Clogging of Leachate Collection Systems in Florida

Dr. Tarek Abichou

Daria Sakharova

Our overall long-term Research Objectives

We want to:

- **Introduce clogging verification into design approaches and into design manuals**
- **We feel that LCS design has not received the attention it should to allow for long-term impact of landfills**

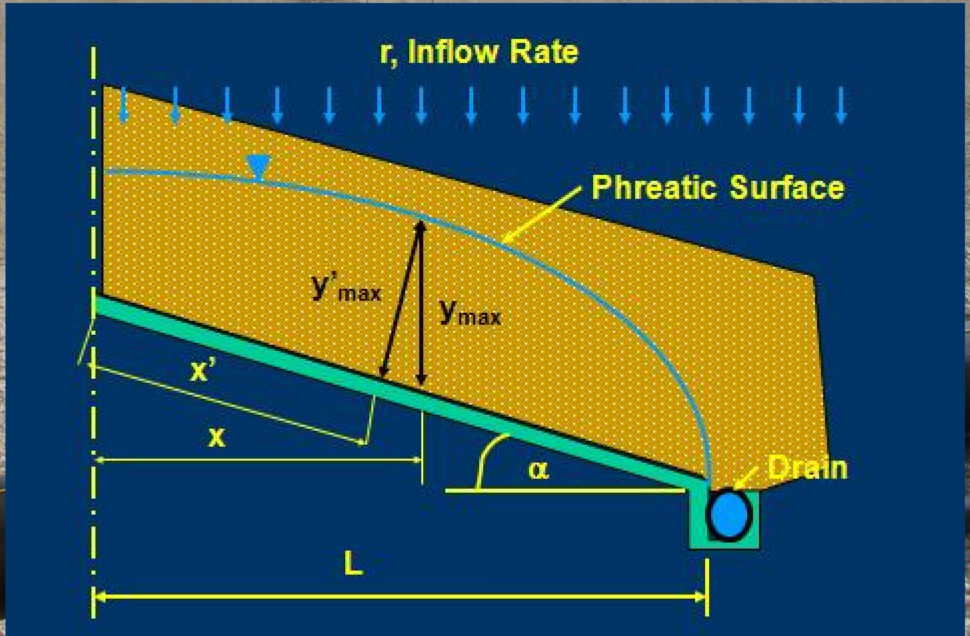
Rationale

- The purpose of LCSs is to collect and remove the leachate from the bottom of landfill and therefore minimize the leachate head which provides the driving force for the leakage of contaminants to the surrounding environment.
- Since the contaminating lifespan of a landfill may be decades or even centuries, the performance of the LCS is critical for a well-designed modern landfill
- There is a need to be able to predict the service life of a given system.

Research Objectives of original Proposal

- Use the reduction in pore space to predict change of hydraulic properties
- Predict leachate head on liner with time using Florida specific leachate composition and generation data for typical landfills operated in different micro-climates of the state.
- Assess Effects and the extent of the co-disposal of MSW and WTE by-products.
- Examine the adequacy of the current design methodology of leachate collection systems in the state of Florida.
- Develop a protocol to estimate service life of LCSs in different regions of Florida for different landfill disposal practices.

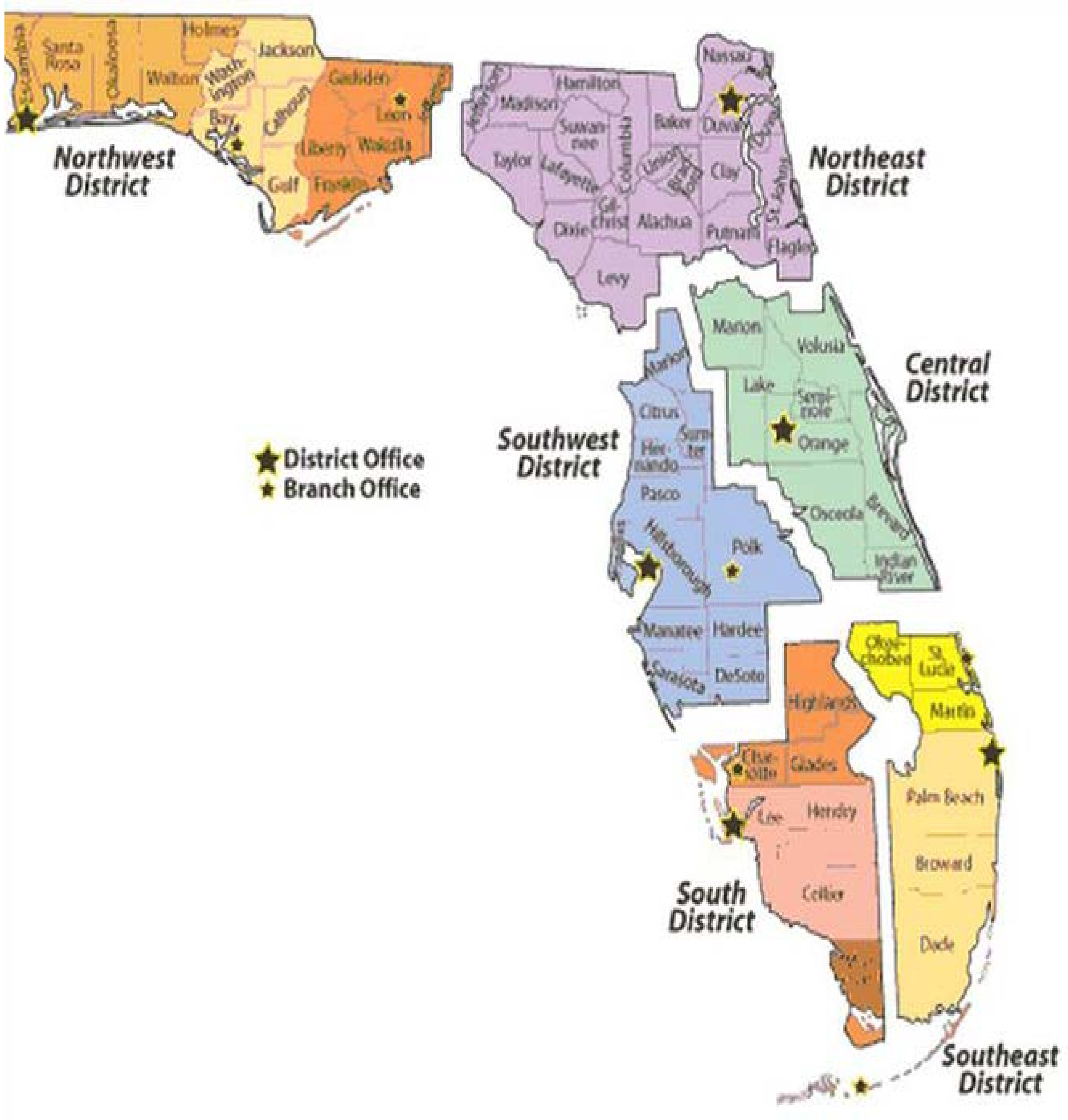
Criteria of LCS:



Phreatic Surface in Landfill Drainage Layer

Districts

- Divided the state into 6 districts following FDEP's map
- Select 3 county landfills from each district
  - Ensure as much diversity in climate as possible
- Compile parameters from each LF into excel, organized by year



NED - Columbia County	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2004	2005	2006	2008	2009	2010	2011	2012	2013
IRON (FE)					49000	36000	1300		1300		8800	16200	6430		11800	22700	3530	14900	1070
COD, CHEMICAL OXYGEN DEMAND																	580	595	91
CHLORIDE					300	320	50		30		500	413	800		1100	1700	1300	1350	170
ALKALINITY, TOTAL (CACO3)					660	760	640		140		830	985	1500		1600	1900	1600	1820	320
SPEC. CONDUCTANCE (FIELD)					2320	2600		478	437		3333	3279	4890		6874	6849	6931	7226	1312
DISSOLVED OXYGEN (FIELD BY PROBE)					1.4	1.6		2.5	1.9		2.57	3.26	1.62		1.03	0.71	0.92	1.19	3.67
TEMPERATURE (FIELD)						23.7		21.9	20.2		23.6	22	22.61		24.04	25.54	26.19	24.17	25.64
TURBIDITY, FIELD						268	1000	60.4	12.8		292	270	69.3		117	204	102	62.3	9.96
PH, FIELD					6.3	6.54		6.96	7.52		6.83	6.96	7.8		6.82	6.92	7.17	6.8	7.56
AMMONIA (NH3) TOTAL AS N					120	100	180		6.7		150	156	200		290	350	350	443	35
BOD, 5 DAY, 20 DEG C																	17	60.9	16
TOTAL DISSOLVED SOLIDS TDS, (RES DISS)					790	900	1200		270		1300	1350	2300		2600	2800	2900	2850	680
SODIUM					180	210	160		20		290	279	513		569	588	639	766	95.7
COPPER											50	0.6	3.1		2.2	2.2	2.2	2.5	2.88
BOD/COD																	0.0293	0.1024	0.1758

NED - Duval County	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2004	2005	2006	2008	2009	2010	2011	2012	2013
IRON (FE)										30000				11000			71000	77000	59000
COD, CHEMICAL OXYGEN DEMAND																			
CHLORIDE										1600				1900			2700	3100	2800
ALKALINITY, TOTAL (CACO3)										4500				1					
SPEC. CONDUCTANCE (FIELD)										9300				15160			20590	22810	18810
DISSOLVED OXYGEN (FIELD BY PROBE)										0.4				0.6			0.1	0.2	0.1
TEMPERATURE (FIELD)										18.1				28.6			35.9	38.2	25.6
TURBIDITY, FIELD										1000				14 (lab)					
PH, FIELD										7.73				7.35			7.29	7.35	7.79
AMMONIA (NH3) TOTAL AS N										960				1000			1300	1700	1200
BOD, 5 DAY, 20 DEG C																			
TOTAL DISSOLVED SOLIDS TDS, (RES DISS)										4400				5700			12000	12000	12000
SODIUM										680				1600			2600	2900	520
COPPER										770				12			15	55	15

NED - Putnam County	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2004	2005	2006	2008	2009	2010	2011	2012	2013
IRON (FE)	59000	62000	46000	38000	23000	17000		17000					13000						
COD, CHEMICAL OXYGEN DEMAND				758															
CHLORIDE				1080	1100	1000		960					1200						
ALKALINITY, TOTAL (CACO3)				3680	3920	3500		3000					3700						
SPEC. CONDUCTANCE (FIELD)	420	4300	2960	3400	8500	314		4.8					9833						
DISSOLVED OXYGEN (FIELD BY PROBE)	4			0.8	2.5	3.2		6.2					1.31						
TEMPERATURE (FIELD)	27.7	21.4	22.1	24	24.1	20.1		30					27.58						
TURBIDITY, FIELD				140	114.2	39.7		74.5					24.9						
PH, FIELD	6.2	7.06	7.07	7.04	7.74	7		7.3					7.13						
AMMONIA (NH3) TOTAL AS N				123	64.2	480		420					600						
BOD, 5 DAY, 20 DEG C	418	898	213	81															
TOTAL DISSOLVED SOLIDS TDS, (RES DISS)				3860	4300	3600		3500					4200						
SODIUM				890	1000	570		210					1000						
COPPER			280			2.5		20					3						

NWD - Jackson County	1993	1994	1995	1996	1997	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
IRON (FE)		21.1										19000	40000	8100	7200
COD, CHEMICAL OXYGEN DEMAND													13000	12000	5700
CHLORIDE		731										1700	2500	2700	2300
ALKALINITY, TOTAL (CACO3)		2320										6000	8600	8300	6400
SPEC. CONDUCTANCE (FIELD)		4270										15670	25460	19980	17420
DISSOLVED OXYGEN (FIELD BY PROBE)		1.6										0.9	0.6	0.3	0.1
TEMPERATURE (FIELD)												16.9	27.7	25.8	25.7
TURBIDITY, FIELD												329.7	411.6	35.47	31.66
PH, FIELD		7.72										7.93	7.52	7.73	7.57
AMMONIA (NH3) TOTAL AS N		381										110	1700	1900	4000
BOD, 5 DAY, 20 DEG C													4100	1400	192.3
TOTAL DISSOLVED SOLIDS TDS, (RES DISS)		2730										6800	9500	10000	9000
SODIUM												1800	2700	2400	2400
COPPER												5.6	23	17	76

NWD - Escambia County	1993	1994	1995	1996	1997	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
IRON (FE)			18	28				4300	5650				7200	6270	
COD, CHEMICAL OXYGEN DEMAND									920				2200	1100	
CHLORIDE			1100	710				700	650				1500	950	
ALKALINITY, TOTAL (CACO3)								2100	2400				5000	2200	
SPEC. CONDUCTANCE (FIELD)			680	5600				3979	6652				11362	6523	
DISSOLVED OXYGEN (FIELD BY PROBE)			0.06	4.8				0.9	0.34				0.5	4.36	
TEMPERATURE (FIELD)			30.2	25.9				31.45	15.86				17.05	16.92	
TURBIDITY, FIELD								16	40				120	115	
PH, FIELD			7.5	5.9				6.99	8.04				8.42	8.47	
AMMONIA (NH3) TOTAL AS N			420	250				300	340					260	
BOD, 5 DAY, 20 DEG C									50				110	39	
TOTAL DISSOLVED SOLIDS TDS, (RES DISS)			1100	2800				2700	3500				6100	3600	
BICARBONATE ION (HCO3) LAB			0.5	0.5					2400						
SODIUM			870	670				630	798				1480	859	
COPPER			30	30				11	3.3				6	7.5	

NWD - Leon County	1993	1994	1995	1996	1997	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
IRON (FE)	7.3	480	29			28000		23000				9800	18000	22000	
COD, CHEMICAL OXYGEN DEMAND															
CHLORIDE	310	650	540			790		870				420	470	600	
ALKALINITY, TOTAL (CACO3)	860					2200		2500				1300	1500	1800	
SPEC. CONDUCTANCE (FIELD)	2200	5100	4900			6300		6110				4060	4270	4967	
DISSOLVED OXYGEN (FIELD BY PROBE)		2	1			1.07		1.38				1.3	0.86	0.7	
TEMPERATURE (FIELD)															
TURBIDITY, FIELD															
PH, FIELD	6.67	6.68	6.4			7.26		6.72				6.83	6.67	6.96	
AMMONIA (NH3) TOTAL AS N	110		220			3.8		490				190	210	270	
BOD, 5 DAY, 20 DEG C															
TOTAL DISSOLVED SOLIDS TDS, (RES DISS	31.2	2500	2400			2700		2700				1800	1700	1700	
BICARBONATE ION (HCO3) LAB			2000												
SODIUM	270	15	240			680		780				370	400	450	

IRON (FE)		4100			10300	10300																
COD, CHEMICAL OXYGEN DEMAND				58.8																		
CHLORIDE		11		270	216	178																
ALKALINITY, TOTAL (CACO3)				312	434	348																
SPEC. CONDUCTANCE (FIELD)				710	1410																	
DISSOLVED OXYGEN (FIELD BY PROBE)																						
TEMPERATURE (FIELD)				25																		
TURBIDITY, FIELD		46																				
PH, FIELD		6.8		7.1	6.69	6.49																
AMMONIA (NH3) TOTAL AS N				12.9		5.8																
BOD, 5 DAY, 20 DEG C				0.3																		
TOTAL DISSOLVED SOLIDS TDS, (RES DISS)		500		674	931	729																
SODIUM		58			127	92.3																
COPPER		890			1																	
BOD/COD				0.0051																		

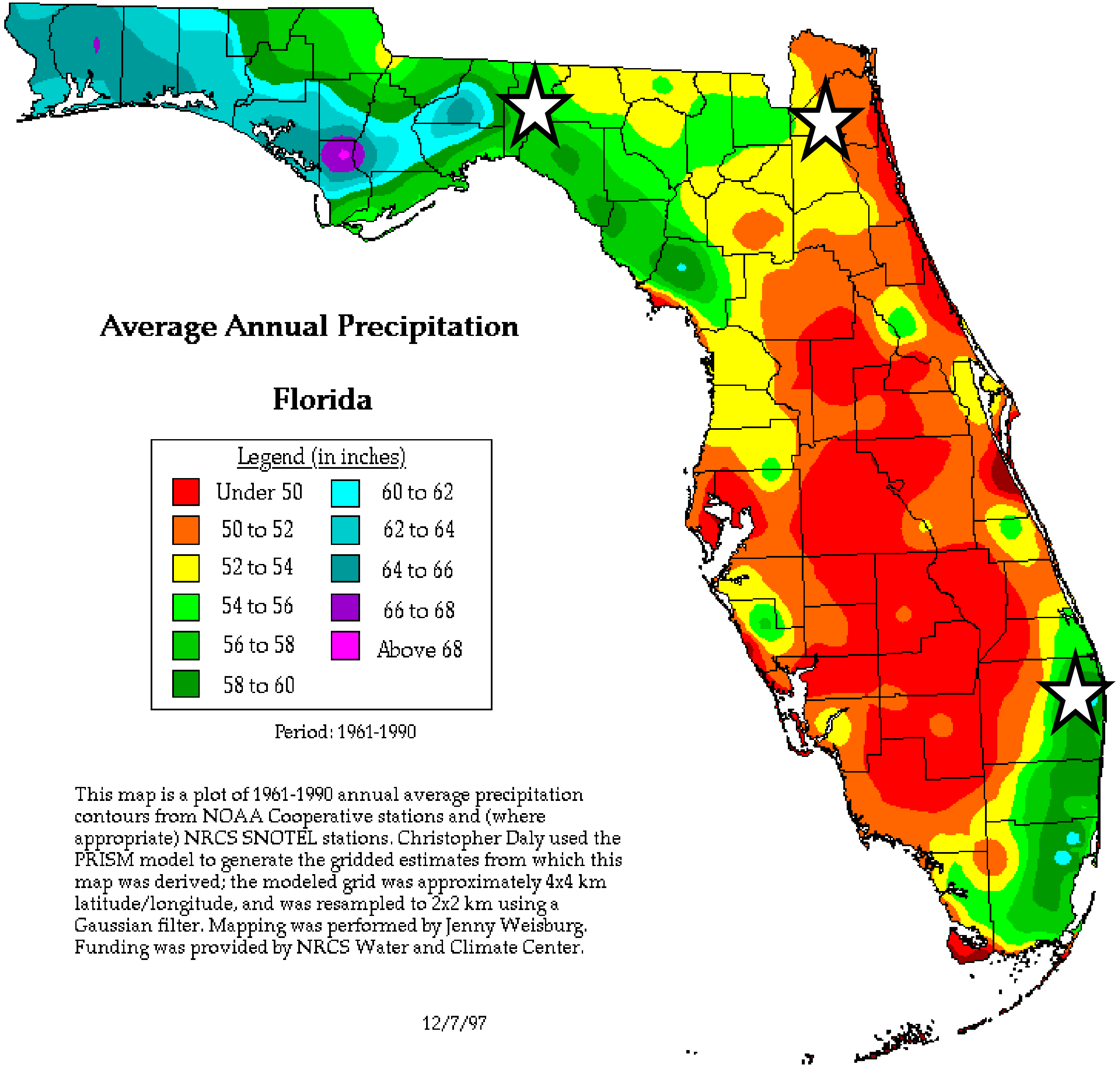
SD - Hendry County	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
IRON (FE)																				1970	18500	
COD, CHEMICAL OXYGEN DEMAND																						
CHLORIDE																				266	11100	
ALKALINITY, TOTAL (CACO3)																				660	394	
SPEC. CONDUCTANCE (FIELD)																				2230	32700	
DISSOLVED OXYGEN (FIELD BY PROBE)																				1	0.51	
TEMPERATURE (FIELD)																				23.6	30.5	
TURBIDITY, FIELD																						
PH, FIELD																				6.68	6.68	
AMMONIA (NH3) TOTAL AS N																				14.7	1160	
BOD, 5 DAY, 20 DEG C																						
TOTAL DISSOLVED SOLIDS TDS, (RES DISS)																				1470	20000	
SODIUM																				102	2670	
COPPER																				1.2	14.4	

SD - Highlands County	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
IRON (FE)																			36800	7910	11000	
COD, CHEMICAL OXYGEN DEMAND																						
CHLORIDE																			1380	1600	1780	
ALKALINITY, TOTAL (CACO3)																			4310		5310	
SPEC. CONDUCTANCE (FIELD)																			11800	13902	14300	
DISSOLVED OXYGEN (FIELD BY PROBE)																			0.04	2.4	2.3	
TEMPERATURE (FIELD)																			25	27.3	25.9	
TURBIDITY, FIELD																			1.1	9.06	2.35	
PH, FIELD																			7.2	8.01	7.46	
AMMONIA (NH3) TOTAL AS N																			815	670	961	
BOD, 5 DAY, 20 DEG C																						
TOTAL DISSOLVED SOLIDS TDS, (RES DISS)																			5980	6880	7000	
SODIUM																			1070	1360	1710	
COPPER																			2	2	2	

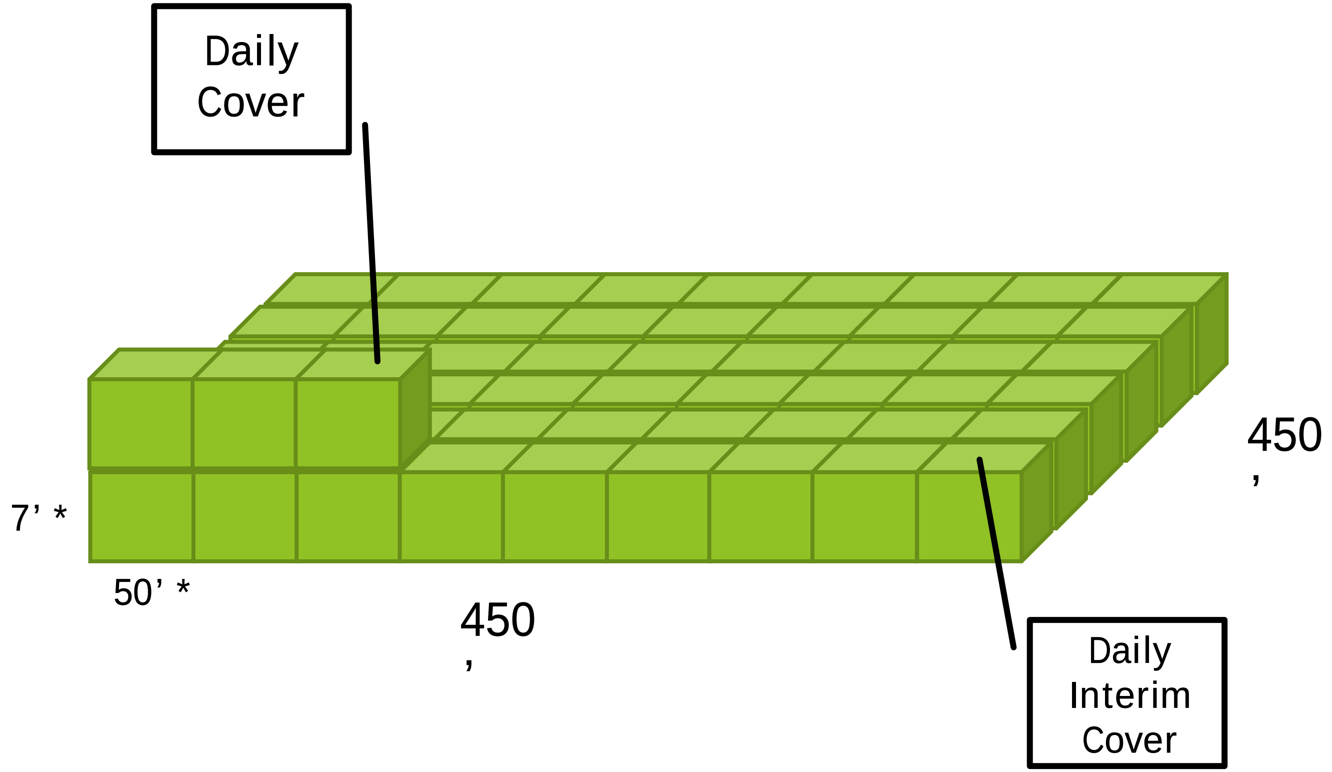
Biggest problem is that there is no discernable pattern or conclusion that can be drawn from this data.
Too many holes, too much missing data, NO QUANTITY data.
What now??

What Now?

- Make “model” landfills
  - 5, 10 & 20 acres
- Three climate zones based on average monthly precipitation:
  - West Palm Beach – 5.19 in
  - Tallahassee – 4.93 in
  - Jacksonville – 4.36 in



5 Acre 500 TPD Cell



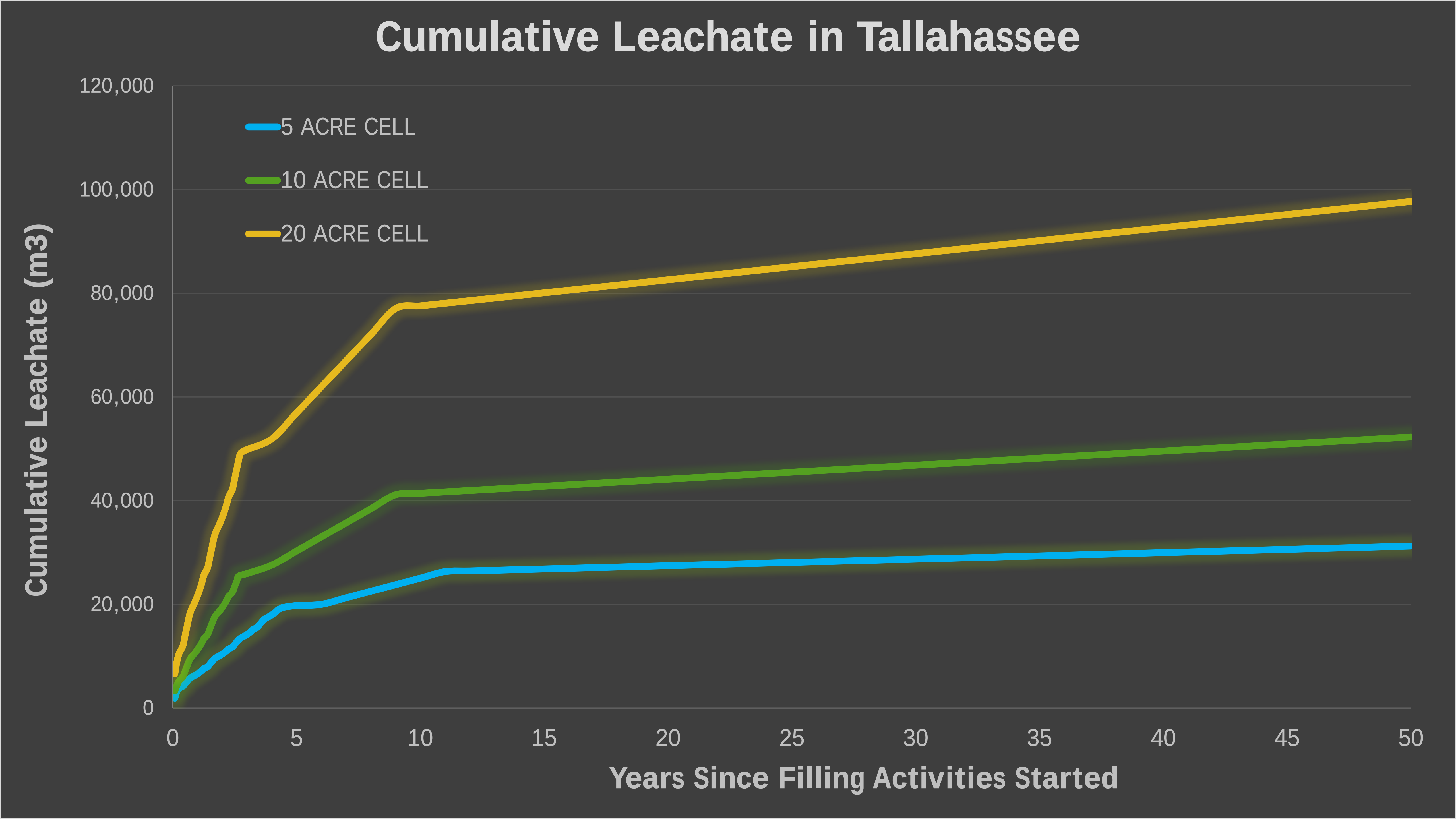
Open	1
Daily Cover	0.5
Interim Cover	0.1
Final Cover	0

- While the first layer is built, some of the area is open to rainfall – "open area"
- After first layer is down, one 50x50' block of the area is being actively filled – "daily cover" and some is already filled – "daily interim cover"
- When entire cell is finished, a "final cover" is placed on top
- Each cover type has a different rainfall coefficient

* Block height and width are not to scale, enlarged to clarify structure and placement.

Compiling Data

- Made a database of all relevant information for each cell and location
  - Rainfall, evaporation, temperature, volume and mass of waste
  - Time scale is in months during filling activities, then years post-closure
- From these, calculated:
  - Cumulative volume of leachate (m^3)
  - Monthly leachate production (gal/day)
  - Monthly leachate production per unit area (in)
  - COD and BOD concentrations throughout the landfill
  - Rate of vertical inflow per unit area (in/day) – “r”
  - Leachate head on the LF liner based on the calculated r - y_{max}

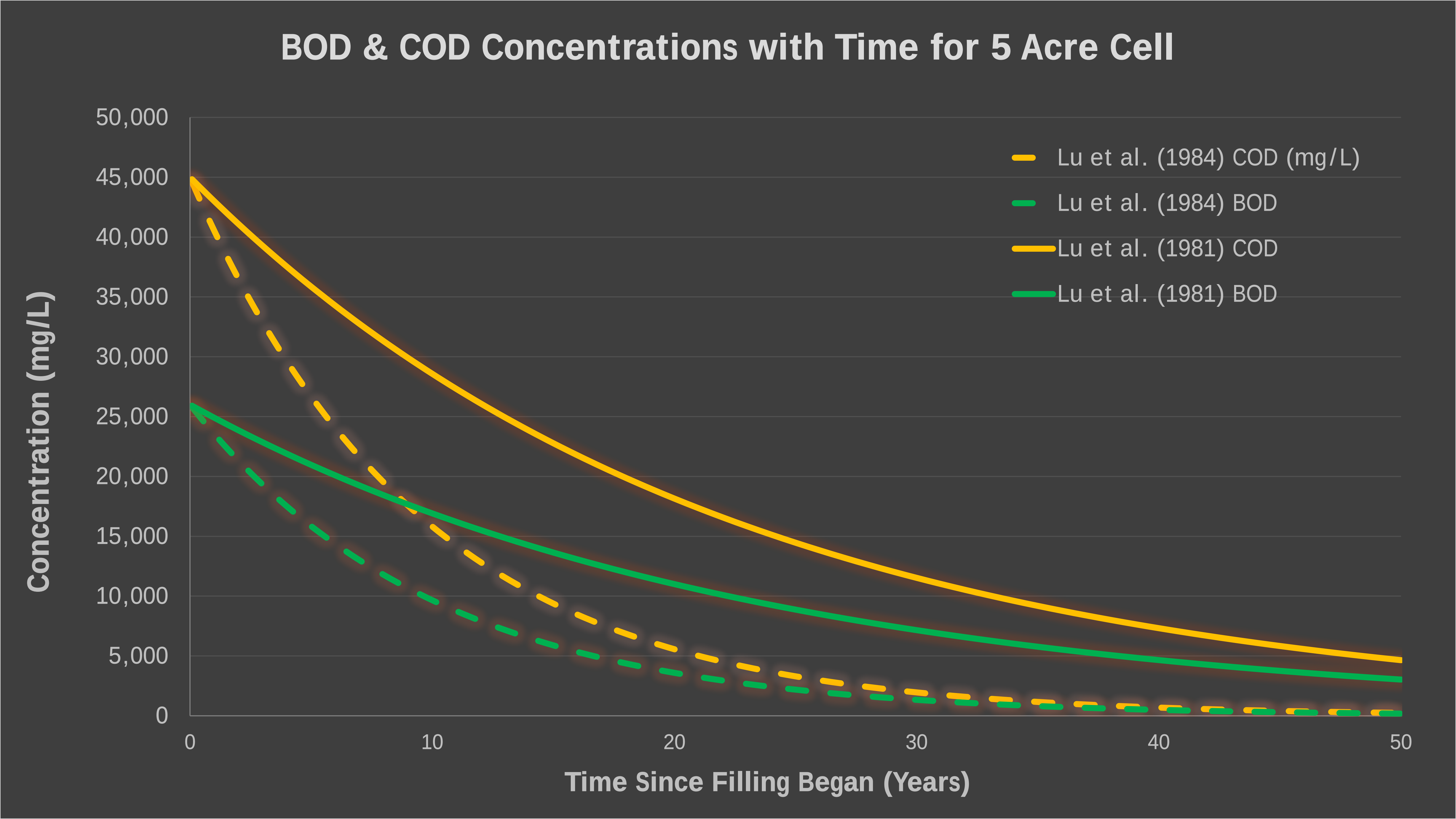

Cumulative Leachate in Tallahassee
5 ACRE CELL
10 ACRE CELL
20 ACRE CELL
Cumulative Leachate (m3)
120,000
100,000
80,000
60,000
40,000
20,000
0
0
5
10
15
20
25
30
35
40
45
50
Years Since Filling Activities Started

COD and BOD Concentrations

- Three models used:
  - Lu et al. (1981): $C = C_0 e^{-kt}$
  - Lu et al. (1984): $C = C_0 10^{-kt}$
  - Wigh et al. (1979): $C = C_{max} \frac{e^{-k_1 v} - e^{-k_2 v}}{e^{-k_1 v_{max}} - e^{-k_2 v_{max}}}$
- Lu et al. equations are most commonly used in literature, so we decided to use those for further calculations

C_0	Max/initial COD concentration
k	First-order reaction rate constant
t	Time
v	Leachate volume
v_{max}	Cumulative leachate volume where C_{max} value occurred

C_{0COD}	45,000
C_{0BOD}	26,000
K_{COD} (yr^{-1})	0.0454
K_{BOD} (yr^{-1})	0.043



BOD & COD Concentrations with Time for 5 Acre Cell
Lu et al. (1984) COD (mg/L)
Lu et al. (1984) BOD
Lu et al. (1981) COD
Lu et al. (1981) BOD
50,000
45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
0
10
20
30
40
50
Concentration (mg/L)
Time Since Filling Began (Years)

Rate of Vertical Inflow per Unit Area

- A measure of how much liquid will actually make its way into the LCS pipes per unit area
- Calculated using:

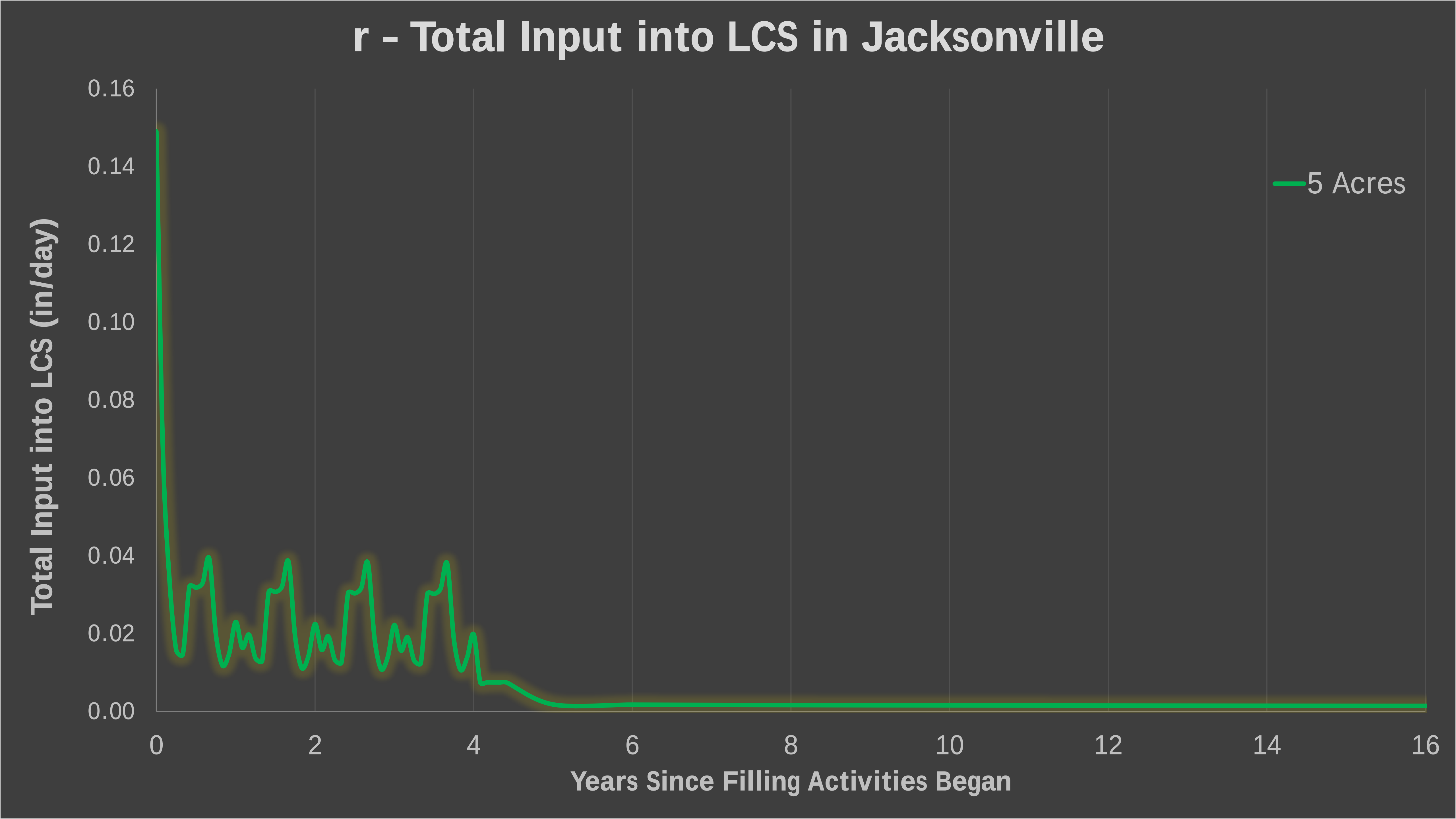
Monthly leachate per unit arear

+

Vertical squeezing → $(0.0013 * t^{0.7}) + (0.03 * \log \frac{t}{t_0})$

=

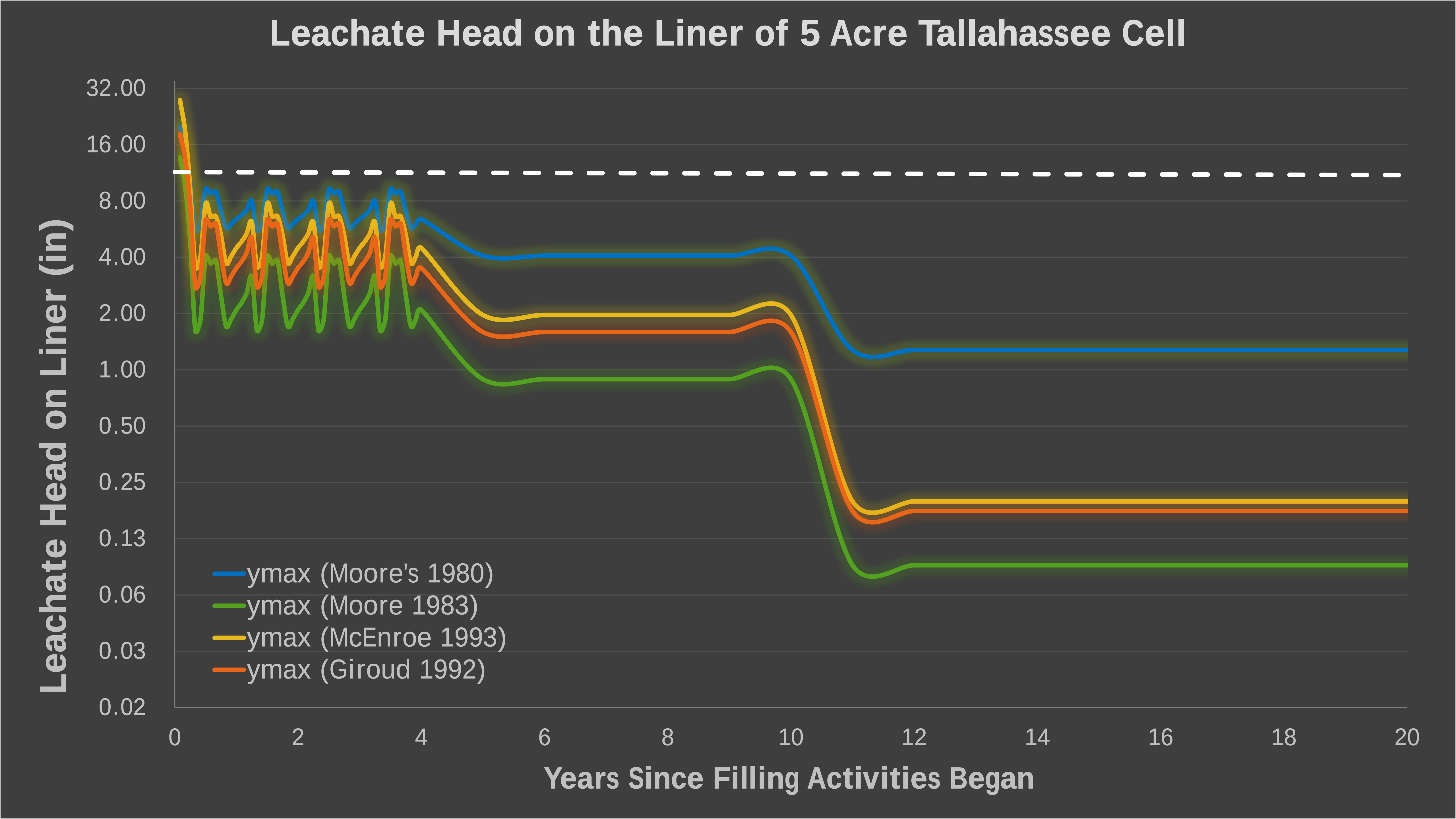
Total input into LCS (in/day/unit area)


r - Total Input into LCS in Jacksonville
Total Input into LCS (in/day)
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0
2
4
6
8
10
12
14
16
Years Since Filling Activities Began
5 Acres

Leachate Head on the Liner Calculations

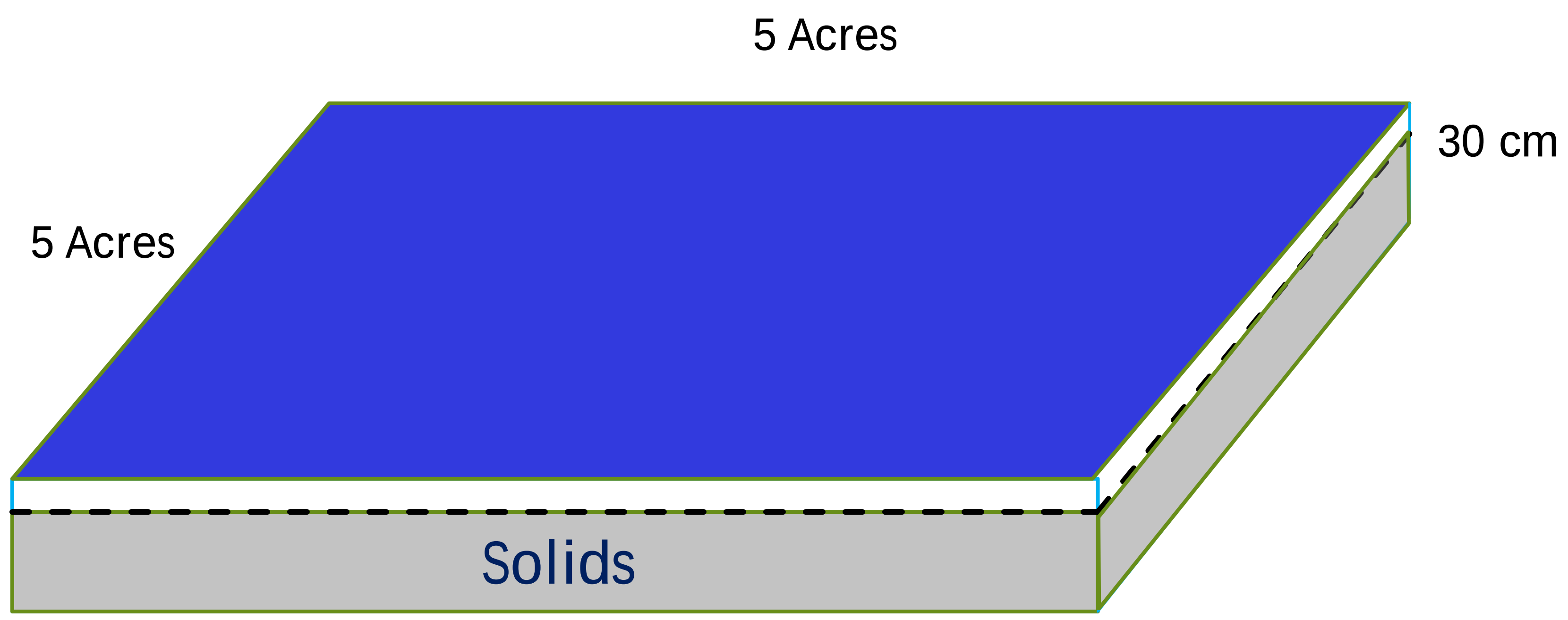
Four models used to calculate leachate head on the liner:

- Moore's (1980): $y_{max} = L * \left(\frac{r}{k}\right)^{\frac{1}{2}} \left(\frac{kS^2}{r} + 1 - \frac{kS}{r}\left(S^2 + \frac{r}{k}\right)^{\frac{1}{2}}\right)$
- Moore's (1983): $y_{max} = L * \left(\left(\frac{r}{k} + S^2\right)^{\frac{1}{2}} - S\right)$
- Giroud (1992): $y_{max} = j * L * \left(\left(4 * \frac{r}{k} + S^2\right)^{\frac{1}{2}} - S\right) / (2 * cos\alpha)$
- McEnroe (1993):
- If R < 1/4,
- $y_{max} = L * S * (R - RS + R^2S^2)^{\frac{1}{2}} * \left(\frac{((1-A-2R)(1+A-2RS))}{((1+A-2R)(1-A-2RS))}\right)^{\frac{1}{2}*A}$
- If R = 1/4,
- $y_{max} = L * S * R * \frac{1-2RS}{1-2R} * \exp(((2R * (S-1))/((1-2RS)(1-2R)))$
- If R > 1/4,
- $y_{max} = L * S * (R - RS + R^2S^2)^{\frac{1}{2}} * \exp\left(\left(\frac{1}{B}\right) tan^{-1}\left(\frac{2RS-1}{B}\right) - \left(\frac{1}{B}\right) tan^{-1}\left(\frac{2R-1}{B}\right)\right)$

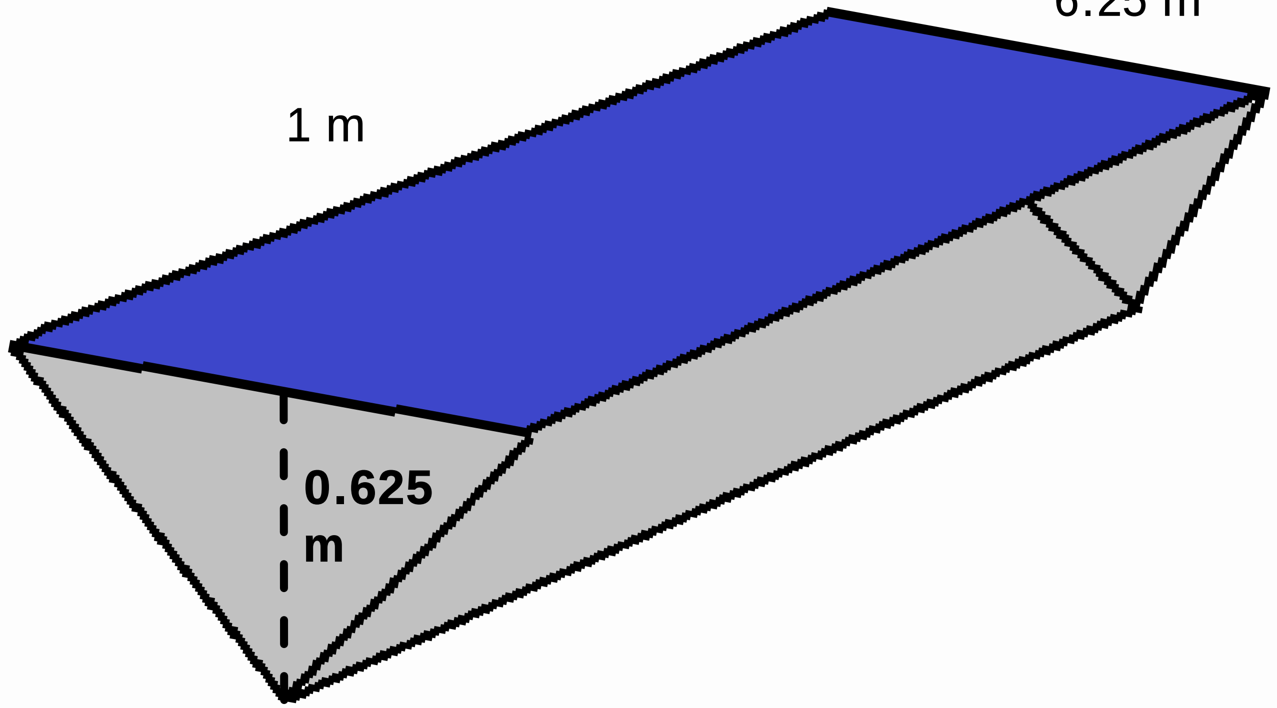


Leachate Head on the Liner of 5 Acre Tallahassee Cell
Leachate Head on Liner (in)
32.00
16.00
8.00
4.00
2.00
1.00
0.50
0.25
0.13
0.06
0.03
0.02
0
2
4
6
8
10
12
14
16
18
20
Years Since Filling Activities Began
ymax (Moore's 1980)
ymax (Moore 1983)
ymax (McEnroe 1993)
ymax (Giroud 1992)

Uniform Blanket Clogging

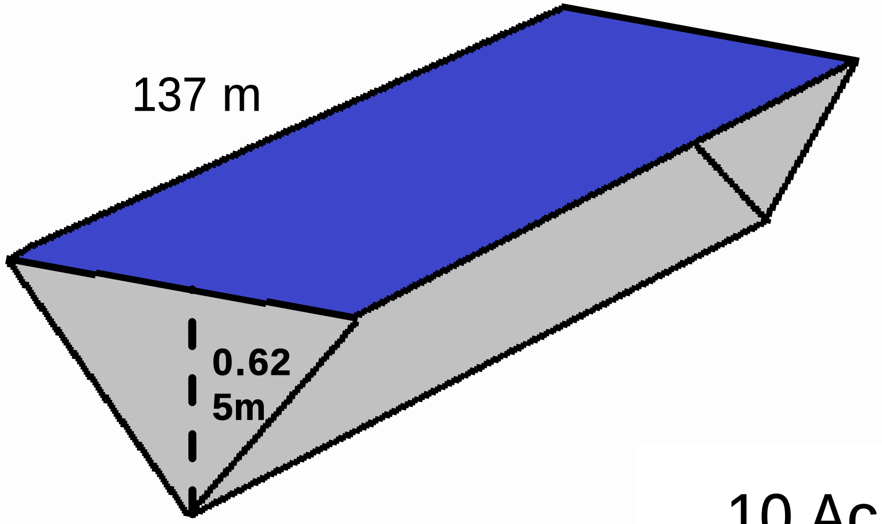


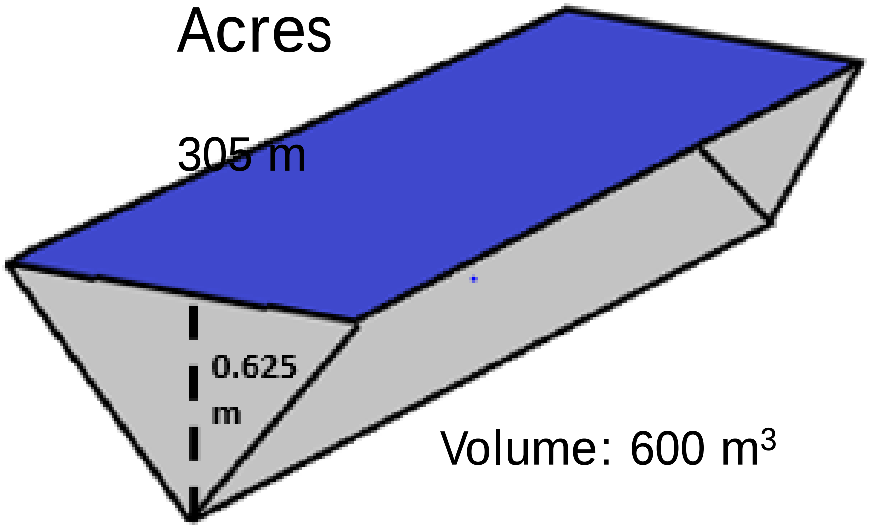
Trench-Only Clogging

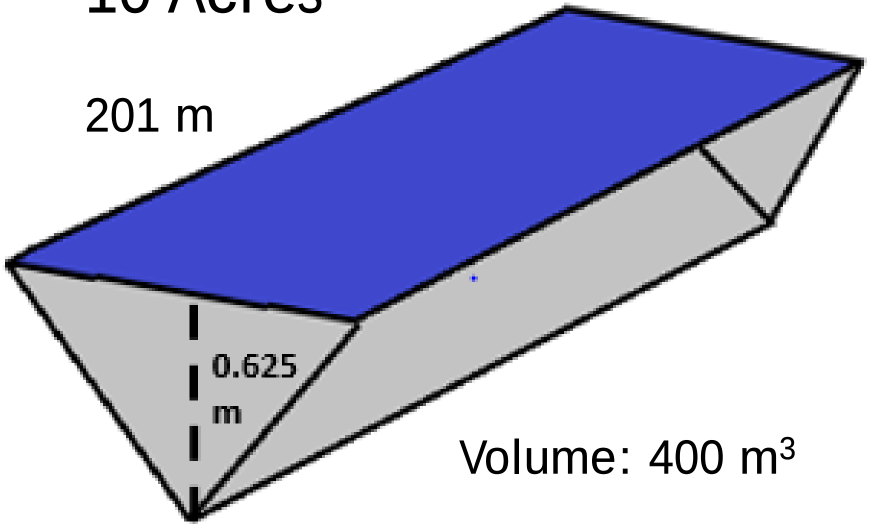


Volume: 1.95 m³

Trench-Only Clogging







100% MSW Jacksonville

5 Acres

Time Period	Average r	% of Average Daily Rain
Active	0.024	16%
Intermediate	0.003	2%
Post Closure	0.001	1%

10 Acres

Time Period	Average r	% of Average Daily Rain
Active	0.041	28%
Intermediate	0.0193	13%
Post Closure	0.0015	1%

20 Acres

Time Period	Average r	% of Average Daily Rain
Active	0.021	14%
Intermediate	0.0065	4%
Post Closure	0.0012	1%

50% MSW/50% Ash Jacksonville

5 Acres

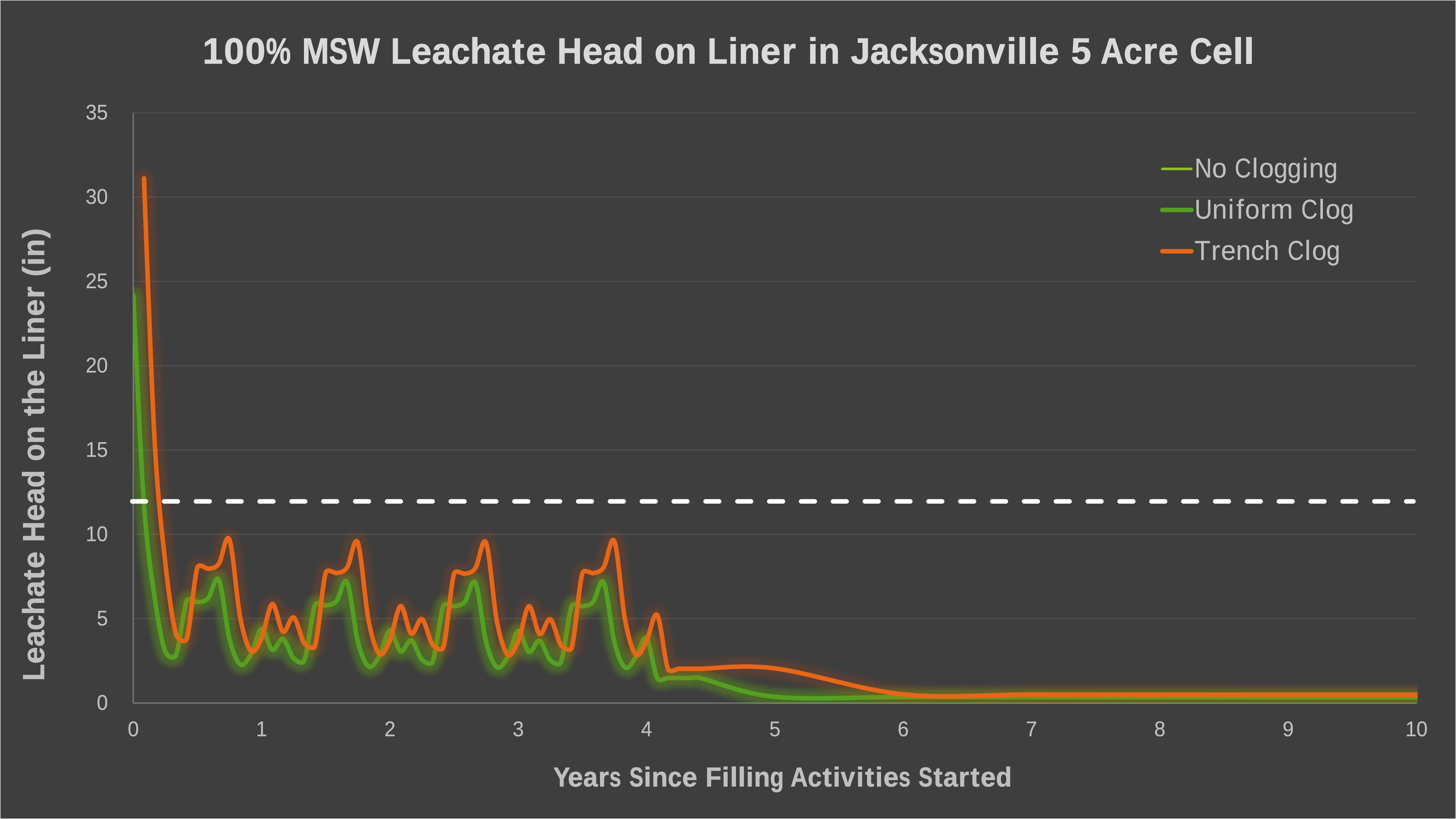
Time Period	Average r	% of Average Daily Rain
Active	0.024	16%
Intermediate	0.003	2%
Post Closure	0.001	1%

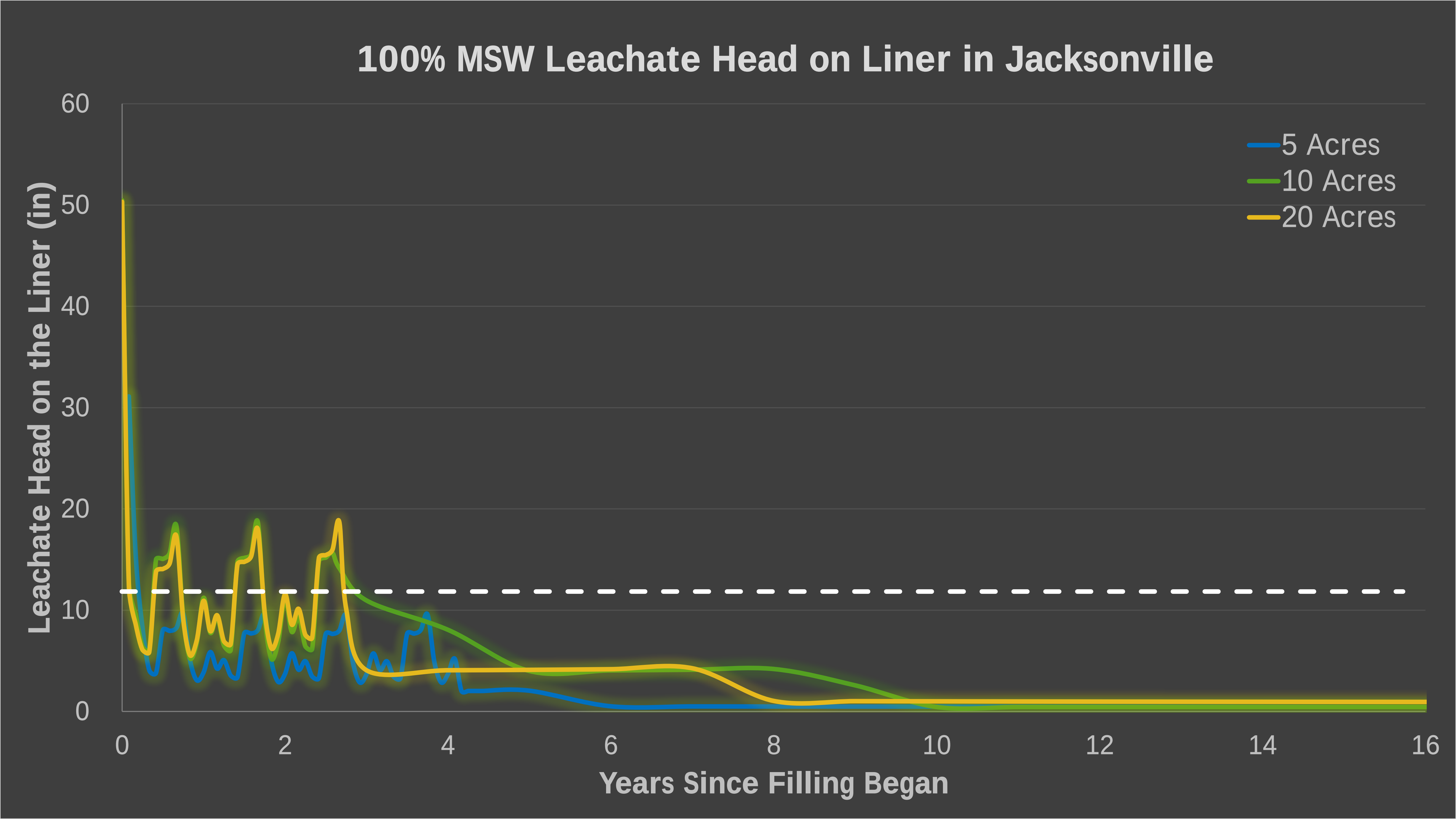
10 Acres

Time Period	Average r	% of Average Daily Rain
Active	0.041	28%
Intermediate	0.019	13%
Post Closure	0.001	1%

20 Acres

Time Period	Average r	% of Average Daily Rain
Active	0.021	14%
Intermediate	0.0065	4%
Post Closure	0.0012	1%


100% MSW Leachate Head on Liner in Jacksonville 5 Acre Cell
Leachate Head on the Liner (in)
Years Since Filling Activities Started
No Clogging
Uniform Clog
Trench Clog
0
5
10
15
20
25
30
35
0
1
2
3
4
5
6
7
8
9
10


100% MSW Leachate Head on Liner in Jacksonville
Leachate Head on the Liner (in)
0
10
20
30
40
50
60
Years Since Filling Began
0
2
4
6
8
10
12
14
16
5 Acres
10 Acres
20 Acres

100% MSW Jacksonville

5 Acres

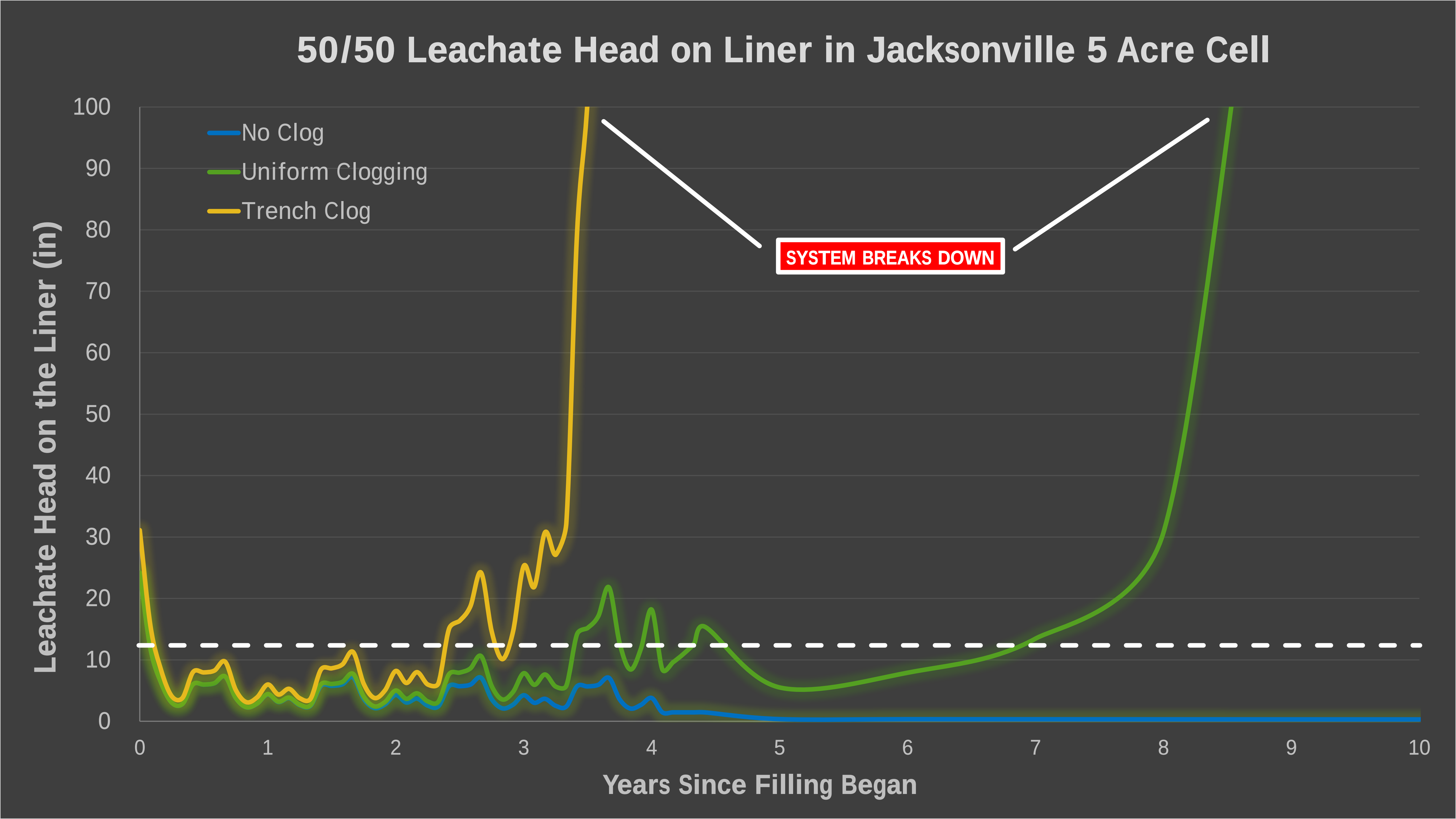
Clogging Occurrence					
Month	Moore 1983	Month	Uniform Clog	Month	Trench Clog
1	24.18	1	24.19	1	31.11
				2	15.53

10 Acres

Month	Moore 1983	Month	Uniform Clog	Month	Trench Clog
1	39.66	1	39.86	1	50.47
9	13.94	9	13.95	2	12.75
21	14.21	21	14.24	6	15.00
				7	15.06
				8	15.61
				9	18.32
				18	14.77
				19	15.16
				20	15.53
				21	18.69
				30	14.83
				31	15.19
				32	15.65
				36	14.16

20 Acres

Month	Moore 1983	Month	Uniform Clog	Month	Trench Clog
1	38.71	1	38.74	1	50.32
9	13	9	13.01	2	12.46
21	13.48	21	13.52	6	13.80
33	13.86	33	14.05	7	14.07
				8	14.62
				9	17.31
				18	14.53
				19	14.77
				20	15.30
				21	17.98
				30	15.18
				31	15.44
				32	15.99
				36	18.71



50/50 Leachate Head on Liner in Jacksonville 5 Acre Cell
Leachate Head on the Liner (in)
100
90
80
70
60
50
40
30
20
10
0
No Clog
Uniform Clogging
Trench Clog
SYSTEM BREAKS DOWN
0
1
2
3
4
5
6
7
8
9
10
Years Since Filling Began

50% MSW/50% Ash Jacksonville

5 Acres

Month	Moore 1983	Month	Uniform Clog	Month	Tench Clog
1	24.18	1	24.19	1	31.11
		42	14.16	2	15.53
		43	15.20	30	15.07
		44	17.13	31	16.37
		45	21.80	32	18.71
		46	12.71	33	24.22
		49	18.19	34	14.63
		53	12.71	36	14.60
		60	15.39	37	25.26
		96	13.46	38	21.91
		108	30.77	39	30.76
		120	154.86	40	27.11
		SYSTEM BREAKS DOWN		41	32.28
				42	79.34
				43	101.39
				44	139.64
				45	222.83
				46	234.47
				47	364.31
				48	5370.52
				SYSTEM BREAKS DOWN	

10 Acres

Month	Moore 1983	Month	Uniform Clog	Month	Tench Clog
1	39.66	1	39.68	1	50.47
9	13.94	9	13.99	2	12.75
21	14.21	18	12.14	6	15.00
		19	12.72	7	15.07
		20	13.35	8	15.64
		21	16.56	9	18.38
		30	20.02	18	16.20
		31	21.97	19	17.01
		32	24.40	20	17.90
		36	24.41	21	22.19
		48	22.56	25	15.89
		60	22.10	27	15.08
		72	17.18	30	28.81
		84	30.23	31	31.97
		96	67.78	32	35.92
		108	290.89	36	36.77
		120	215.94	48	35.68
		SYSTEM BREAKS DOWN		60	38.04
				72	34.91
				84	77.75
				96	360.12
				SYSTEM BREAKS DOWN	

20 Acres

Month	Moore 1983	Month	Uniform Clog	Month	Trench Clog
1	38.71	1	38.74	1	50.32
9	13	9	13.08	2	12.47
21	13.48	18	12.74	6	13.81
33	13.86	19	13.49	7	14.09
		20	14.65	8	14.66
		21	18.19	9	17.41
		25	15.82	18	17.40
		26	12.96	19	18.53
		27	17.00	20	20.26
		28	14.36	21	25.30
		29	15.74	22	15.11
		30	36.44	24	14.16
		31	43.00	25	23.38
		32	52.43	26	19.66
		33	72.46	27	26.23
		36	53.58	28	22.88
		48	35.13	29	25.86
		60	66.43	30	59.94
		72	198.90	31	73.25
		84	1789.17	32	93.03
		SYSTEM BREAKS DOWN		33	134.01
				36	113.03
				48	97.95
				60	308.55
				72	839.52
				SYSTEM BREAKS DOWN	

Significance

- Instead of using HELP Model “r”, landfills can use this method to find “r”
- From that, can find their specific landfill’s maximum head on leachate (y_{max}) at every time increment for the duration of its lifetime
- Can plan accordingly when to flush the system
  - Suggestion: Once after completion of filling, then as necessary