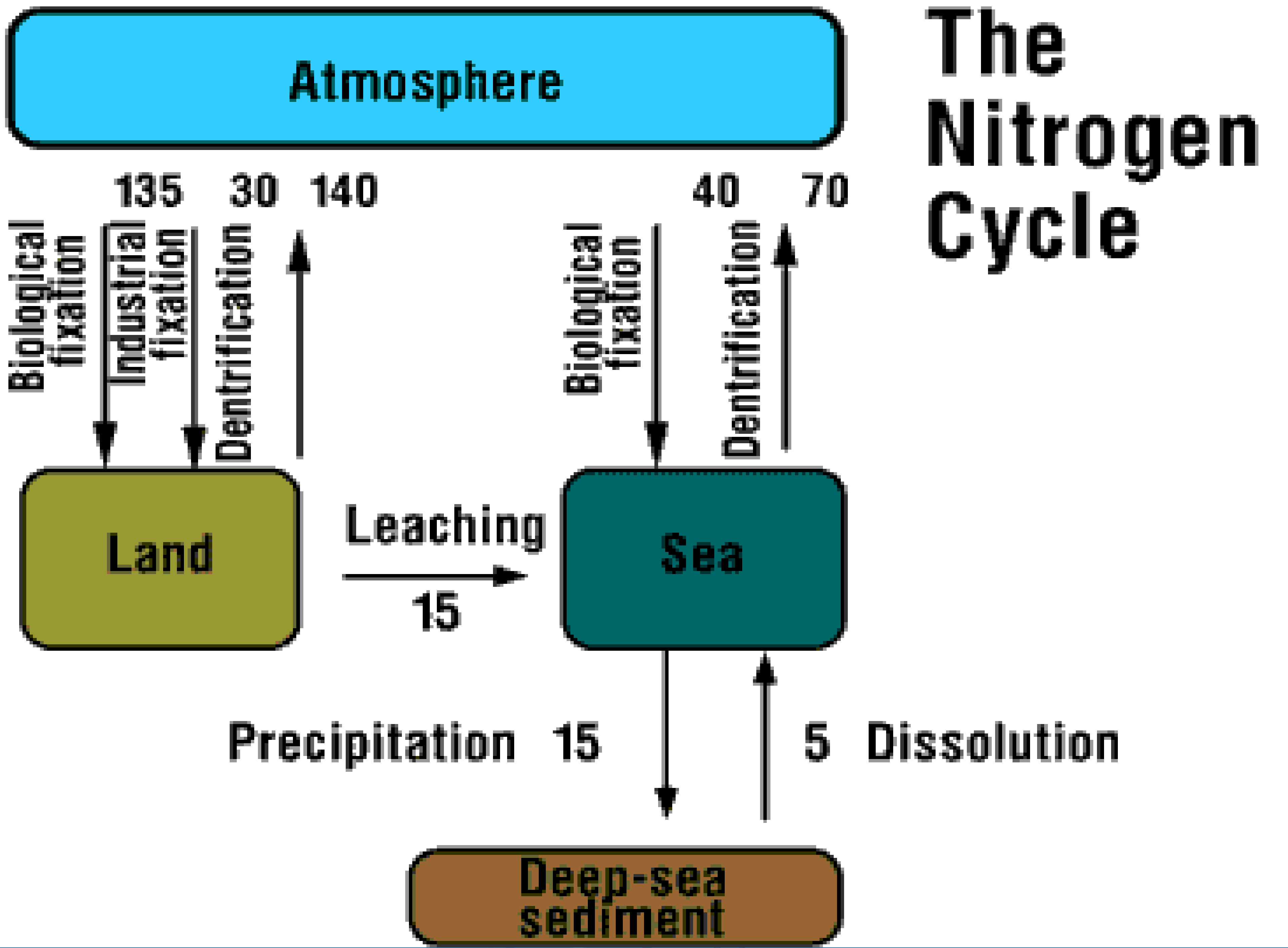
Wekiva Aquifer Vulnerability Assessment (WAVA)



Legend
Wekiva Study Area
Springs
Wekiva River Surface Water Basin
Approximate Area Contributing
Groundwater to Wekiva River System
Wekiva River Protection Area
Lakes and Rivers
Recharge 1995, In St. Johns River WMD
> 12 inches
8 - 12
4 - 8
0 - 4
Discharge
N
1 0 1 2 3 4 5 Miles
February 12, 2004
Wekiva Study Area
Surface and
Groundwater Basins,
and Recharge Rates
Wekiva River Basin
Coordinating Committee
Prepared for
WRBCC by Fla.
Dept. Community
Affairs/Div. of
Community
Planning
Lake Yale
Lake Eustis
Lake
Lake Dora
Lake Harris
Orange
Lake Apopka
Seminole
Lake Monroe
Lake Jessup
Wekiva River
Florida's Turnpike
44
19
441
46
27
50
91
438
423
424
436
435
17
4

Nitrogen Cycle



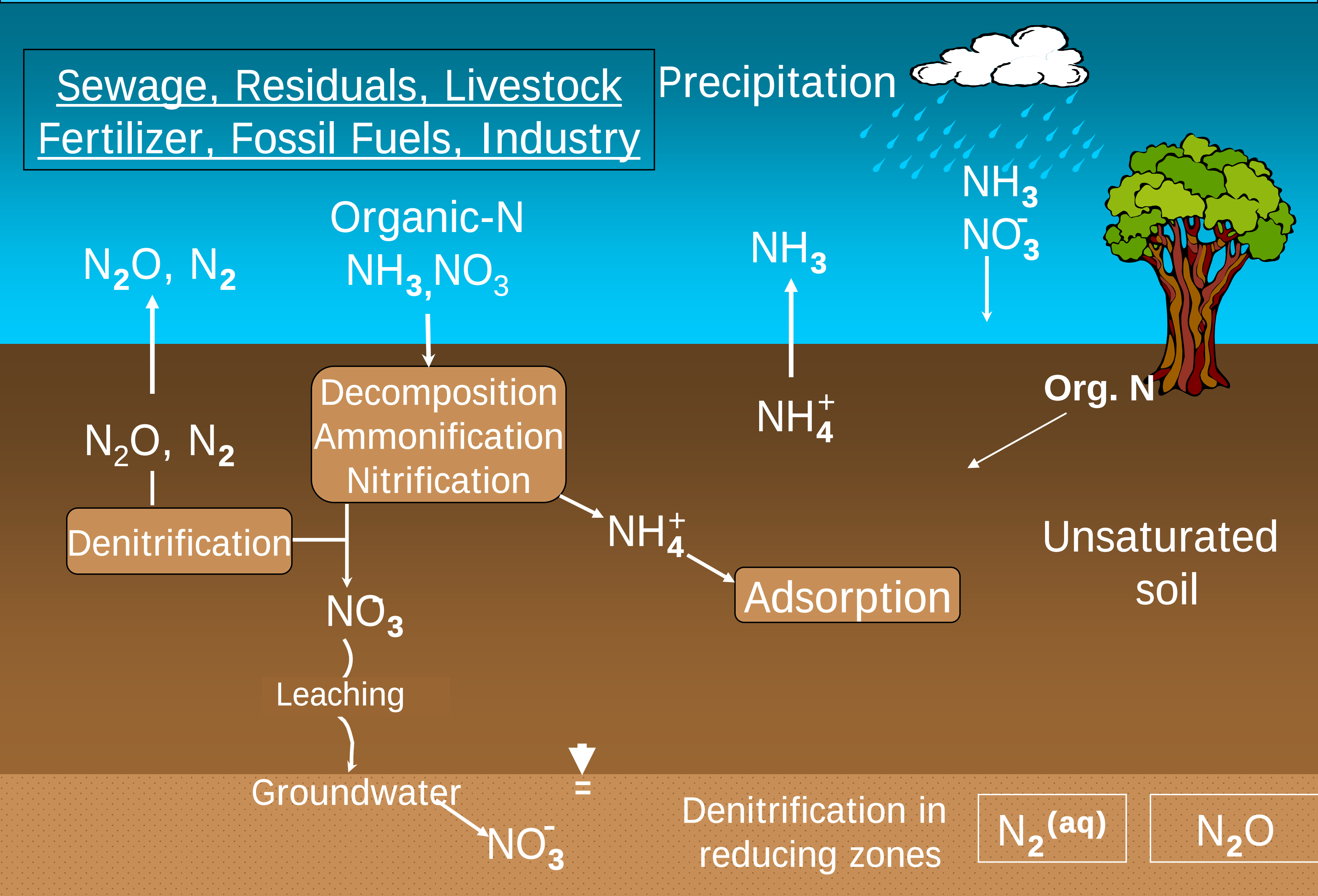


The Nitrogen Cycle
Atmosphere
135
30
140
Biological fixation
Industrial fixation
Dentrification
40
70
Biological fixation
Dentrification
Land
Leaching
15
Sea
Precipitation 15
5 Dissolution
Deep-sea sediment

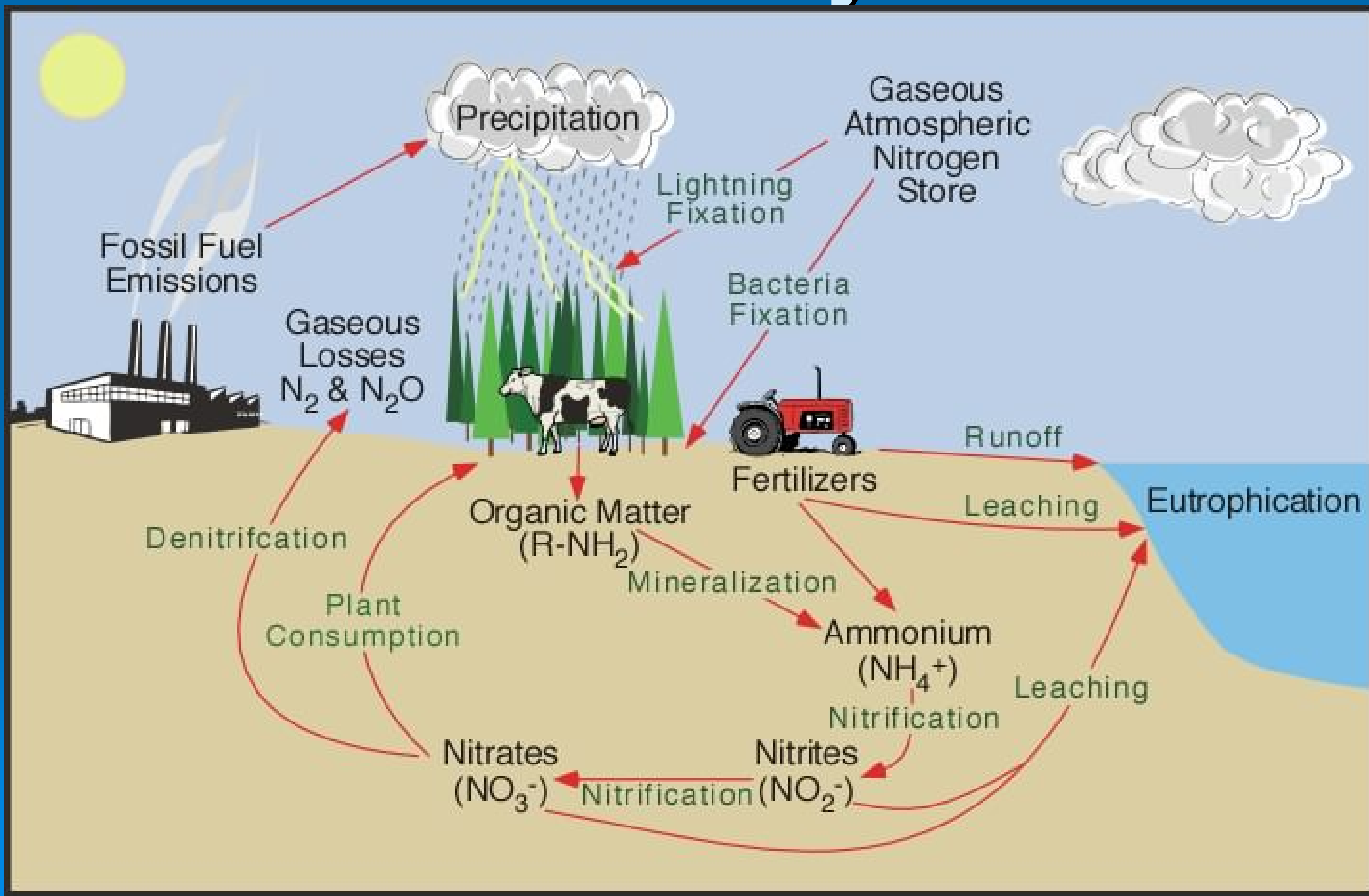
Nitrogen Removal/Reduction?

- Nitrogen is an element, can’t be reduced
- Law of Conservation of Matter:
  - "Matter can neither be created nor destroyed“
- However, we are releasing N that was not recently in the biosphere:
  - Fertilizer
  - Fossil Fuels
- We are not creating more N, just concentrating it in certain areas

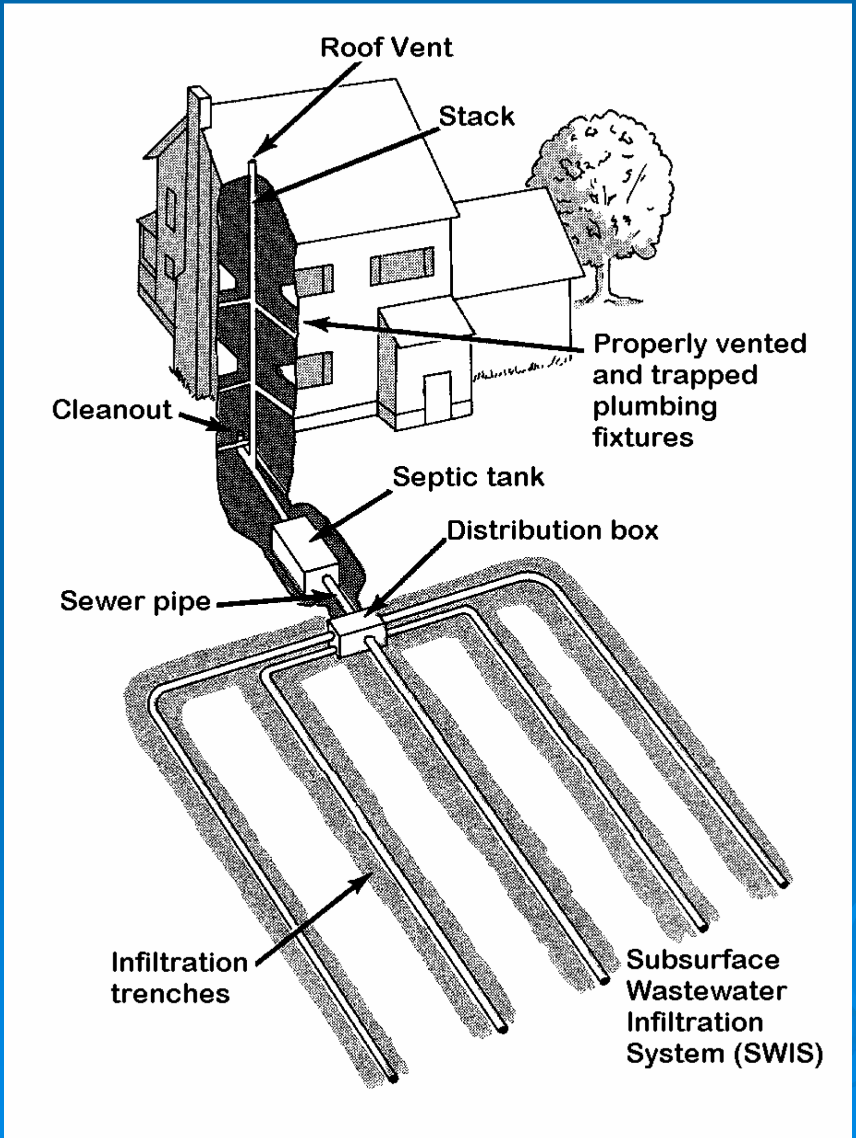
SOURCES AND PATHWAYS OF WASTEWATER NITROGEN IN THE SUBSURFACE ENVIRONMENT (Freeze & Cherry, 1979)



Man's Activities Disrupt the Natural N Cycle



Typical Onsite Wastewater Treatment System (OWTS)

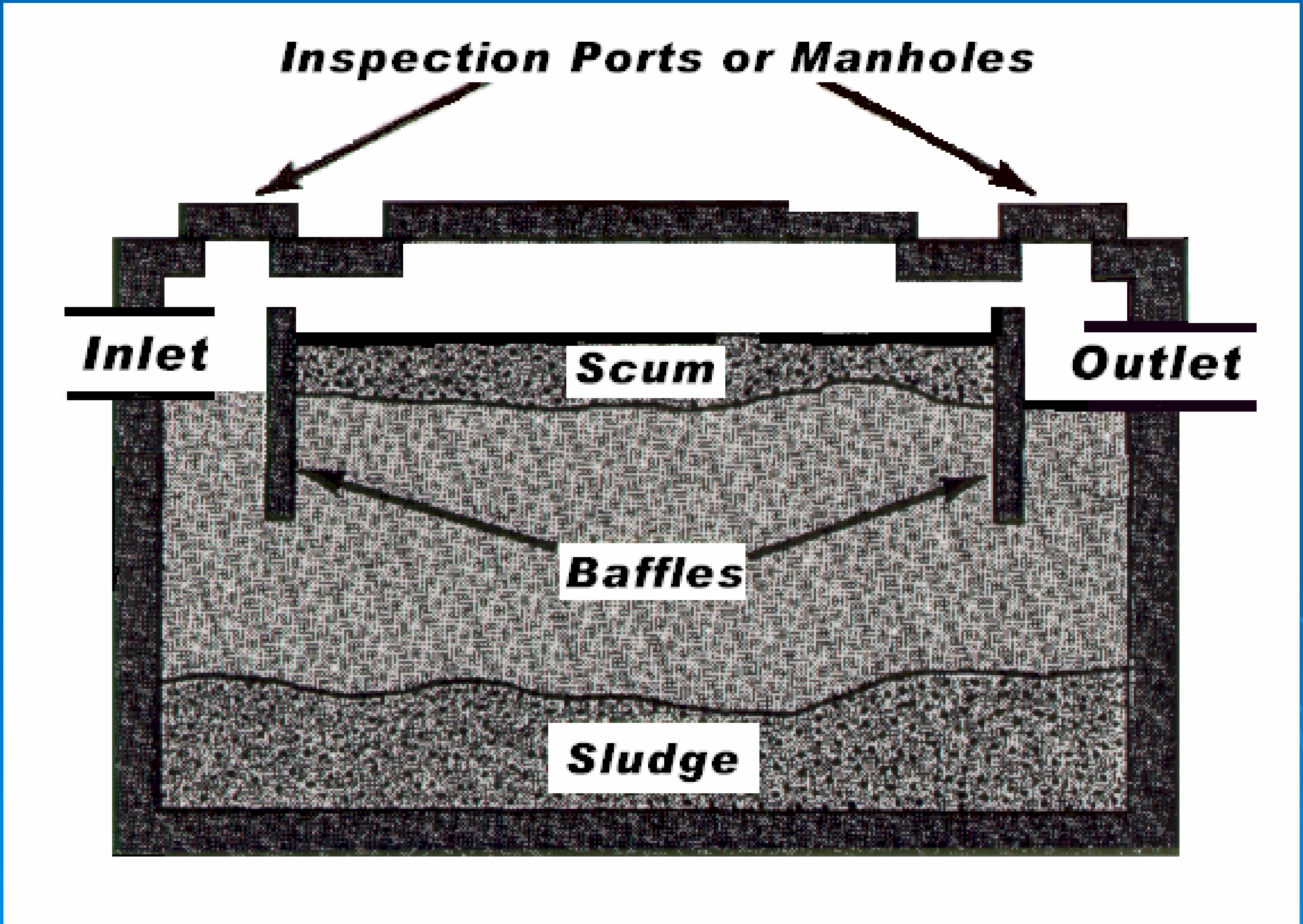


Estimated N Loading to OWTS

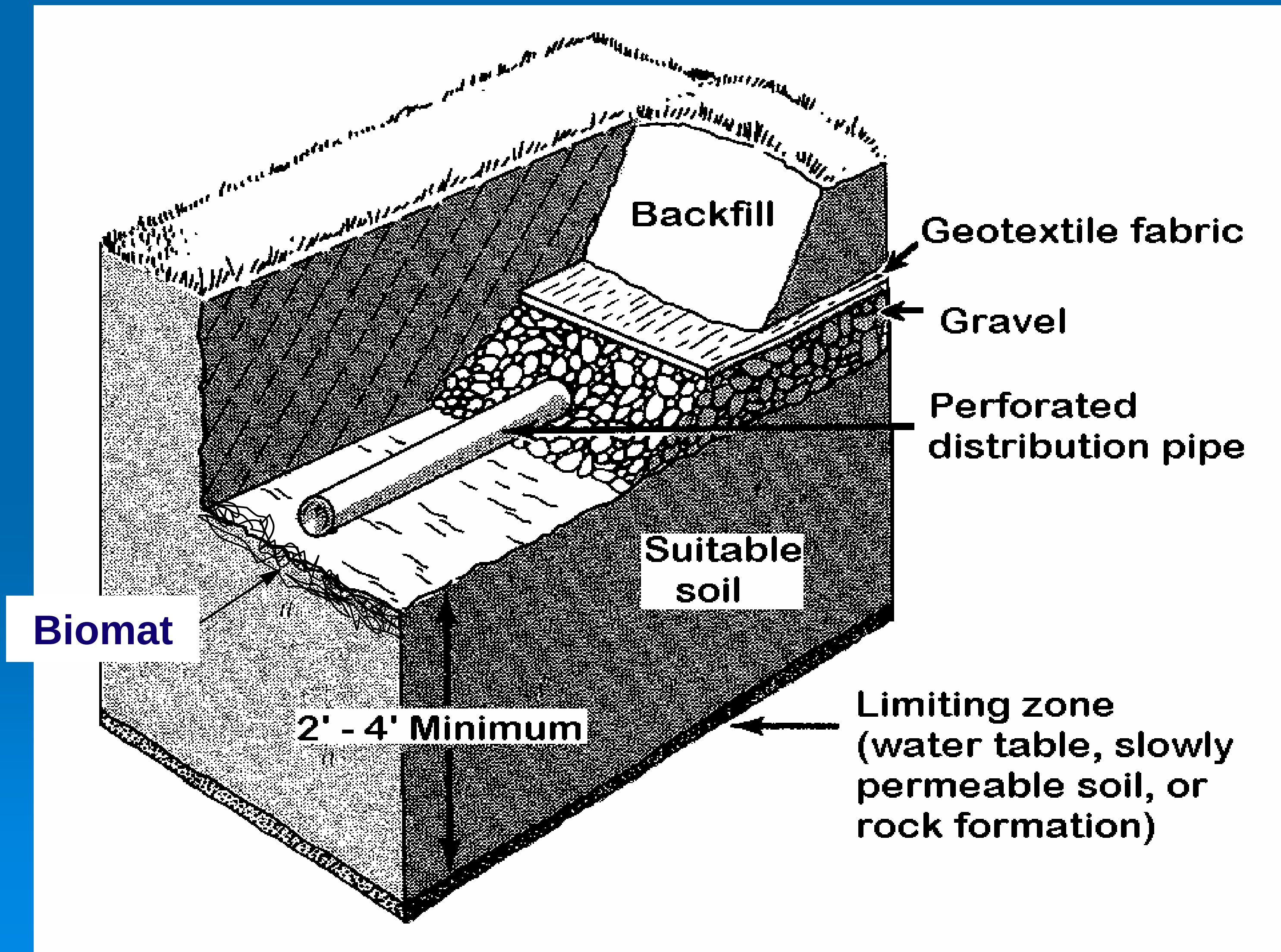
- **N discharged to OWTS in WSA:**
  - 11.2 grams N per person per day
  - 23.4 lbs N per home per year
  - 55,416 homes in WSA

- **1.3 Million lbs N discharged to OWTS per year**

Cross Section
Typical Septic Tank



Subsurface Wastewater Infiltration System, trench type



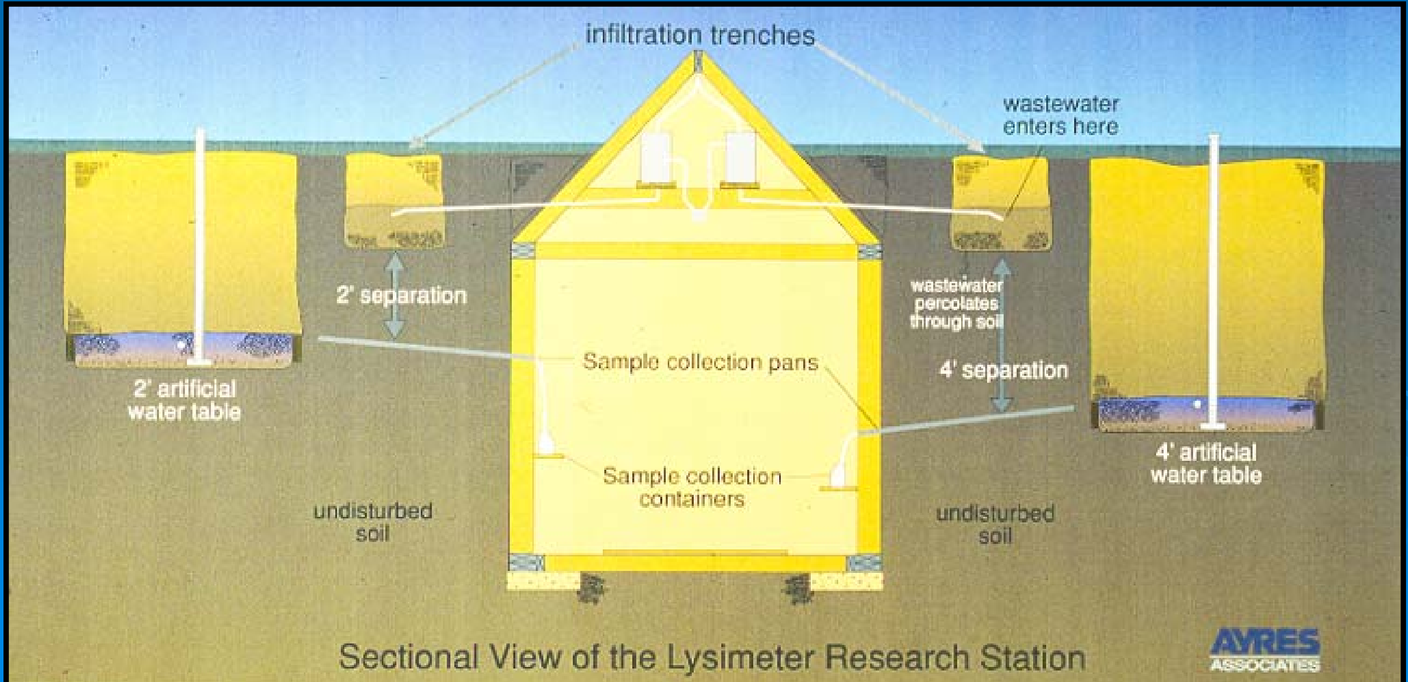
Soil Infiltration System Performance

Parameter	Applied concentration in milligrams per liter	Percent removal	References
BOD_5	130–150	90–98	Siegrist et al., 1986 U. Wisconsin,1978
Total nitrogen	45–55	10–40	Reneau 1977 Sikora et al., 1976
Total phosphorus	8–12	85–95	Sikora et al., 1976
Fecal coliforms	NA[a]	99–99.99	Gerba, 1975

[a] Fecal coliforms are typically measured in other units, e.g., colony-forming units per 100 milliliters.

Source: Adapted from USEPA, 1992.

USF *In-situ* Lysimeter Facility



Potential N Loading From OWTS

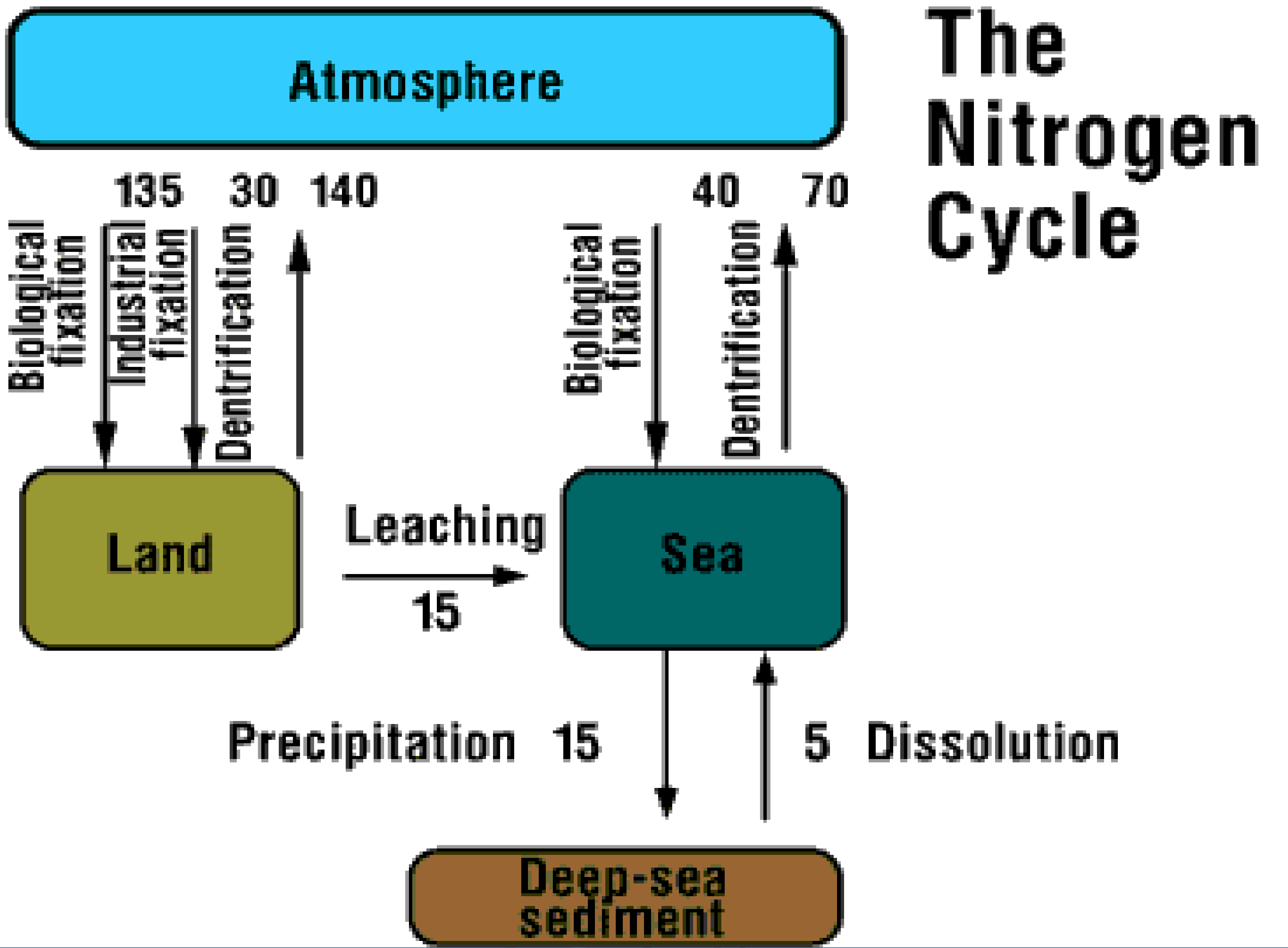
- 23.4 lbs N per home discharged to OWTS per year
- 21.1 lbs N from septic tank to SWIS (10% reduction)
- 15.8 lbs N from SWIS to GW (25% reduction)
- High-end estimate of OWTS N load to GW in WSA: 876,000 lbs/year
- Further reduced by natural denitrification in GW zone

Denitrification by Heterotrophic Bacteria

Simplified denitrification reaction is:

$$NO_3 \rightarrow NO_2 \rightarrow NO \rightarrow N_2O \rightarrow N_2$$

- **Process performed by heterotrophic, facultative bacteria**
- **Utilize nitrate instead of oxygen as electron acceptor**
- **Generally considered anoxic process, but recent research indicates aerobic denitrification does occur.**
- **Controlling factors in natural environment are DO, organic carbon, pH, temp., and nutrient availability**



The Nitrogen Cycle
Atmosphere
135
30
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70
Biological fixation
Industrial fixation
Dentrification
Biological fixation
Dentrification
Land
Leaching
15
Sea
Precipitation 15
5 Dissolution
Deep-sea sediment

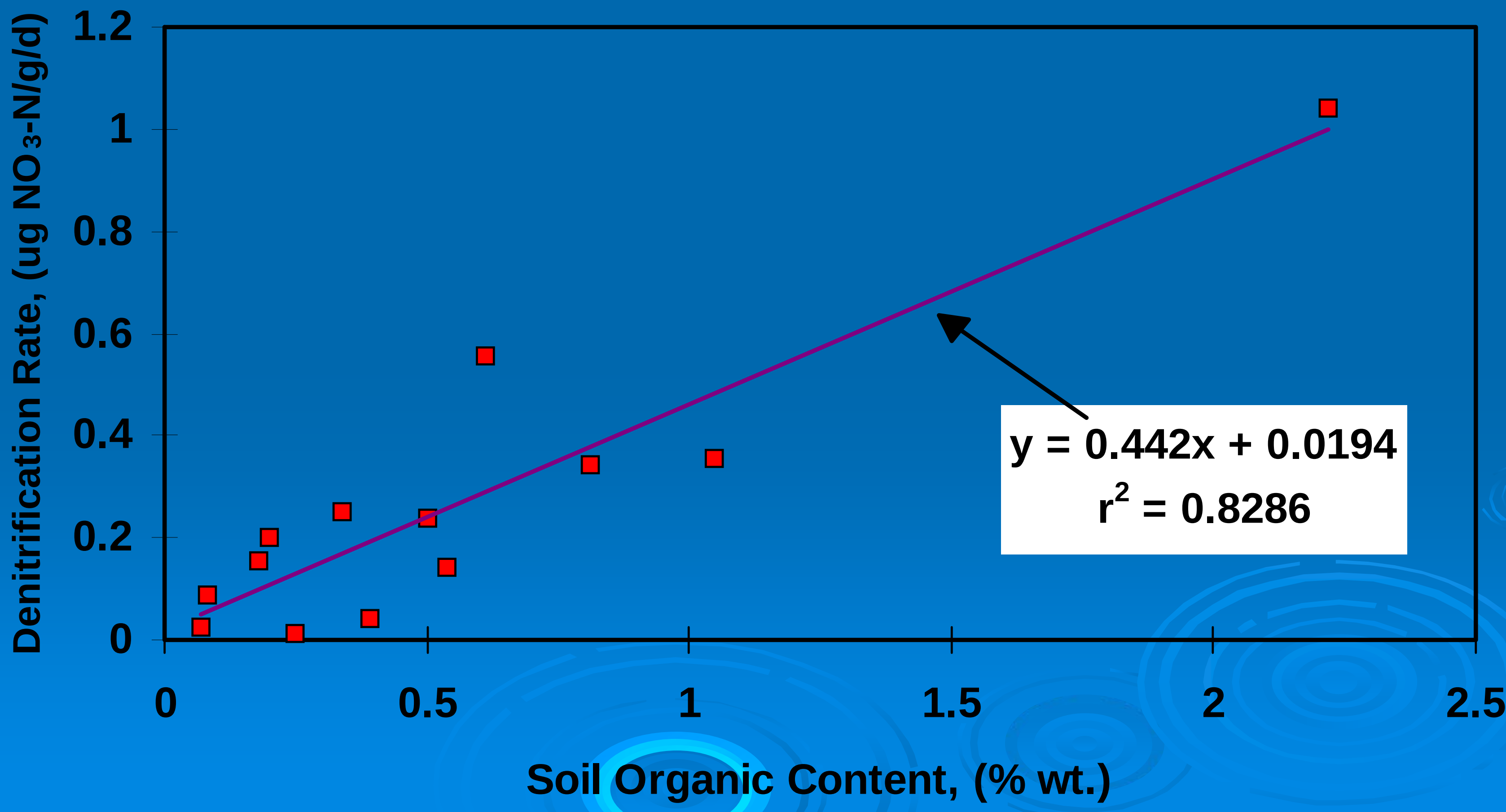
Previous Studies of Natural Denitrification in Surficial GW

Reference	Soil Organic Content (% wt.)	Dissolv. O_2 Conc. (mg/L)	NO_3-N Conc. (mg/L)	Denit. Rate (ug NO_3-N/g-d)
Slater & Capone (1987) (sandy glacial outwash)	0.5	<0.10	3.8	0.24
Smith & Duff (1988) (sand & gravel aquifer)	NR	0 - 5	0 - 25	0.009 - 0.24
Ward (1985) (soil cores near OWTS drainfield)	NR	NR	NR	52.4 - 64.5
Trudell et al. (1986) (shallow sand aquifer)	0.08 - 0.16	NR	8 - 15	0.086 - 1.32
Bengtsson & Annadotter (1989) (sandy aquifer matl.)	0.2	9.9 - 1.3	3.8	0.20
Bradley et al. (1992) (fine sand water table)	0.07 - 2.22	<0.4	2.8 - 120	0.013 - 1.04

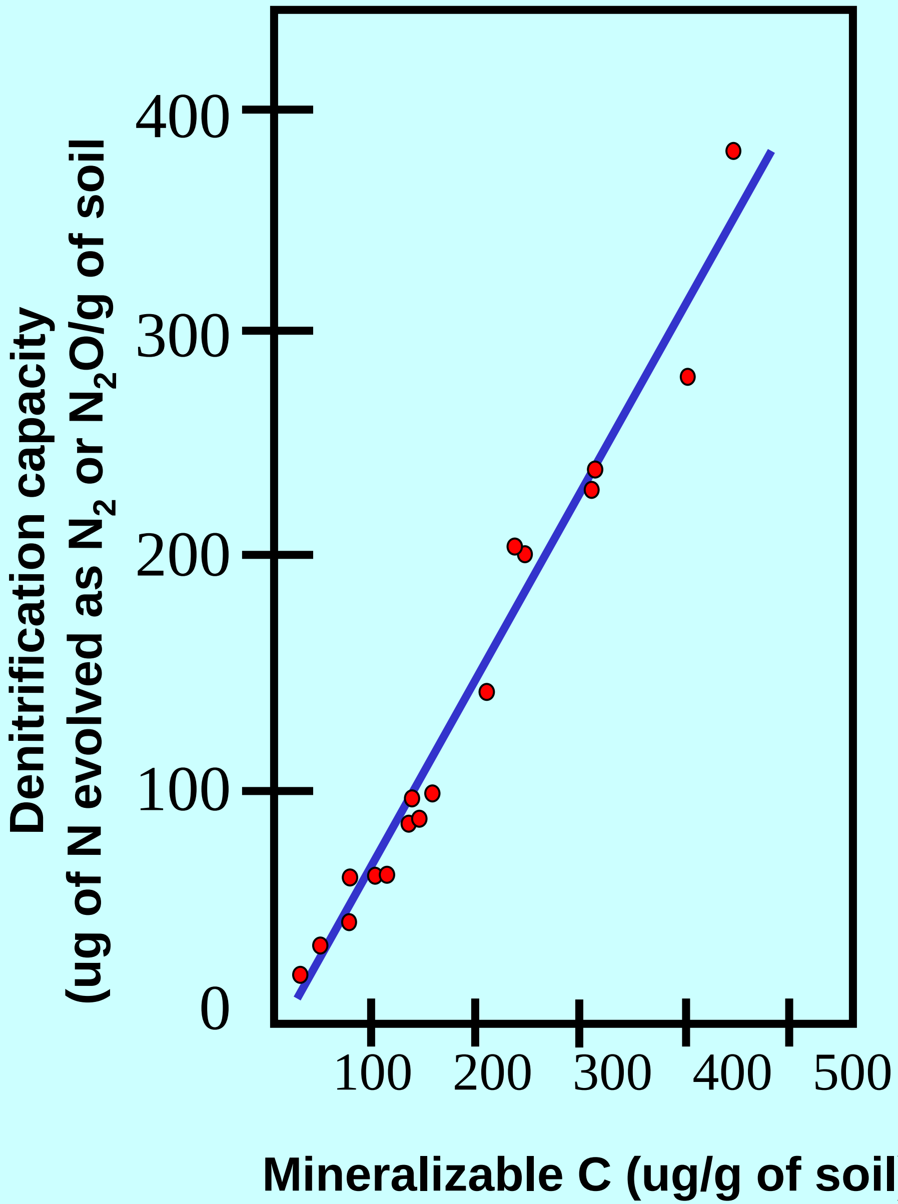
Conditions Necessary for Denitrification

- Oxidation of NH4-N to NO3-N (nitrification)
- Presence of a subsequent anoxic environment (NO3-N acts as alternative electron acceptor in low O2 environments)
- Sufficient residence time in the anoxic environment for denitrification to occur
- Adequate carbon source for denitrifying bacteria in the anoxic environment

Correlation of Denitrification Rate vs Soil Organic Content from Previous Studies



Relationship between denitrification capacity and mineralizable carbon (17 soils) (Burford & Bremner, 1975)



Y = 0.856x-23.1
r = 0.99

Florida OSDS Research Project: Early Modeling Results

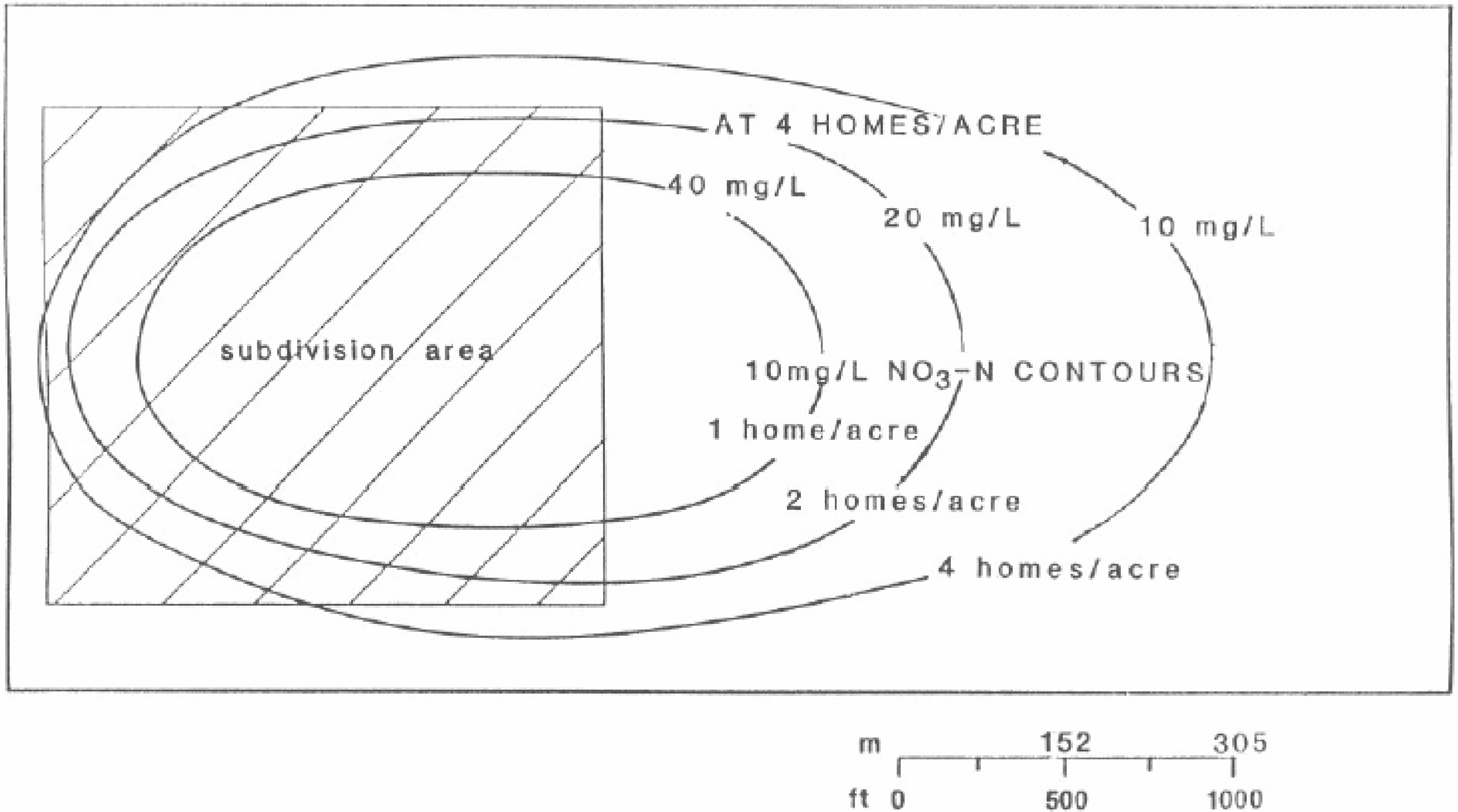
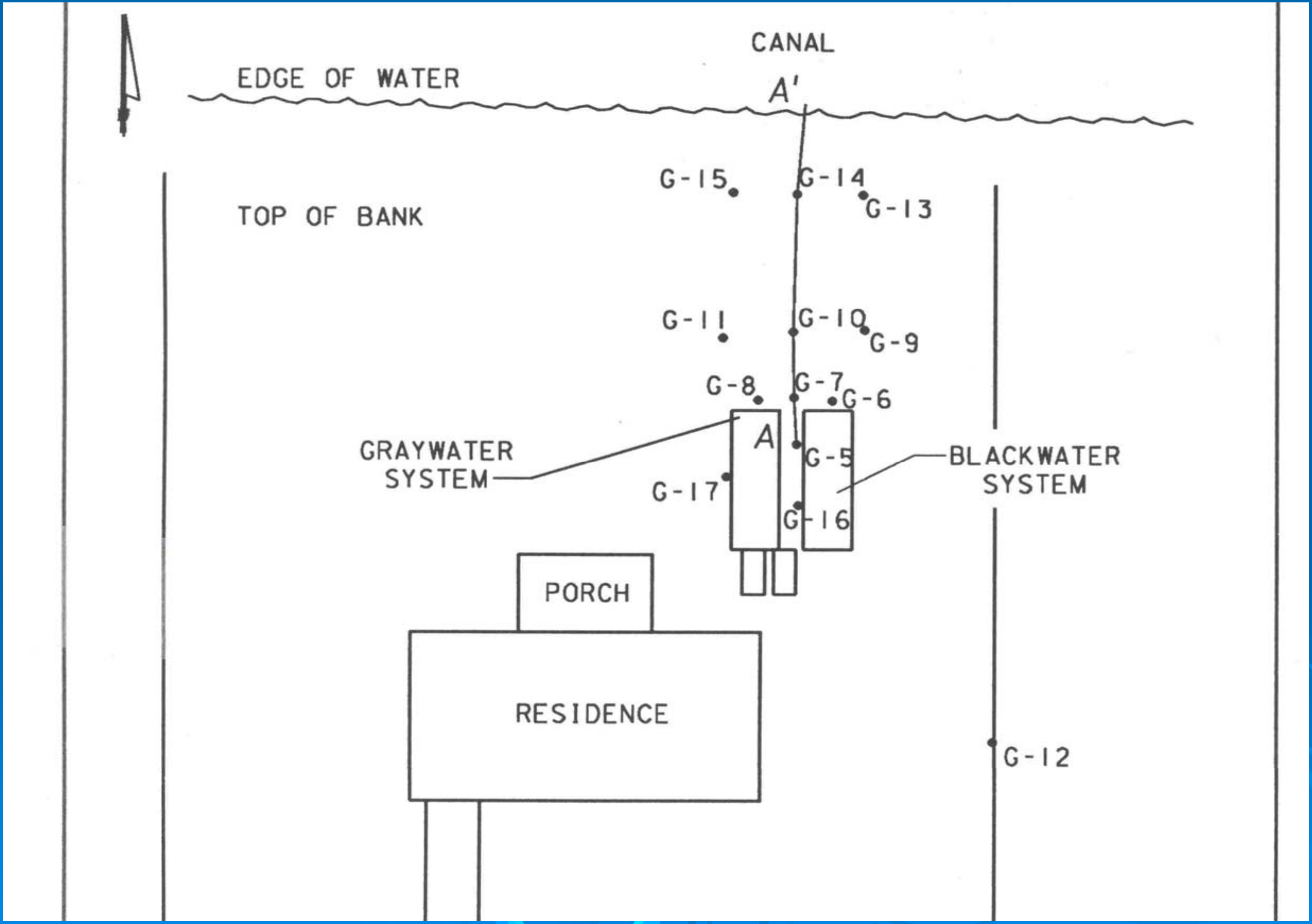


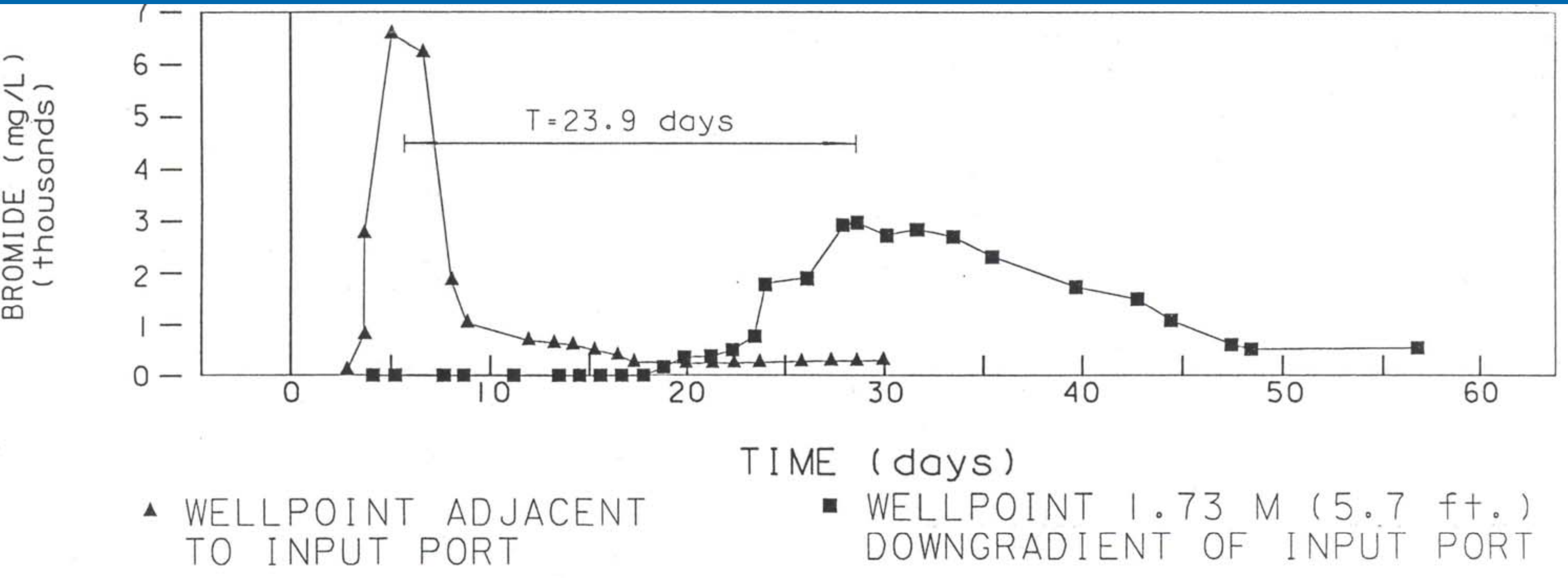
Fig. 5. NO_3-N Contours from Uncertainty Analysis at 5 Years. All Contours are Upper Limits of the 95% Confidence Interval for the Housing Density and No_3-N Concentrations Indicated.

Field Assessment of existing onsite wastewater treatment systems (OWTS)

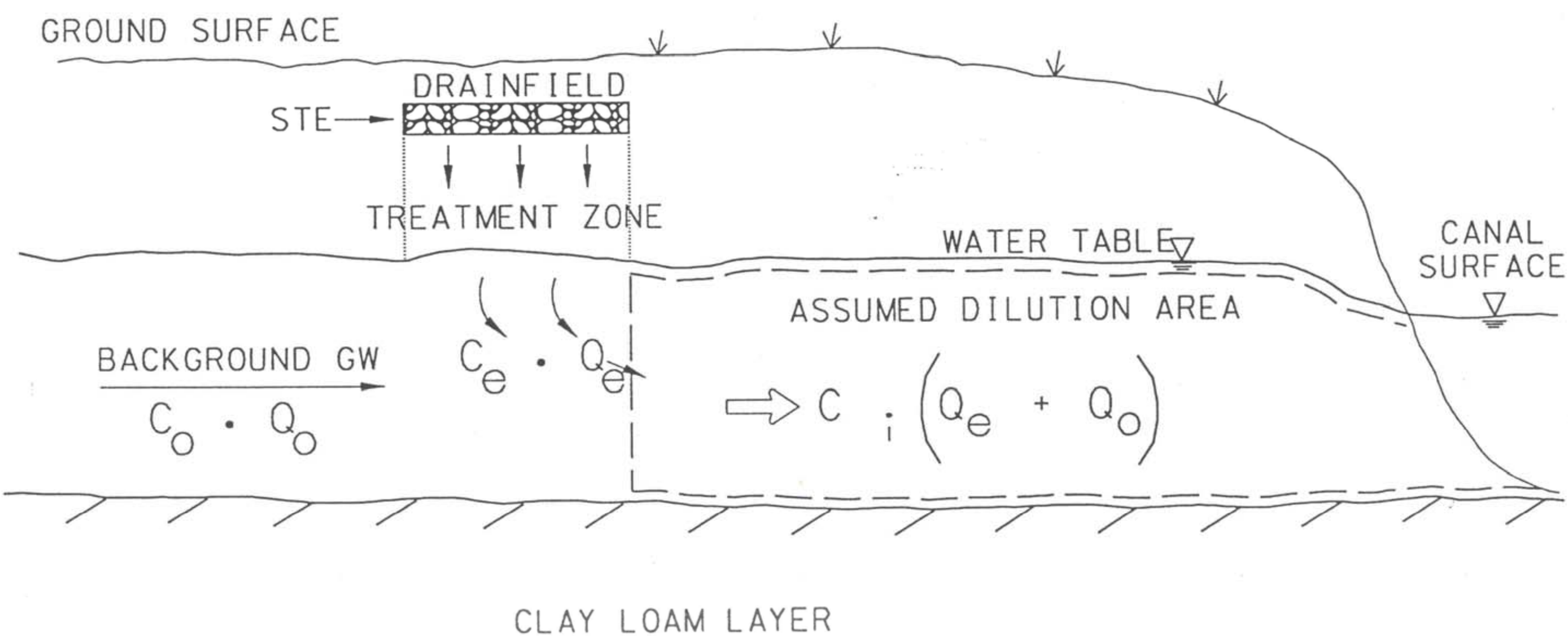
Indian River Lagoon OWTS Study

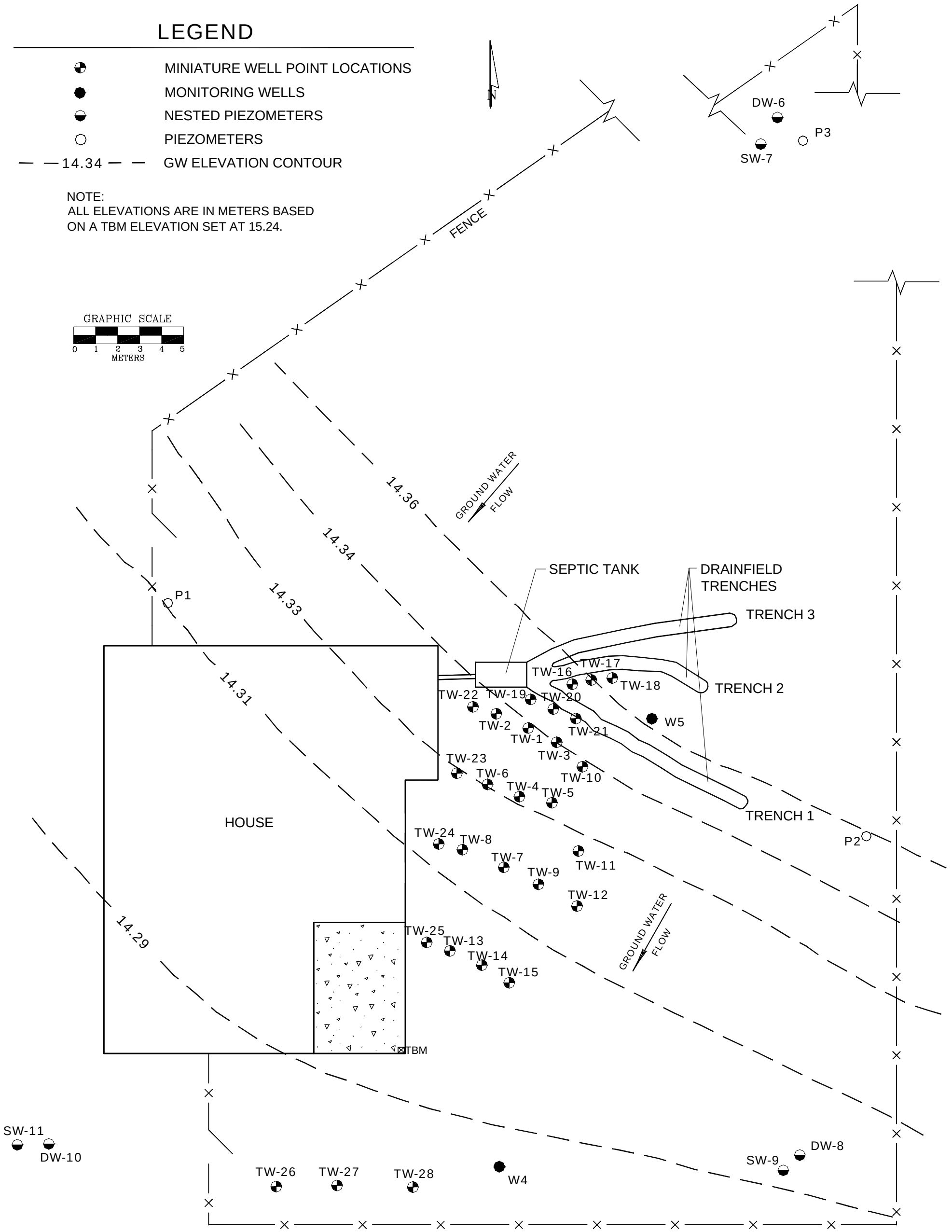


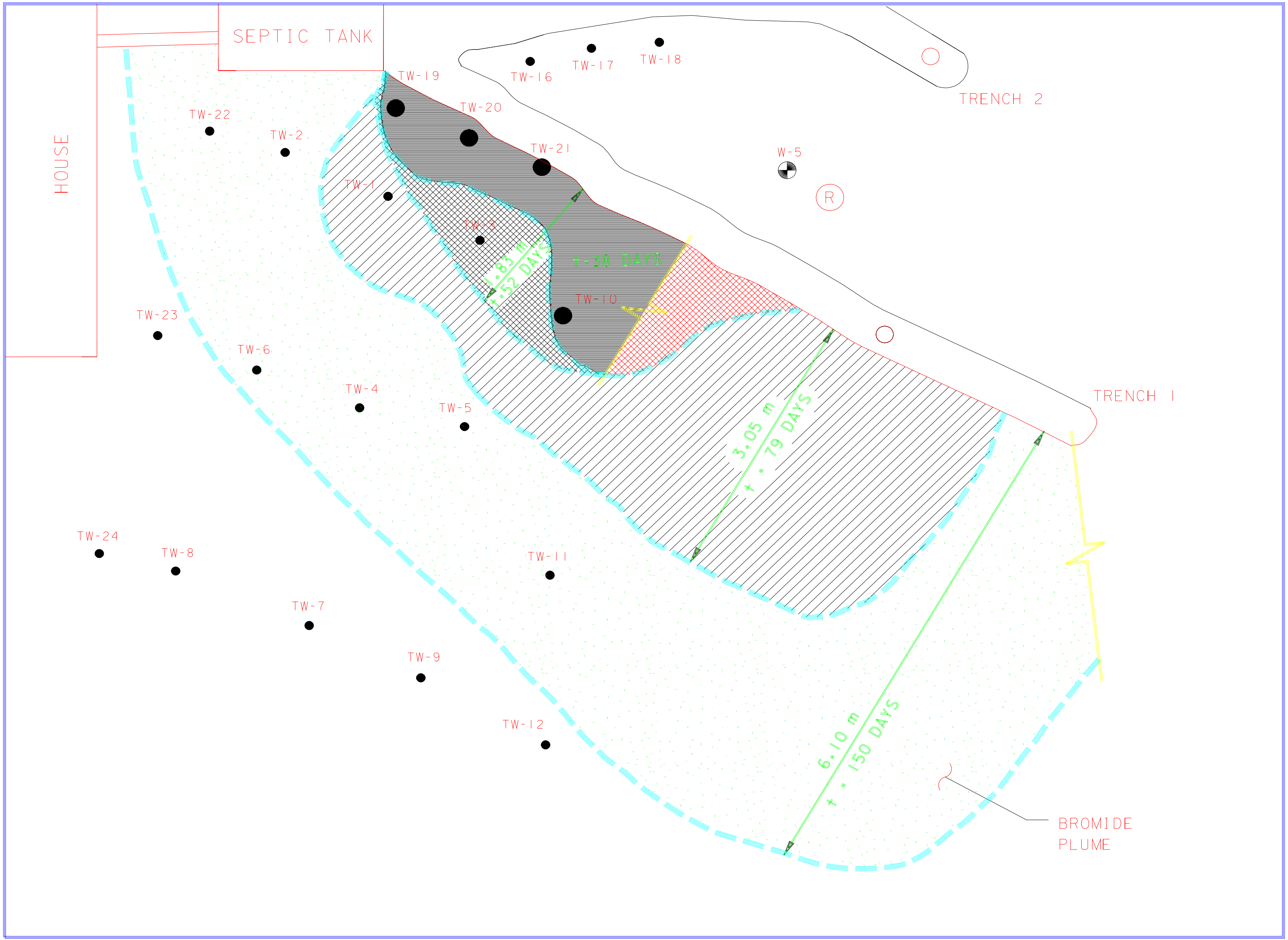
Tracer study to determine GW flow velocity, direction, dilution



Mass balance model to estimate N reduction in GW zone

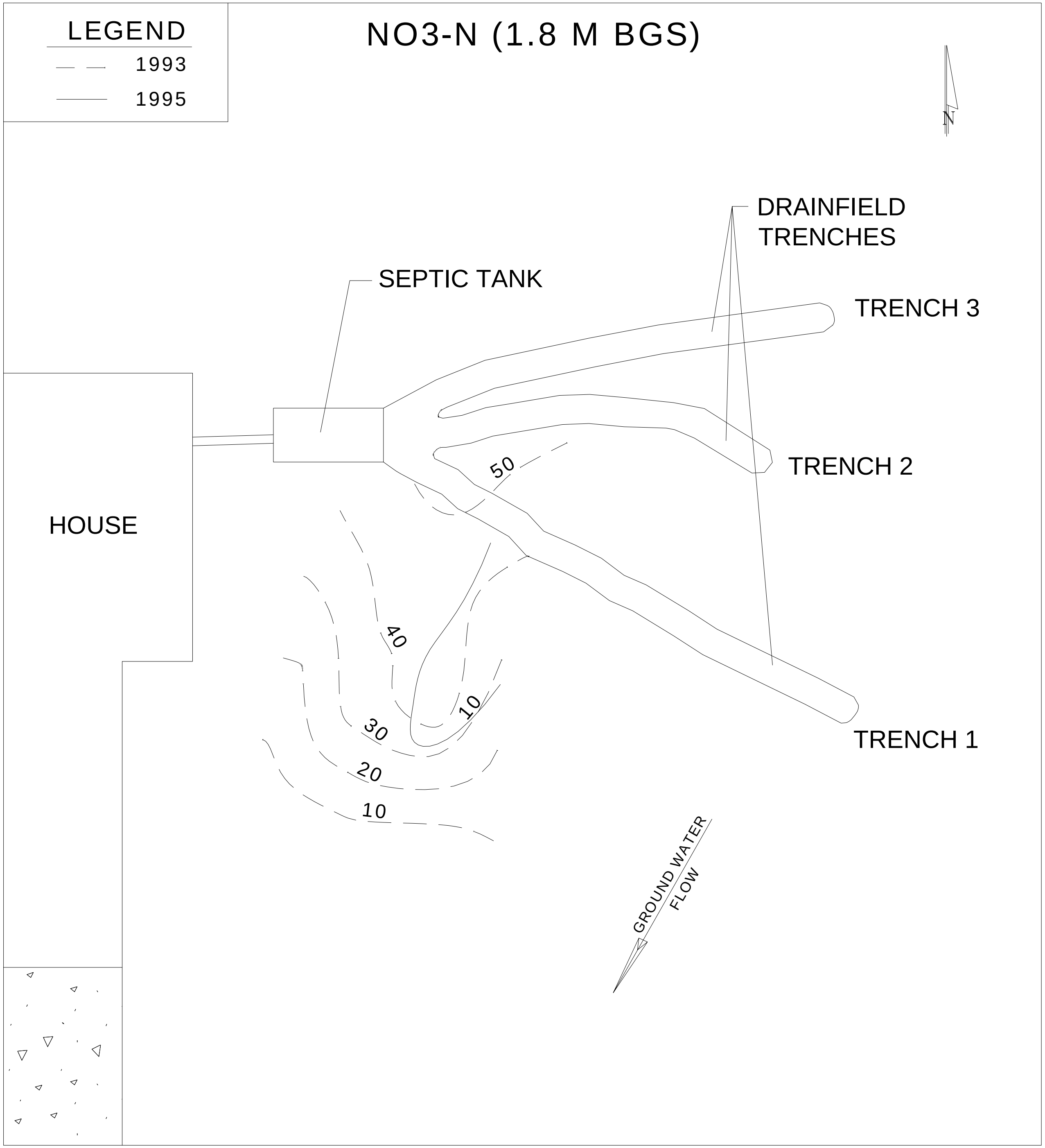



LEGEND
MINIATURE WELL POINT LOCATIONS
MONITORING WELLS
NESTED PIEZOMETERS
PIEZOMETERS
14.34
GW ELEVATION CONTOUR
NOTE:
ALL ELEVATIONS ARE IN METERS BASED
ON A TBM ELEVATION SET AT 15.24.
GRAPHIC SCALE
0 1 2 3 4 5
METERS
FENCE
DW-6
P3
SW-7
GROUND WATER FLOW
14.36
14.34
14.33
14.31
14.29
P1
SEPTIC TANK
DRAINFIELD TRENCHES
TRENCH 3
TRENCH 2
TRENCH 1
TW-16
TW-17
TW-18
TW-22
TW-19
TW-20
W5
TW-2
TW-1
TW-21
TW-3
TW-23
TW-6
TW-4
TW-10
TW-5
HOUSE
P2
TW-24
TW-8
TW-7
TW-11
TW-9
TW-12
GROUND WATER FLOW
TW-25
TW-13
TW-14
TW-15
TBM
SW-11
DW-10
TW-26
TW-27
TW-28
W4
SW-9
DW-8



SEPTIC TANK
HOUSE
TW-19
TW-16
TW-17
TW-18
TRENCH 2
TW-20
TW-21
W-5
R
TW-22
TW-2
TW-1
TW-3
1.83 m
t=52 DAYS
t=30 DAYS
TW-10
TW-23
TW-6
TW-4
TW-5
TRENCH 1
3.05 m
t = 79 DAYS
TW-24
TW-8
TW-11
TW-7
TW-9
TW-12
6.10 m
t = 150 DAYS
BROMIDE
PLUME

NO3-N (1.8 M BGS)



LEGEND
1993
1995
N
DRAINFIELD TRENCHES
SEPTIC TANK
TRENCH 3
TRENCH 2
TRENCH 1
HOUSE
50
40
30
20
10
10
GROUND WATER FLOW

Proposed FDOH Rules

7) Except in areas scheduled, by an adopted local wastewater facility plan, to be served by a central sewage facility by January 1, 2011, the following standards shall apply to all systems in the Wekiva Study Area as defined in 369.316, F.S., requiring permitting. In the primary and secondary protection zones, or where severely limited material below the "O" horizon is removed in the tertiary protection zone systems shall:

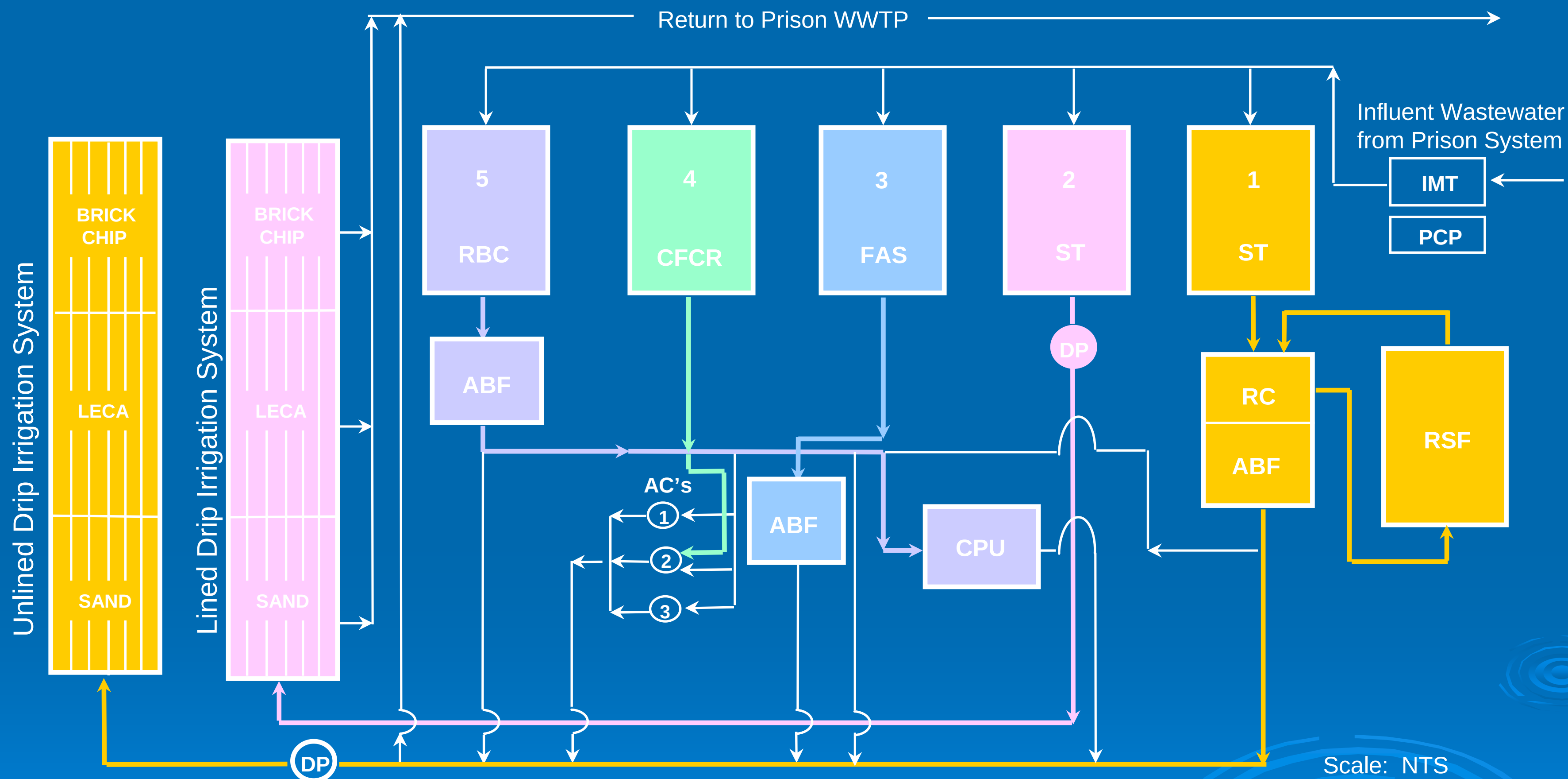
(a) utilize a performance-based treatment system with a total nitrogen discharge limit of 3.0 milligrams per liter at 24 inches below the bottom of the drainfield, or

(b) utilize a performance-based treatment system with a total nitrogen discharge limit of 10.0 milligrams per liter at the outlet of the tank and a drip irrigation drainfield installed no more than 9 inches below finished grade.

Florida Keys Onsite Wastewater Nutrient Reduction System (OWNRS) Demonstration Project

FLORIDA KEYS ONSITE WASTEWATER NUTRIENT REDUCTION SYSTEM (OWNRS) DEMONSTRATION PROJECT

CENTRAL TEST FACILITY SCHEMATIC



AYRES ASSOCIATES

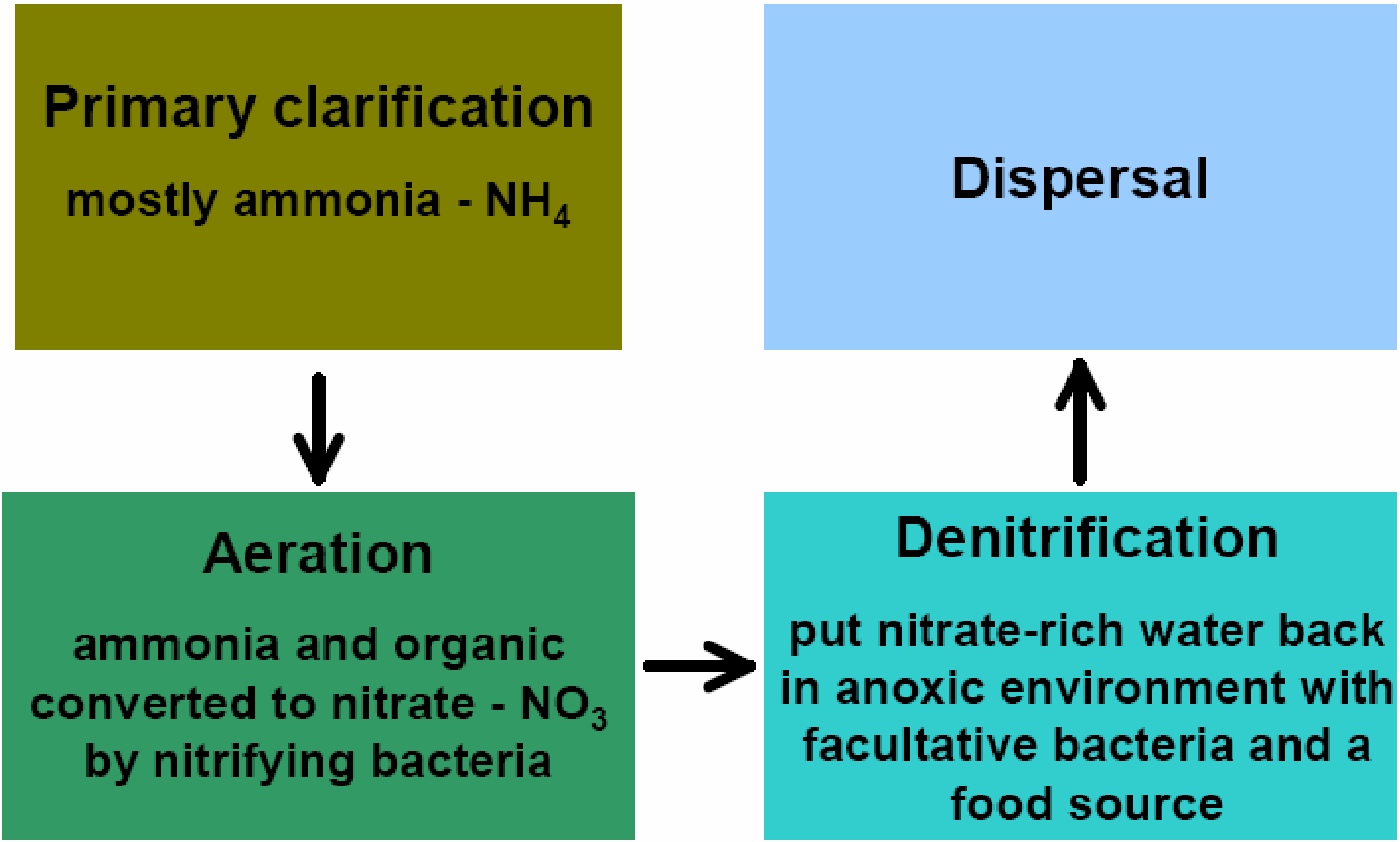
LEGEND

ABF - Anoxic bio-filter
AC - Adsorption Cell
AC-1 - Brick Chips
AC-2 - Aluminum Silicate
AC-3 - LECA

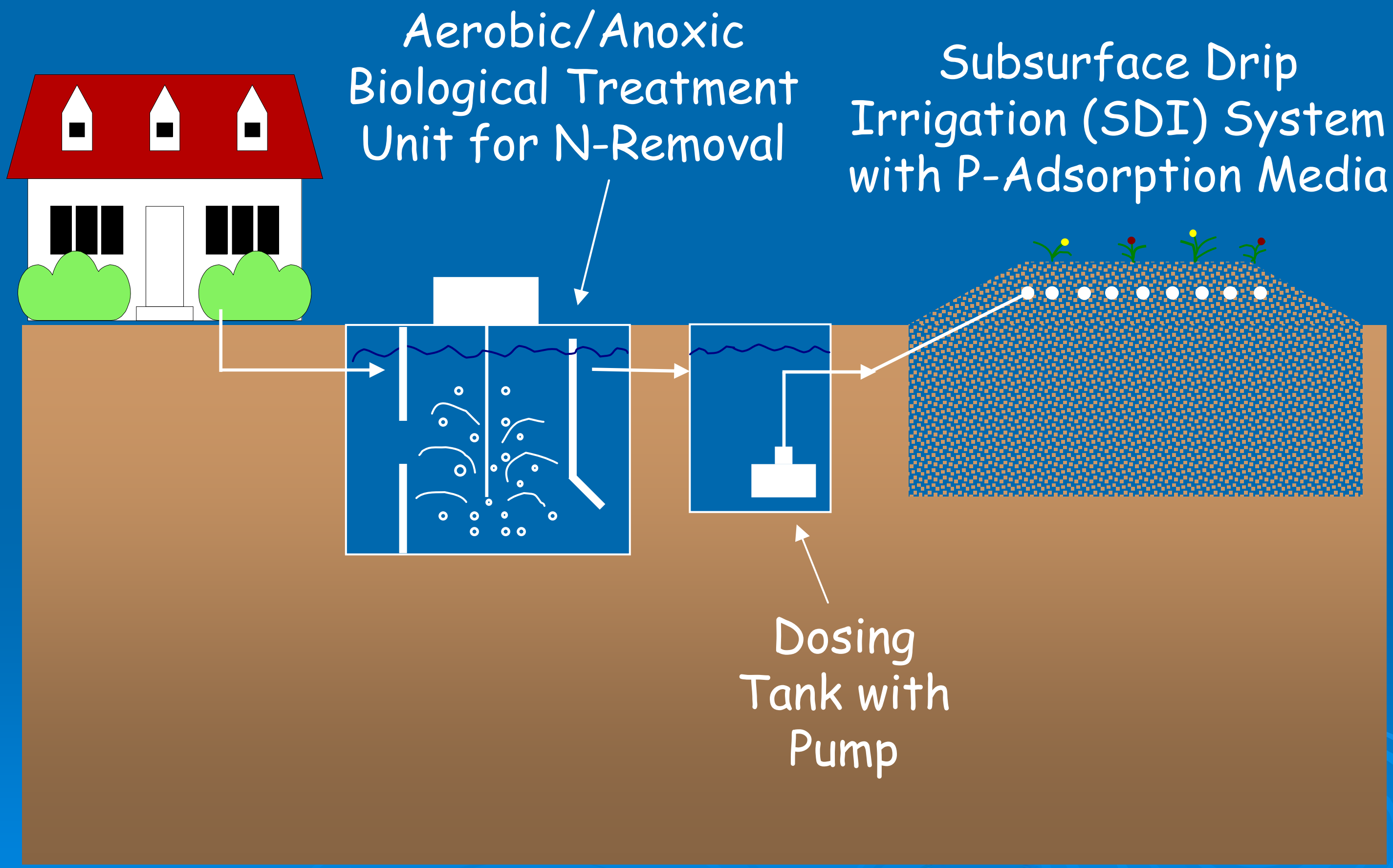
CFCR - Continuous Feed Cyclic Reactor
CPU - Chemical Precipitation Unit
DP - Drip Irrigation Pump System
FAS - Fixed-Film Activated Sludge
IMT - Influent Mix Tank

PCP - Process Control Panels
RBC - Rotating Biological Contactor
RC - Recirculation Chamber
RSF - Recirculating Sand Filter
ST - Septic Tank

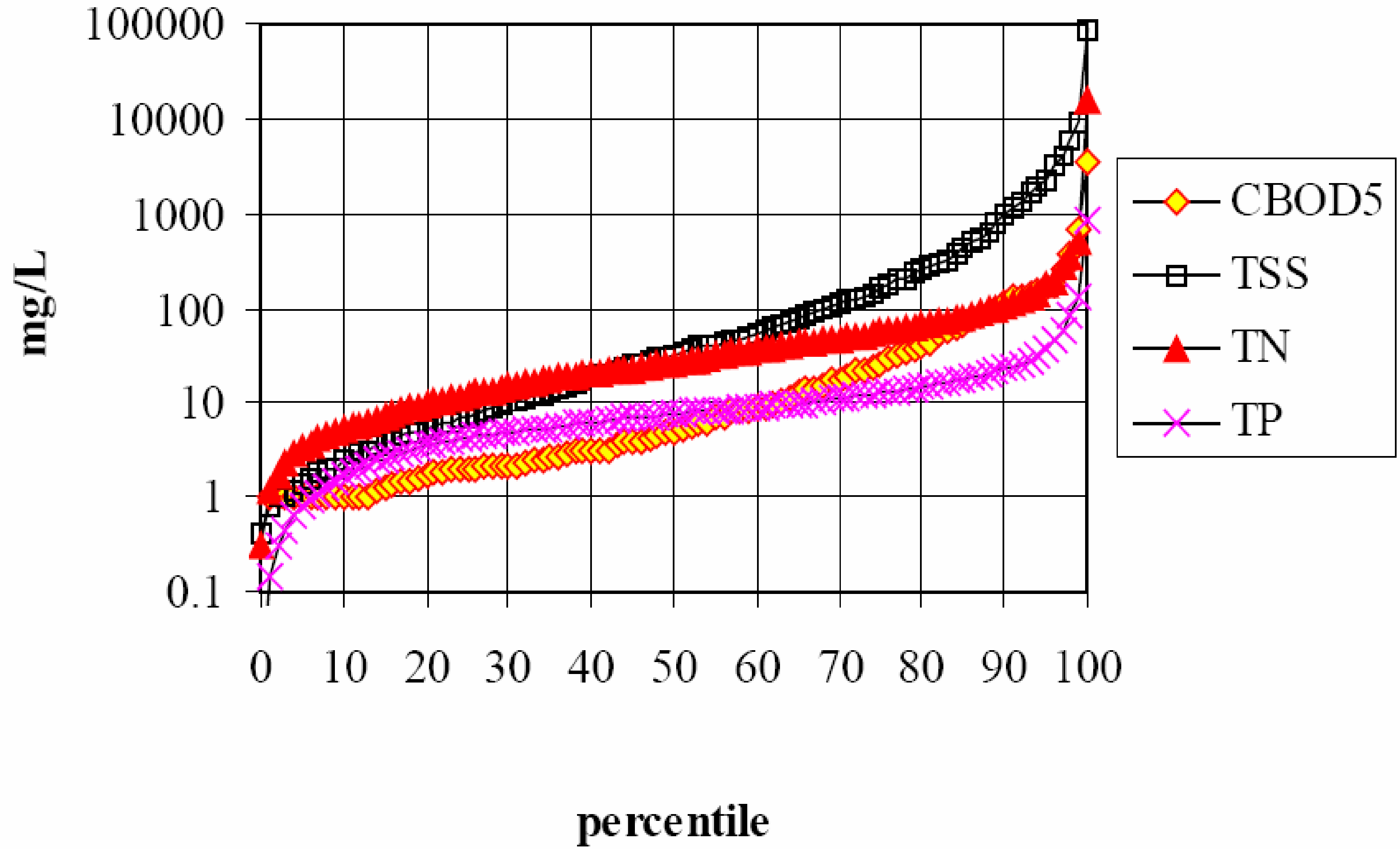
Nitrogen Removal Simplified



Schematic of Typical Onsite Wastewater Nutrient Reduction System (OWNRS) for the Florida Keys



Overall Results, Florida Keys ATUs
(Roeder, 2005)



Exceedance of Design Goals

30 mg/L $CBOD_5$ & TSS (Roeder, 2005)

Study of design goal exceedance (n=number of samples of m=number of systems)	$CBOD_5$ (mg/L)	TSS (mg/L)
This study (n=942 of m=832 ATUs and engineer-designed systems) FL	23 %	50%
Maxfield, Daniell, Treser, & VanDerslice (2003) (n=781 of m=184 ATUs) WA	27%	25%
Kellam, Boardman, Hagedorn, & Reneau (1993) (n=15 of m=5 ATUs) VA	81%	62%
Sexstone et al. (2000) (n=85 of m=85 ATUs) WV	69%	48%

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Various Systems over Time

(Roeder, 2005

System class	Parameter	$CBOD_5$ (mg/L)	TSS (mg/L)	TN (mg/L)	TP (mg/L)
Pre 7/91 ATU "H" (n=137 for CBOD5, n=136 for others)	**Median**	**2.4**	**11.0**	**19.0**	**5.9**
	Mean	11.4	129	38.4	14.0
	Std. Dev.	24.9	377	110	67.5
Post 7/91 ATU "A" (n=764)	**Median**	**6.0**	**38.2**	**28.0**	**8.1**
	Mean	54.8	645	74.3	15.7
	Std. Dev.	214	3609	549	49.2
Engineer-designed "E" (n=32)	**Median**	**6.4**	**44.2**	**17.6**	**4.3**
	Mean	12.3	77.9	28.2	5.9
	Std. Dev.	15.7	91.9	27.6	7.0
Performance-based "P" (n=8)	**Median**	**3.5**	**11.2**	**35.0**	**5.5**
	Mean	7.1	115	38.7	5.6
	Std. Dev.	7.9	239	26.4	1.9

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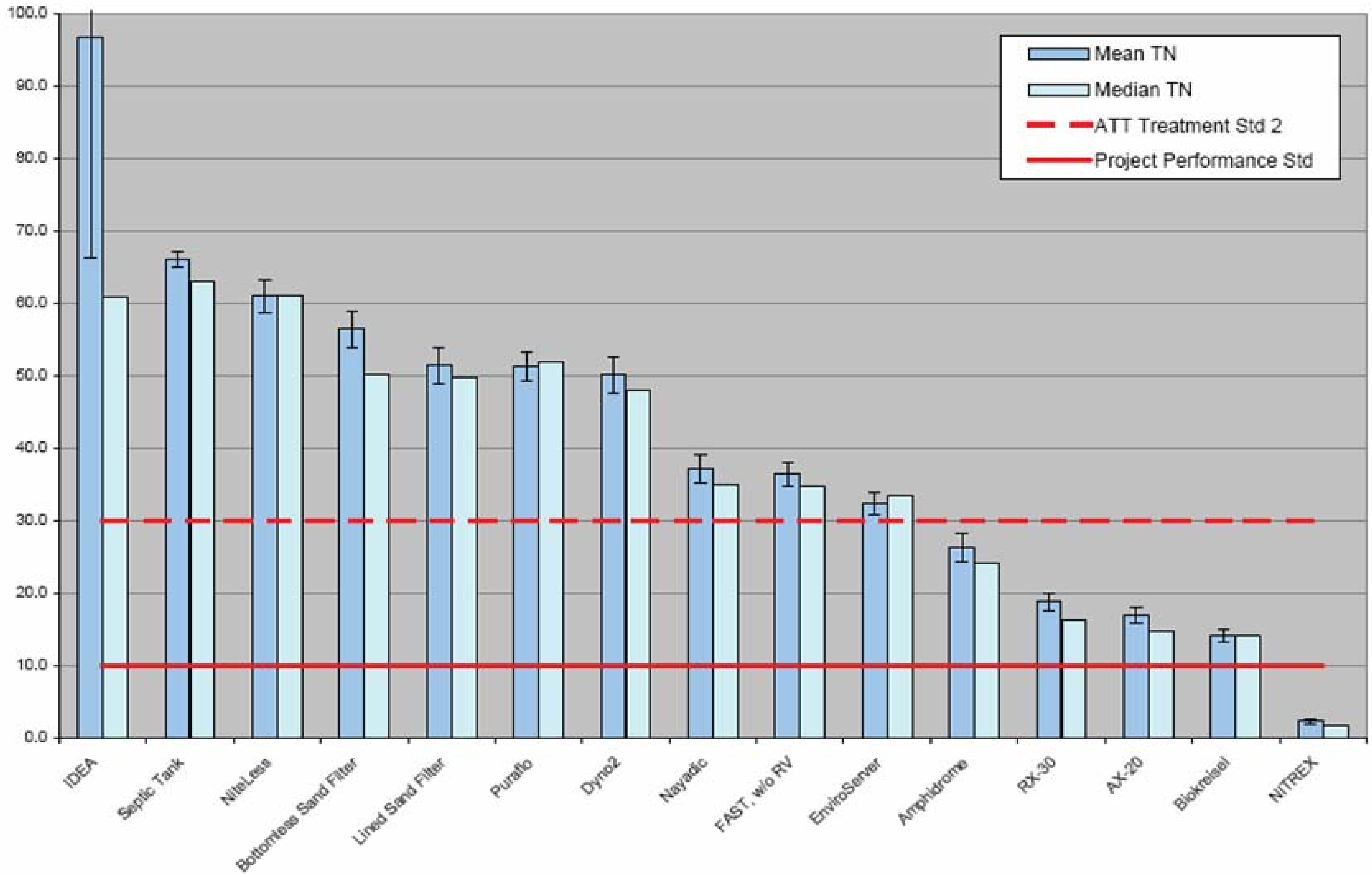
Performance of N-Reduction Systems
(La Pine National Demonstration Project)



Cost of OWNRS

- Capital Cost approximately $12,000 for average home, but will be more for many, less for some
- Operation and Maintenance cost estimated at approximately $1100 per year including all costs over life of system (repairs, replacement, residuals, power,…)

Cost of OWNRS (cont.)

- Annual life-cycle cost approximately $2232; or $186 per month
- This cost compares closely to results of other studies such as Monroe County SWMP and Sarasota County PCSSRP

Cost Analysis - OWTS Alternatives

	System Alternatives	Capital Cost	Annual O&M Cost	Uniform Annual Cost
I	Septic Tank with Mound			
	At-grade	$5,053	$164	$641
	12" Fill	$5,934	$164	$724
	24" Fill	$7,072	$164	$831
II	Septic Tank with SDI			
	In existing grade	$6,690	$425	$1,057
	At-grade	$7,340	$425	$1,118
	12" Fill	$7,859	$425	$1,167
	24" Fill	$8,576	$425	$1,235
III	Secondary Biological Treatment (with SDI, 24" Fill)	$8,578	$1,033	$1,843
IV	Advanced Secondary Biological Treatment (with SDI, 24" Fill)	$10,280	$1,083	$2,054

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Cost Analysis - Collection Alternatives

	Alternatives	Capital Cost	Annual O&M Cost	Uniform Annual Cost
LOW DENSITY				
	Low Pressure	$10,389	$188	$1,324
	Vacuum	$12,652	$138	$1,487
	Gravity	$18,241	$89	$1,966
MEDIUM DENSITY				
	Low Pressure	$8,102	$185	$1,105
	Vacuum	$7,096	$74	$898
	Gravity	$9,032	$51	$1,059
HIGH DENSITY				
	Low Pressure	$8,045	$185	$1,099
	Vacuum	$6,093	$62	$792
	Gravity	$7,740	$46	$932

Comparison of OWTS and Collection Technologies

(Uniform Annual Cost, 1999 $)

•ALTERNATIVE	ESTIMATED TREATMENT & TRANS COST ($/CONNECTION)	LOW DENSITY >0.5 acre lots	MEDIUM DENSITY 0.25-0.5 acre lots	HIGH DENSITY <0.25 acre lots
•Low Pressure GP	•$105	•$1,270	•$1,090	•$1,080
•Vacuum	•$105	•$1,390	•$900	•$810
•Gravity	•$105	•$1,760	•$1,020	•$920
•OWTS				
0’ WT	•N/A	•$840	•$1,240	•$2,060
1’ WT	•N/A	•$730	•$1,170	•$2,010
2’ WT	•N/A	•$650	•$1,120	•$1,980
>3’ WT	•N/A	•$630	•$1,060	•$1,930

Other N Sources

- Stormwater, non-point source contributions
- Fertilizer, Ag and Residential
- Atmospheric Deposition
- Agriculture: Livestock, feedlots, manure
- WWTPs and their discharges
- Drainage Wells
- Wastewater residuals (sludge & septage)

Annual Fertilizer Nitrogen Consumption in Lake, Orange, and Seminole Counties, 2004-2005

County	Land Area (acres)	Total Fertilizer (tons/yr)	N Content (tons/yr)	Ave. N Applied (gross lbs N/acre/yr)
Lake	609,984	26,796	3,196	10.5
Orange	580,864	74,769	7,498	25.8
Seminole	197,248	33,887	2,506	25.4
TOTALS	1,388,096	135,452	13,200	19.0

26,400,000 lbs N per year

Estimated Fertilizer N in WSA

- 300,000 acres x 25 lbs/acre/year =

  7,500,000 lbs N per year

- Non-Farm use was ~ 63%
- Overall Fertilizer use increased from 1992-93 to 2004-05

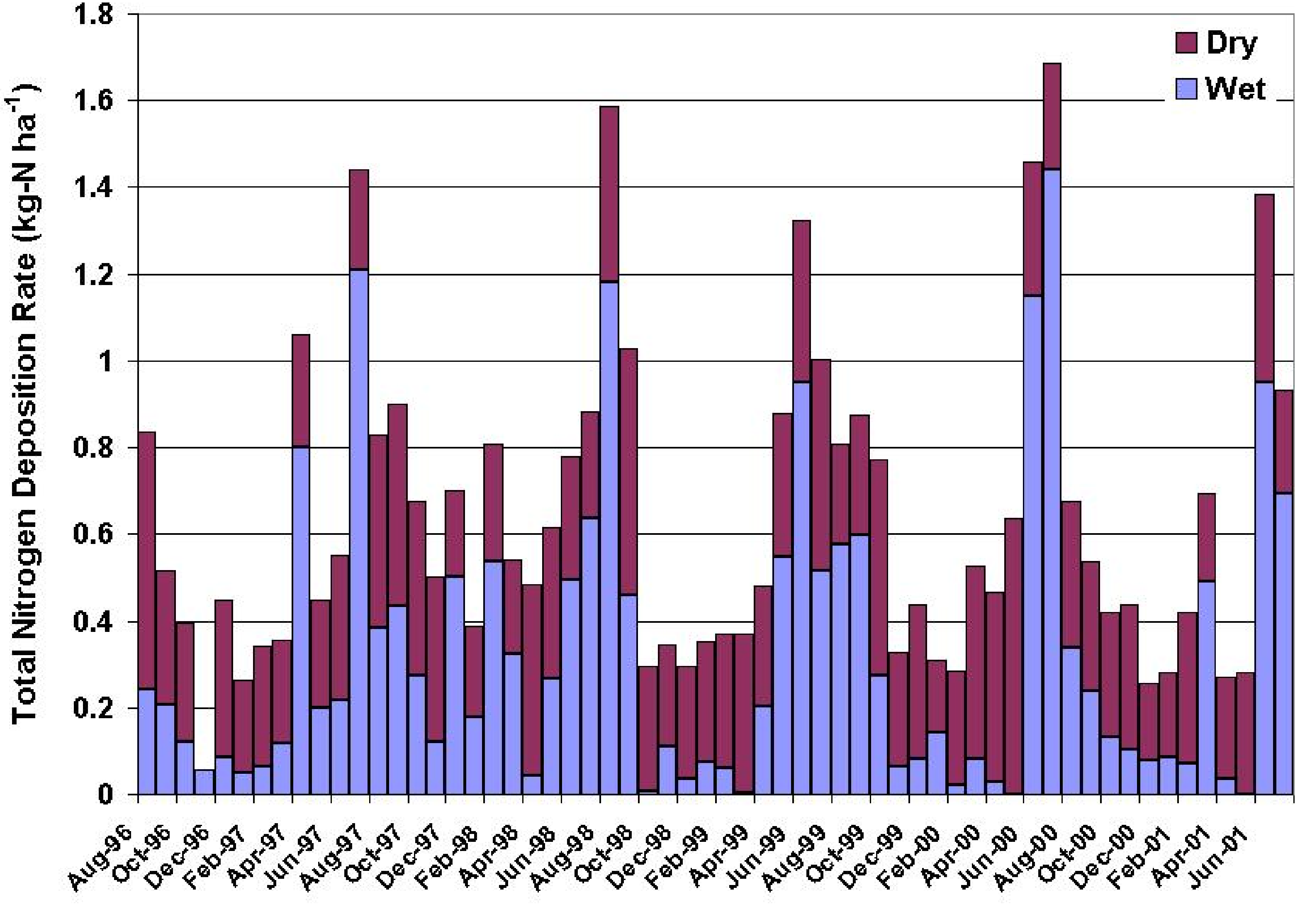
Atmospheric Deposition

- Literature values, urban areas:
  - 6.9 to 16.6 lbs/acre/year
- For WSA, this equates to:
  - 2,100,000 to 5,000,000 lbs N per year

Atmospheric nitrogen deposition rates to Tampa Bay for inorganic ammonia plus nitric acid/nitrate.

Year (August-July)	Dry kg-N/ha	Wet kg-N/ha	Total kg-N/ha	Dry:Wet
1996-1997	3.6	3.4	7.0	1.1
1997-1998	4.1	4.2	8.3	1.0
1998-1999	4.1	4.2	8.2	1.0
1999-2000	4.1	4.5	8.5	0.9
2000-2001	3.4	3.2	6.6	1.1
Average	3.9	3.9	7.7	1.0

Monthly total deposition of nitrogen to Tampa Bay, August 1996-July 2001.

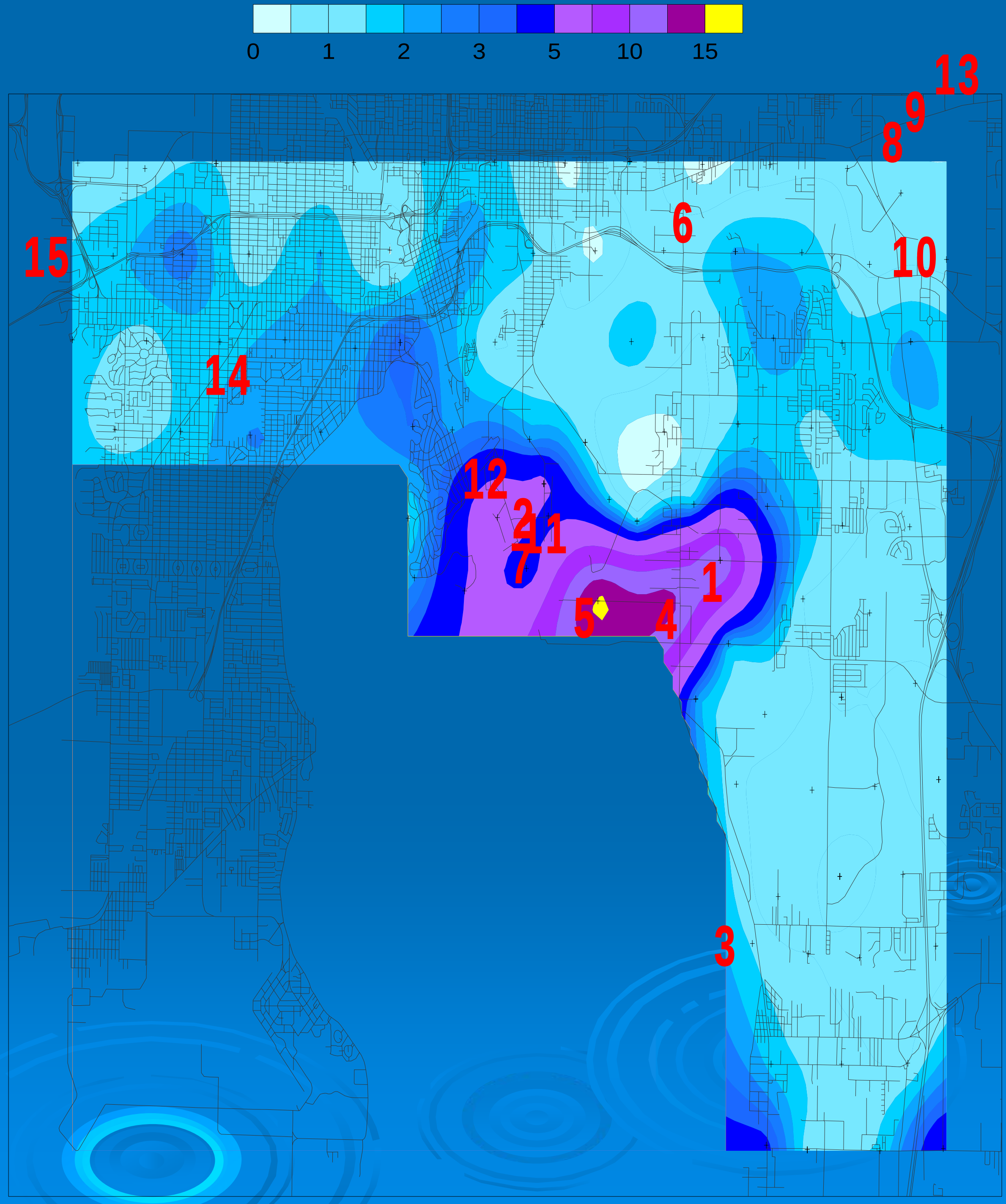


Ammonia Emission Sources Near Tampa Bay

Map Number	Name	Emissions 1000 kg yr^{-1}
1	Nitram	160
2	Howard F. Curren Waste Water Treatment Plant	150
3	Cargill Fertilizer-Riverview Operations	50
4	IMC AGRICO – Port Sutton Terminal	17
5	Farmland Hydro L P – Ammonia Terminal	17
6	AMERICOLD - Tampa	14
7	CF Industries – Ammonia Terminal	13
8	Reddy Ice - Tampa	3.9
9	Coca Cola Bottling - Tampa	3.5
10	Trademark Nitrogen	2.0
11	Harborside Refrigerator Services	1.9
12	AMERICOLD - Port	0.91
13	UNIROYAL Optoelectronics	0.68
14	Rapid Blueprint	0.43

Two-week averaged ammonia concentration gradient across urban Tampa, October 2001

(ug/m_3)

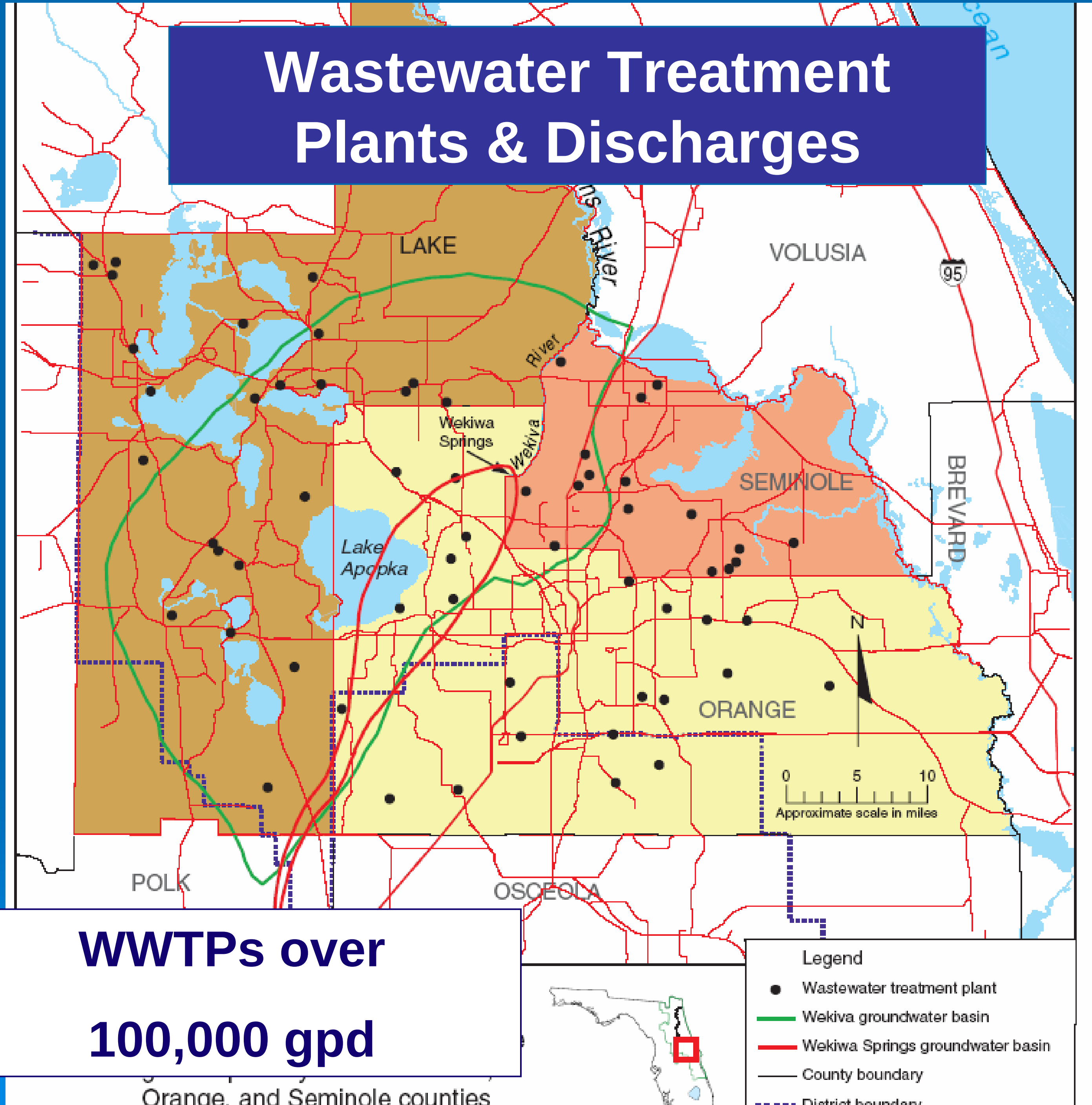


Up to 180 ug/m3 ave. measured adjacent to HFCAWTP, equates to approx. 2200 lbs/day emission

Atmospheric Deposition

- Literature values, urban areas:
  - 6.9 to 16.6 lbs/acre/year
- For WSA, this equates to:
  - 2,100,000 to 5,000,000 lbs N per year

Wastewater Treatment Plants & Discharges

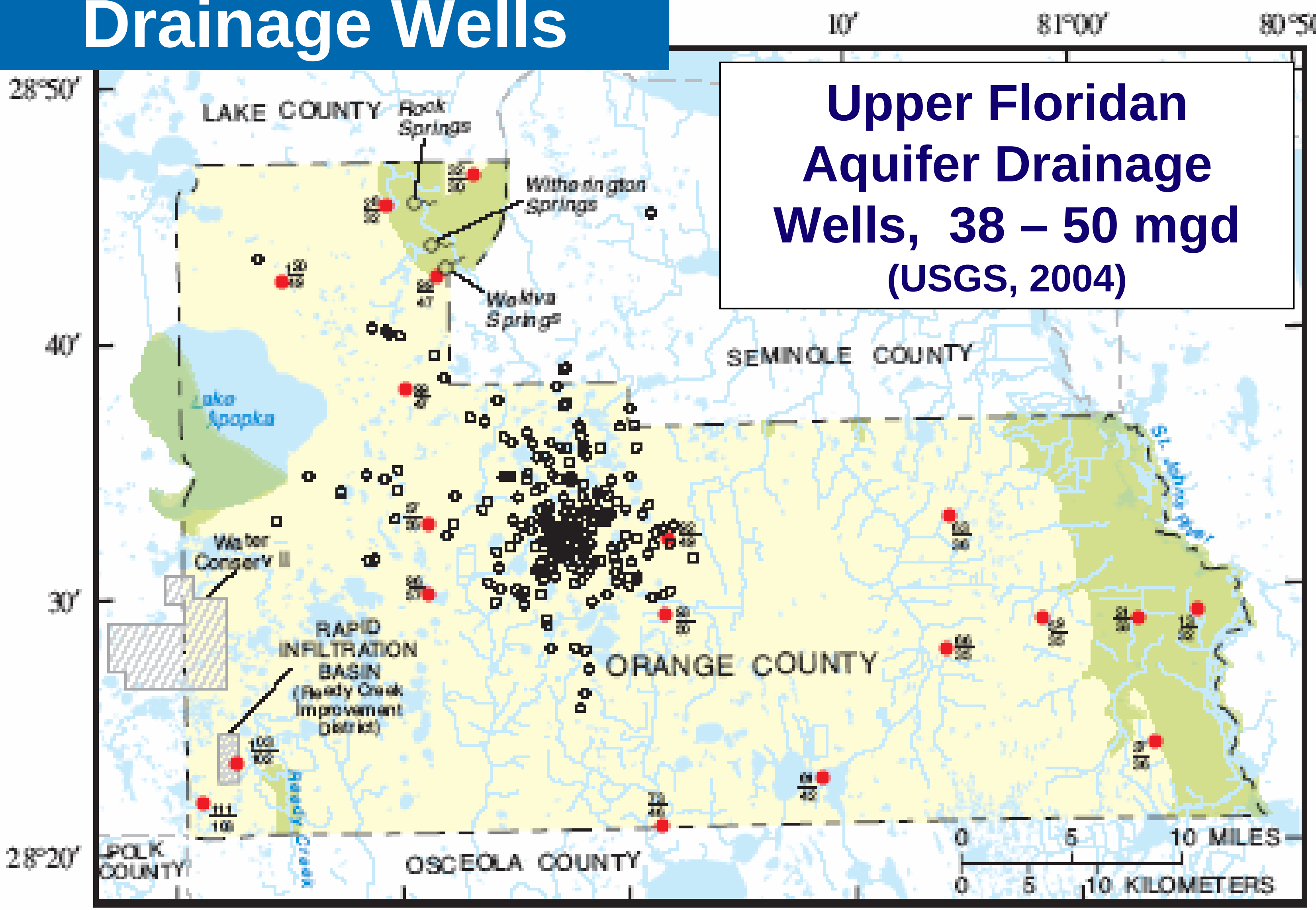


WWTPs over

100,000 gpd

Drainage Wells

Upper Floridan Aquifer Drainage Wells, 38 – 50 mgd
(USGS, 2004)



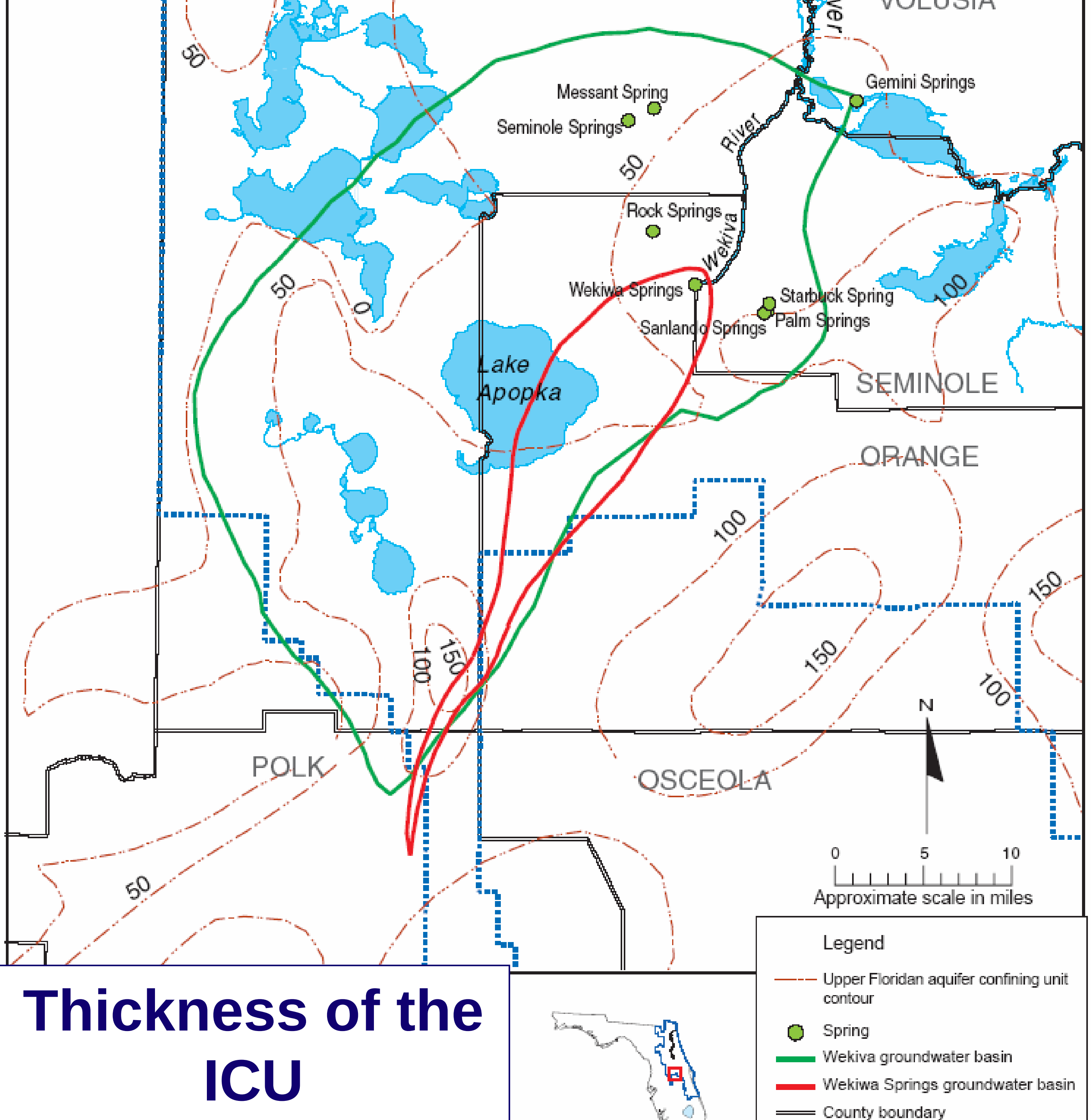
Base modified from U.S. Geological Survey digital data; 1:100,000, 1985
Albers Equal-Area Conic projection
Standard parallels 29°30′ and 45°30′, central meridian -83°00′

EXPLANATION

RECHARGE AREA

POTENTIAL DISCHARGE AREA

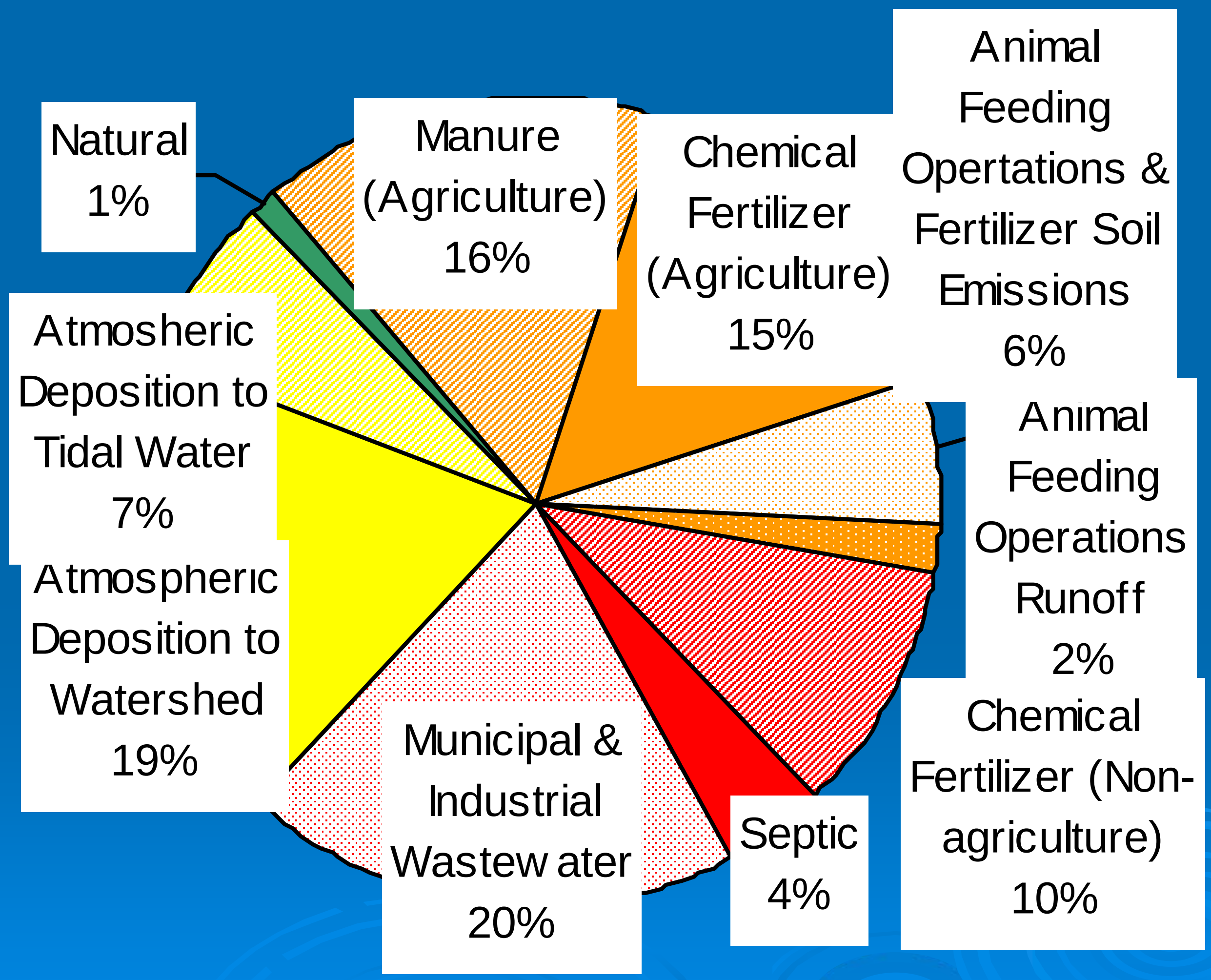
UPPER FLORIDAN AQUIFER DRAINAGE WELL



Thickness of the ICU

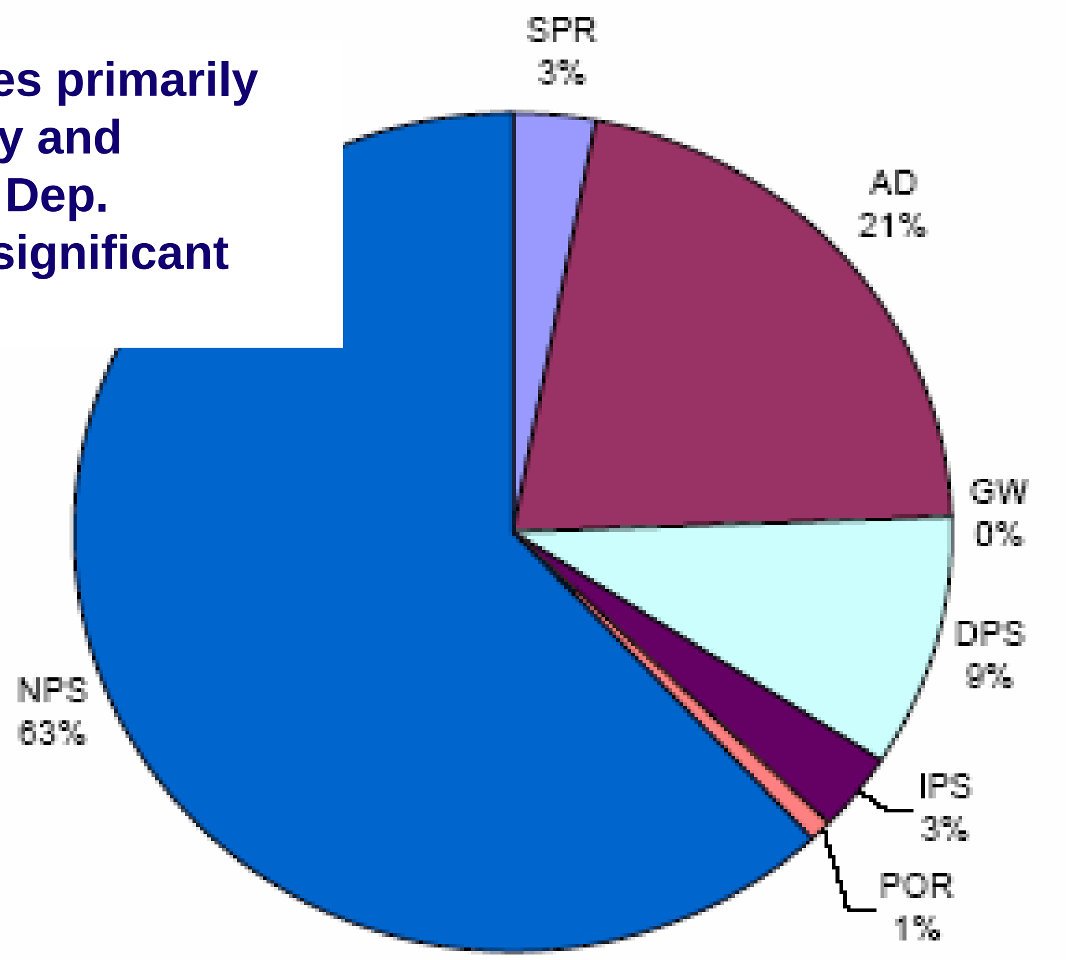
How have other localities dealt with the N issue?

Chesapeake Bay N Loads



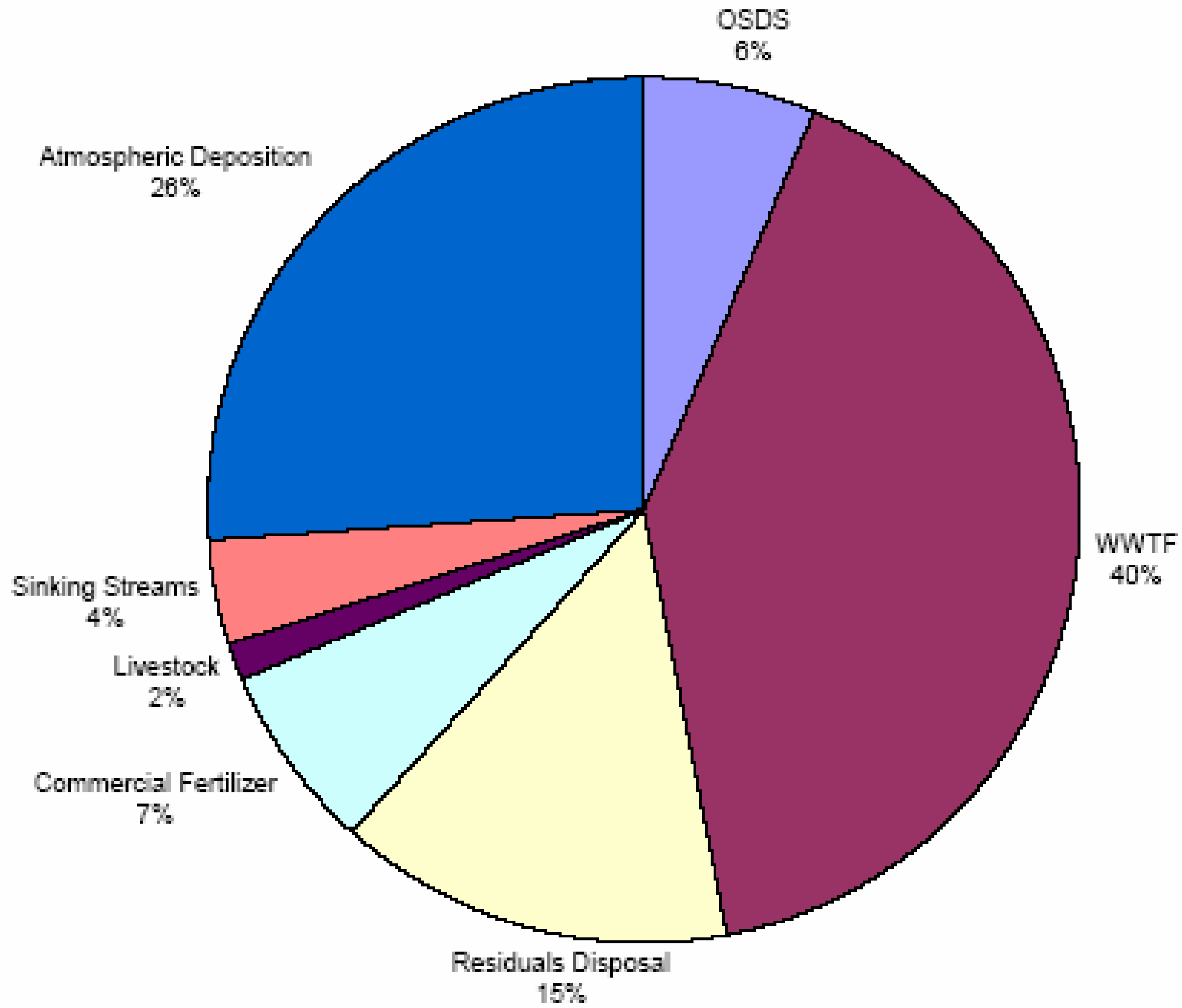
Tampa Bay Mean Annual TN Loads
1999 - 2003

Non-Point Sources primarily stormwater to bay and tributaries. Atm Dep. suspected to be significant portion



Wakulla Springs Inventoried N sources

Relative Contribution 1990-1999



Conclusions

- No studies specific to OWTS identified
- Preliminary estimates suggest OWTS not a leading N source in WSA
- N from Conventional OWTS should undergo ~ 30% reduction or more
- Natural denitrification could increase this
- Complex mechanical units may not perform much better and are expensive

Conclusions (cont.)

- Life-cycle cost of OWNRS could be ~ $186 per month
- Without adequate knowledge of OWTS N contribution, difficult to develop N reduction strategy
- Requirement for 10 mg/L TN from tank may not be appropriate considering cost relative to benefit – need more data

Recommendations

- Further identify sources and refine source quantities
- Rank sources, study largest potential sources in greater detail
- Develop N inventory and relative contributions for WSA
- Develop strategies and costs to reduce N, implement most cost effective strategies

Recommendations (cont.)

- For OWTS, more cost effective strategies are recommended for evaluation:
  - Operating permits for all OWTS with upgrade requirements and mandatory maintenance
  - Dosing of all systems with shallow SWIS placement
  - Investigate more passive methods of N reduction