Rolling the Dice

Using the Monte Carlo Method to Optimize Solids Management

Kevin Campanella, Burgess & Niple

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Acknowledgments

Project Team

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  - Josh Lutz
  - Todd Krenelka
  - Heather Curtis
  - Brandon Fox
- Black and Veatch: Bob O'Bryan
- Burgess & Niple: Tanja Kontautaite

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What if you want to…

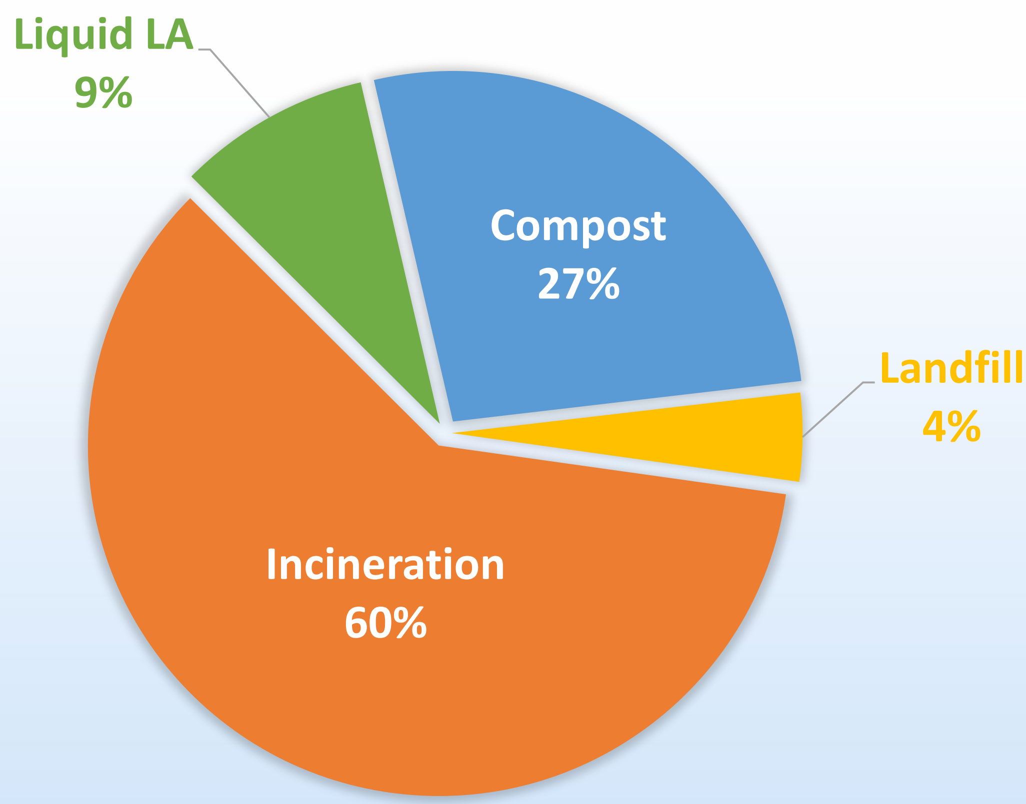
- Model risks of a project or program?
  - Multiple inputs
  - Inputs are complex and variable
  - Potential outcomes are broad ranging

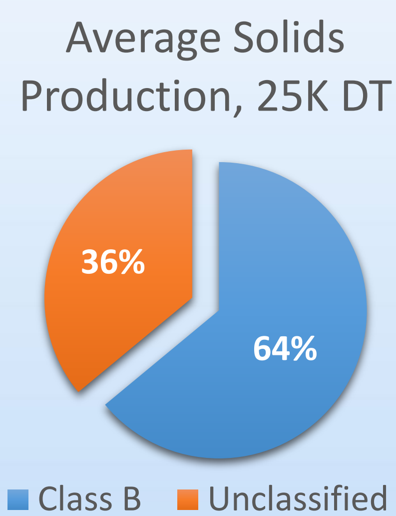
Monte Carlo Analysis

- Monte Carlo Analysis Method
  - Can model many complex input variables
  - Can model “what if” scenarios quickly
  - Typical Monte Carlo analysis involve 5,000+ simulations
  - Produces an understanding of each possible outcome and its likelihood
  - Results help optimize investments and risks



Columbus WW Solids Distribution 2010





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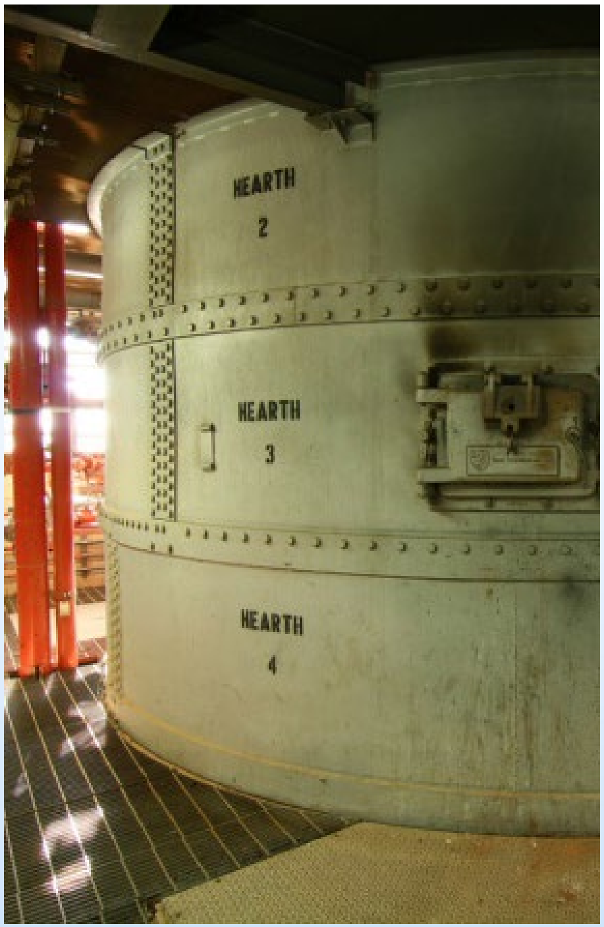
MACT Compliance



Southerly WWTP Multiple Hearth Incinerator (MHI)

- 2010 Title 5 Maximum Achievable Control Technology Standards (MACT)
- MHI Condition Assessment and BCE
  - Initial Goal: Determine what incinerator repairs are necessary at both plants.
  - Revised Goal: Determine the optimal number of incinerators to improve based on available capacity of ALL management outlets.
  - Comprehensive system approach.
- Findings
  - *Incineration improvements not necessary with an expanded beneficial reuse program.*

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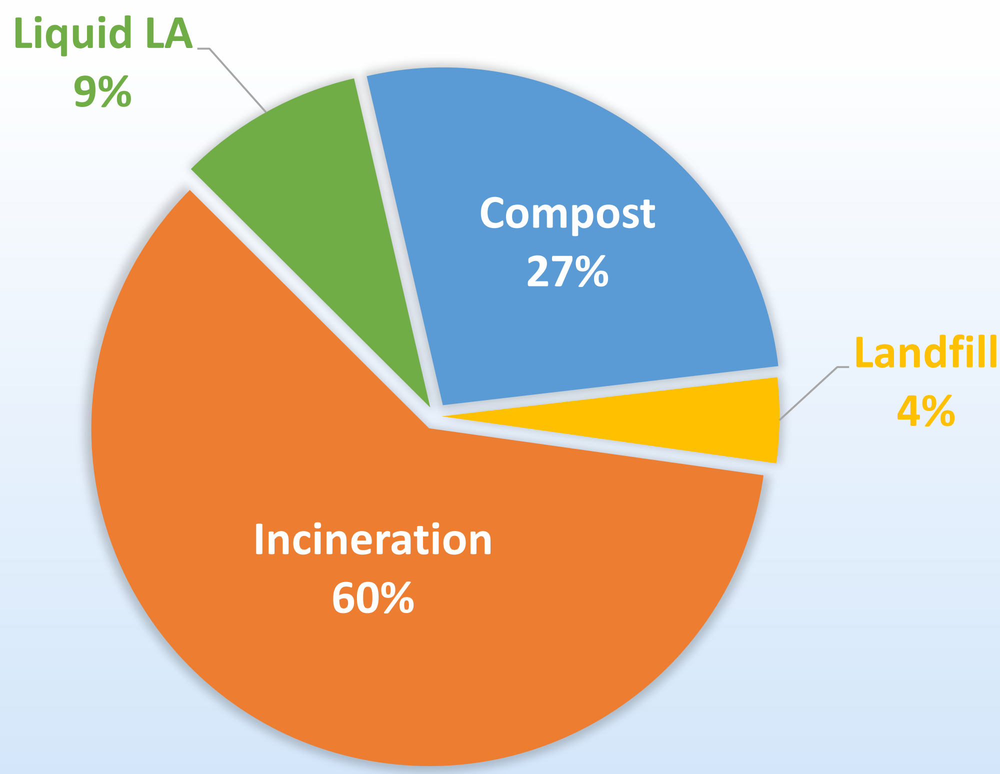
Columbus WW Solids Distribution 2010



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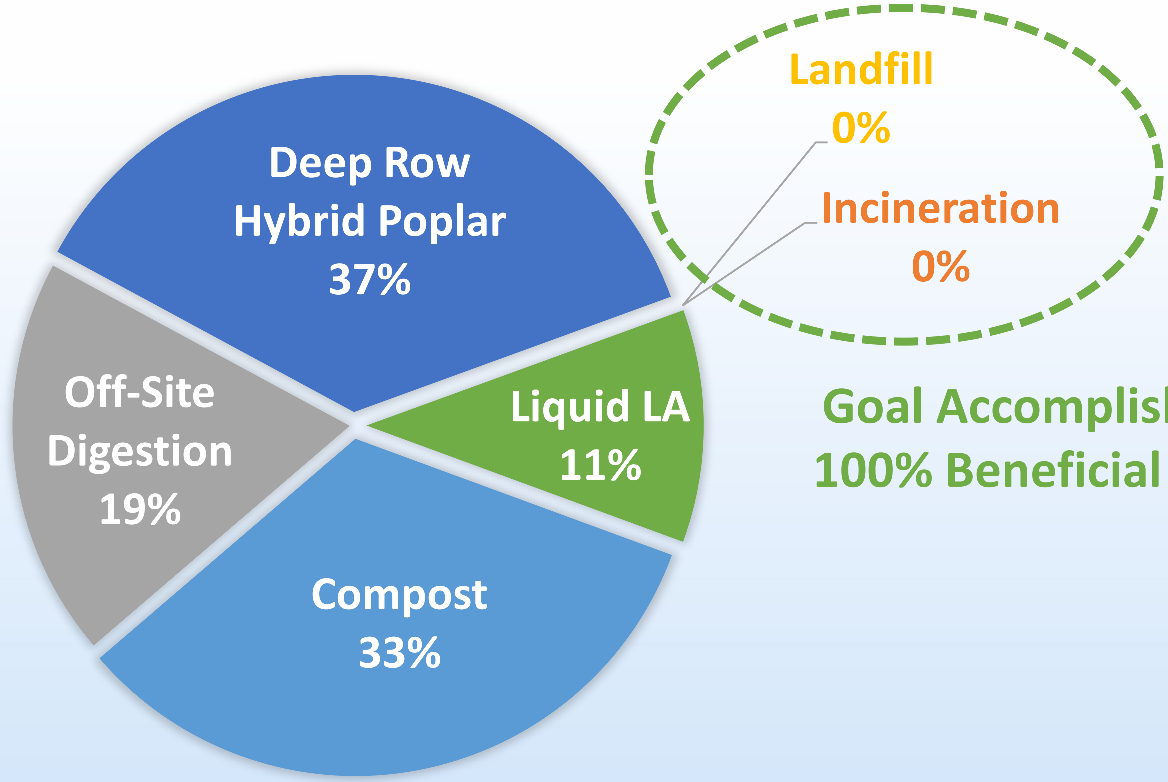
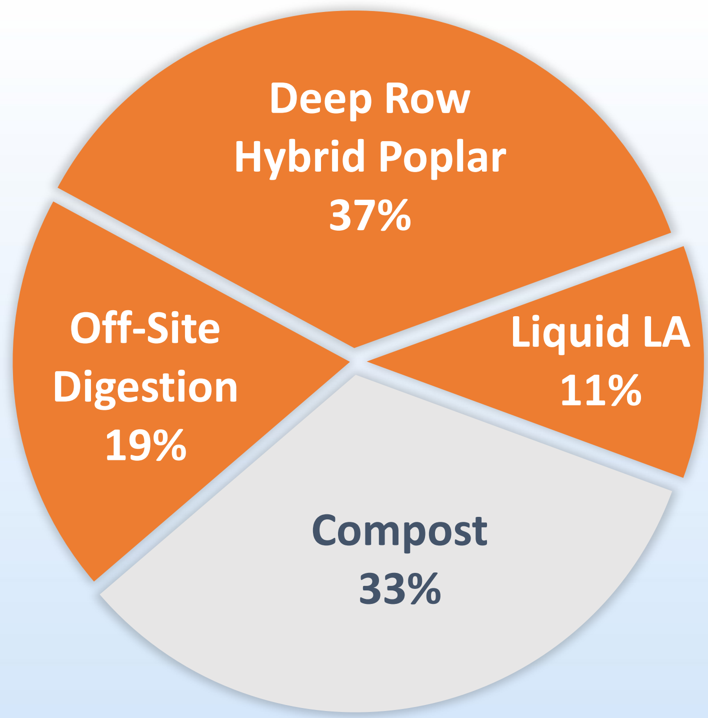
Columbus WW Solids Distribution 2017



Goal Accomplished!!!
100% Beneficial Reuse

Columbus WW Solids Distribution 2017

Heavy Reliance on Private Contractors for Solids Management.



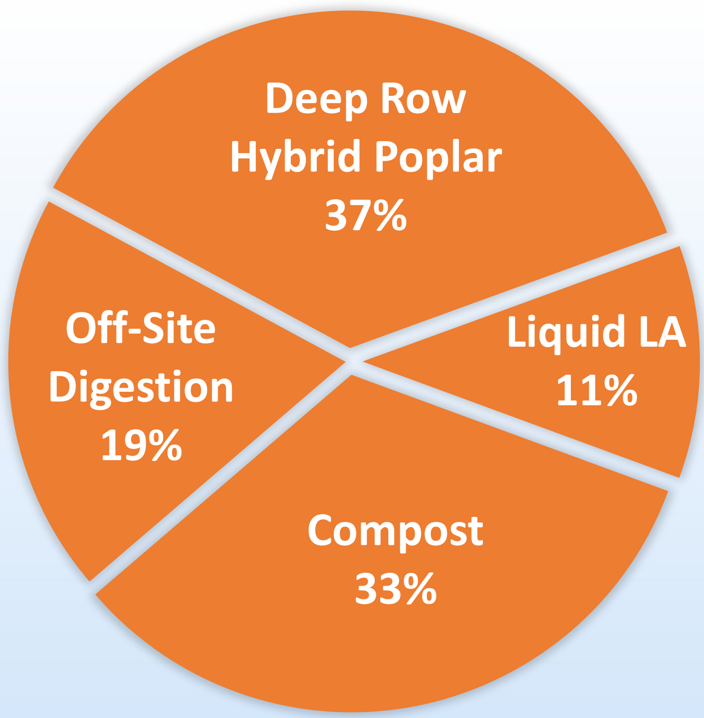
Columbus WW Solids Distribution 2017

Heavy Reliance on Private Contractors for Solids Management.

What if…

… a management outlet goes out of business?

… a regulatory change affects the City's ability to direct solids to a given outlet?



… an unexpected digestion outage creates a large short-term increase in unclassified solids production?

… an economic driver changes the reliability or capacity of a given management outlet?

What are the range of possible outcomes for that scenario?

Can the management system "*weather the storm*"?

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Modeling Solids Handling

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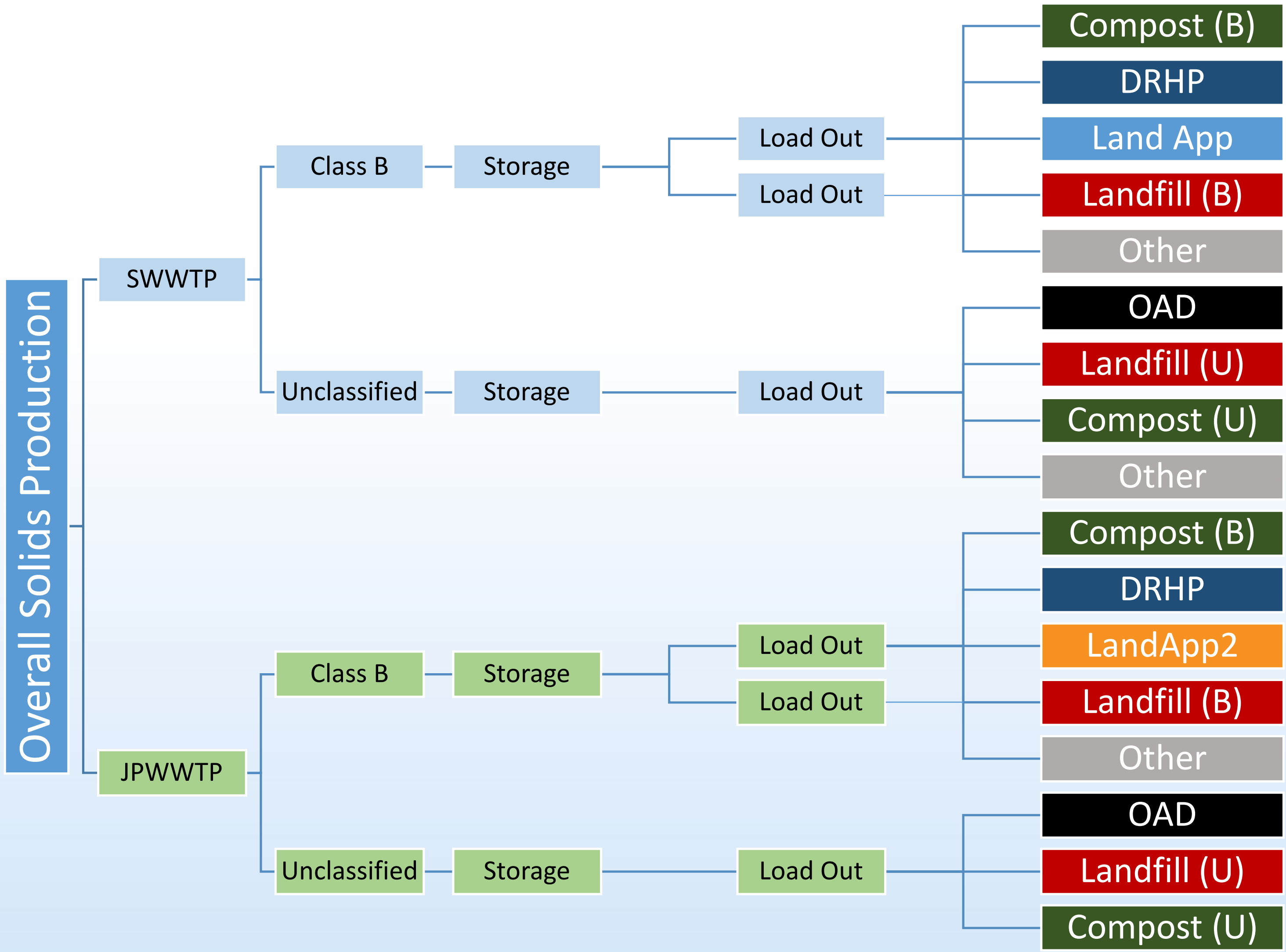

Key:

DRHP = Deep Row Hybrid Poplar Mine Reclamation

OAD = Offsite Anaerobic Digestion

Land App = Land Application

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Monte Carlo Model Overview

Models

Daily

- Production of solids (2 plants, 2 types), based on empirical data
- Solids outlet capacity based on empirical data
- Distribution of solids to six outlets
- BLAF storage utilization at both plants

Monthly

- Digester Reliability/ Catastrophic Failures

Annually

- Costs

Allows for **User-Defined** scenarios

Simulates a full calendar year → **5,000** times

Solids Planning and Risk Evaluation (SPARE) Tool

	A	B	C	D	E	F	G	H	I	J	K	L	M
1													
2						Baseline Solids Production Data (assuming Digesters operational)							Adjusted Daily
3	Day of the week	Count of Days	Month	Week	Date	Overall Solids Production (DT)	JP Class B Solids Production (DT)	SWWTP Class B Solids Production (DT)	JP Unclassified Solids Production (DT)	SWWTP Unclassified Solids Production (DT)	JP Digesters Out of Service for (#) More Days	SWWTP Digesters Out of Service for (#) More Days	JP Class B Production (DT) adjusted for Digester Outage
4	Sunday	1	1	1	1/1/2017	65.95	25.06	23.96	0	16.93	0	0	25.06
5	Monday	2	1	1	1/2/2017	70.98	18.25	22.18	0	30.55	0	0	18.25
6	Tuesday	3	1	1	1/3/2017	56.99	14.13	22.68	0	20.18	0	0	14.13
7	Wednesday	4	1	1	1/4/2017	56.55	16.70	20.79	0	19.06	0	0	16.70
8	Thursday	5	1	1	1/5/2017	77.60	30.22	23.36	0	24.02	0	0	30.22
9	Friday	6	1	1	1/6/2017	61.88	31.46	11.18	0	19.23	0	0	31.46
10	Saturday	7	1	1	1/7/2017	75.56	24.22	33.86	0	17.49	0	0	24.22
11	Sunday	8	1	2	1/8/2017	74.07	24.28	28.32	0	21.47	0	0	24.28
12	Monday	9	1	2	1/9/2017	68.70	30.75	20.46	0	17.49	0	0	30.75
13	Tuesday	10	1	2	1/10/2017	61.65	18.45	22.96	0	20.23	0	0	18.45
14	Wednesday	11	1	2	1/11/2017	76.43	31.92	20.79	0	23.73	0	0	31.92
15	Thursday	12	1	2	1/12/2017	70.73	25.44	23.82	0	21.47	0	0	25.44
16	Friday	13	1	2	1/13/2017	72.83	27.63	24.98	0	20.23	0	0	27.63
17	Saturday	14	1	2	1/14/2017	57.34	19.86	20.00	0	17.49	0	0	19.86
18	Sunday	15	1	3	1/15/2017	74.95	31.17	28.68	0	15.11	0	0	31.17
19	Monday	16	1	3	1/16/2017	79.14	25.02	20.46	0	33.66	0	0	25.02
20	Tuesday	17	1	3	1/17/2017	69.63	19.93	17.72	0	31.98	0	0	19.93
21	Wednesday	18	1	3	1/18/2017	59.45	14.74	24.21	0	20.50	0	0	14.74
22	Thursday	19	1	3	1/19/2017	59.52	18.03	21.63	0	19.87	0	0	18.03

Modeling Undigested (Unclassified) Solids Handling

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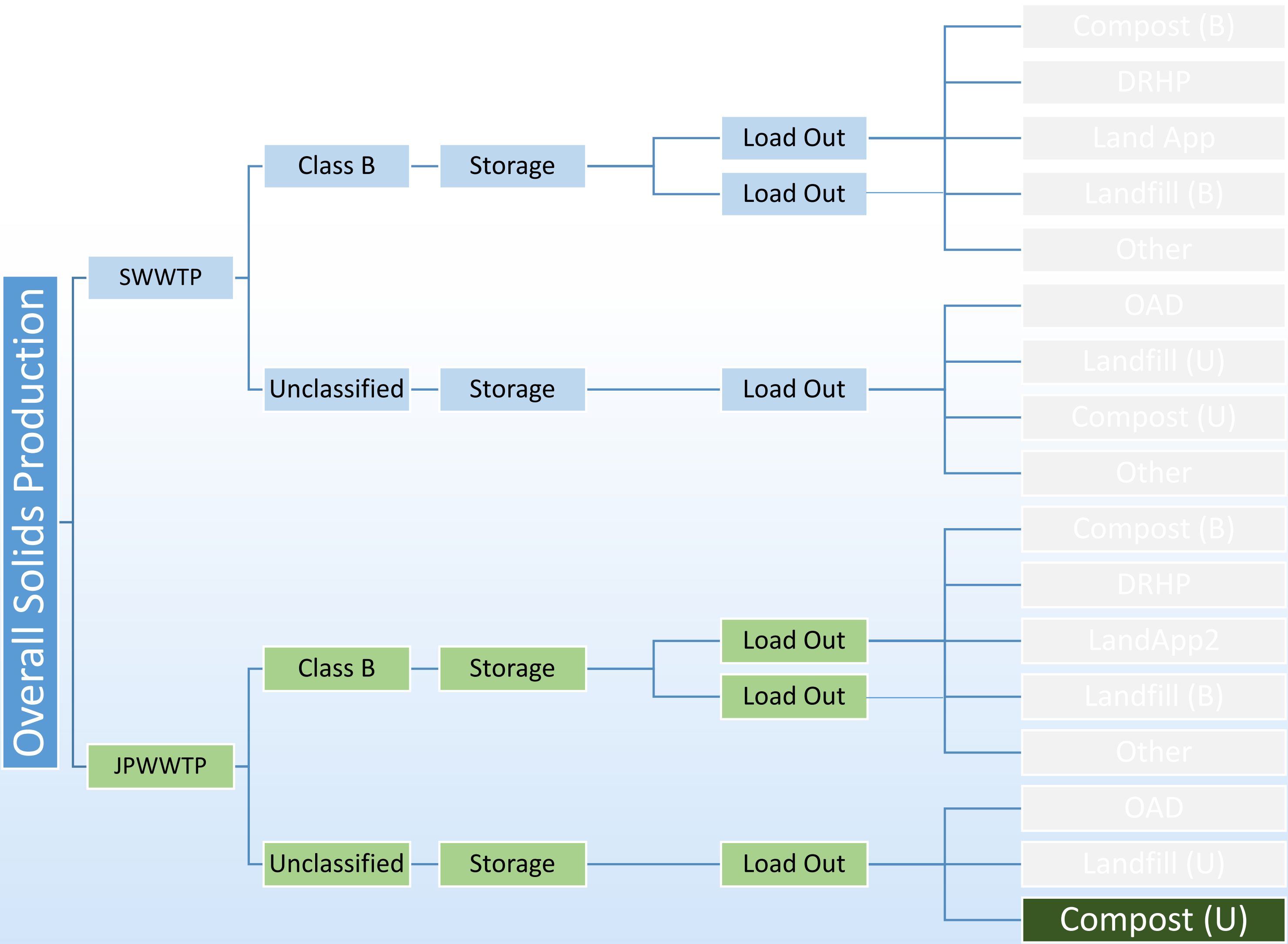

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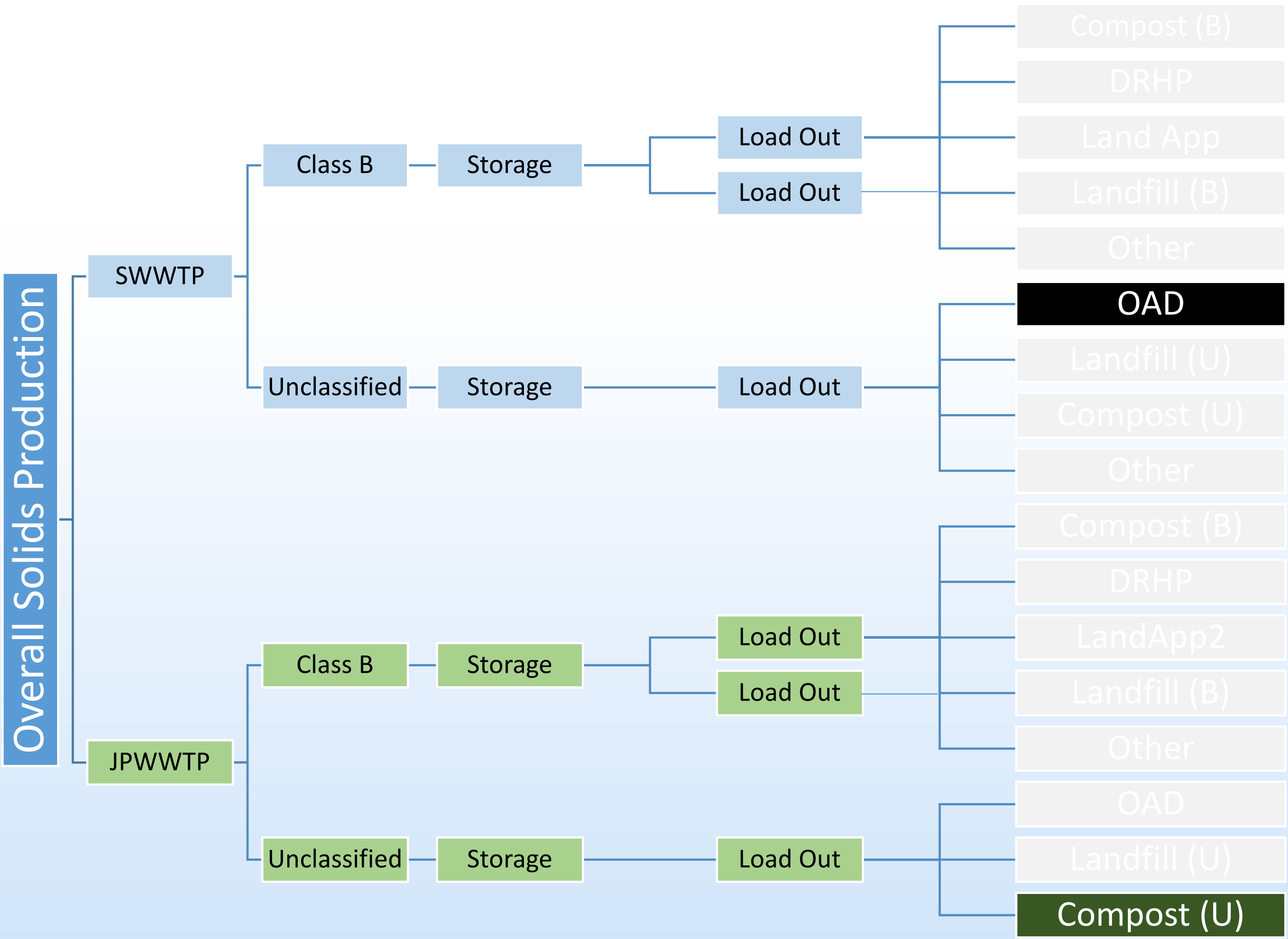

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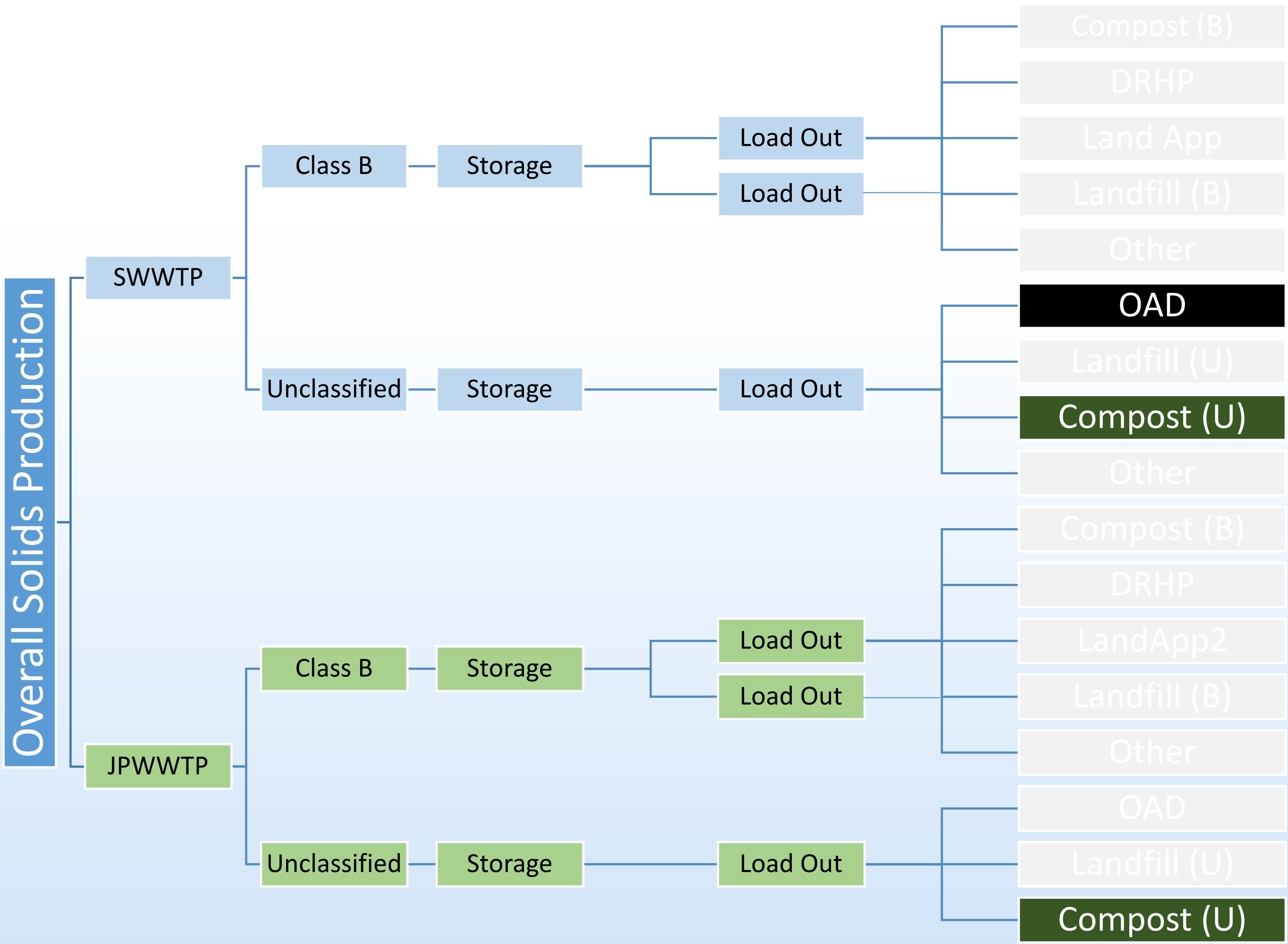

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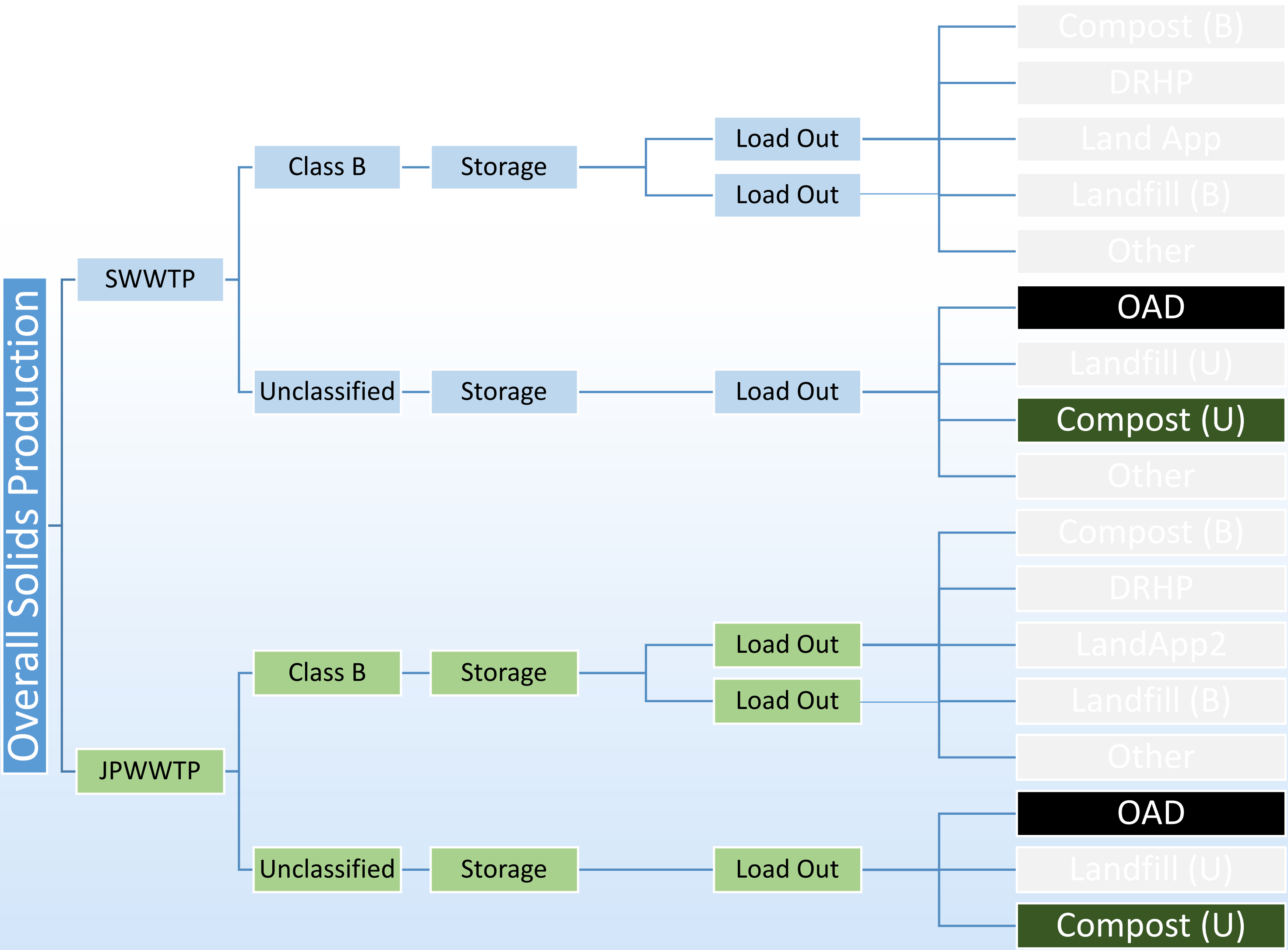

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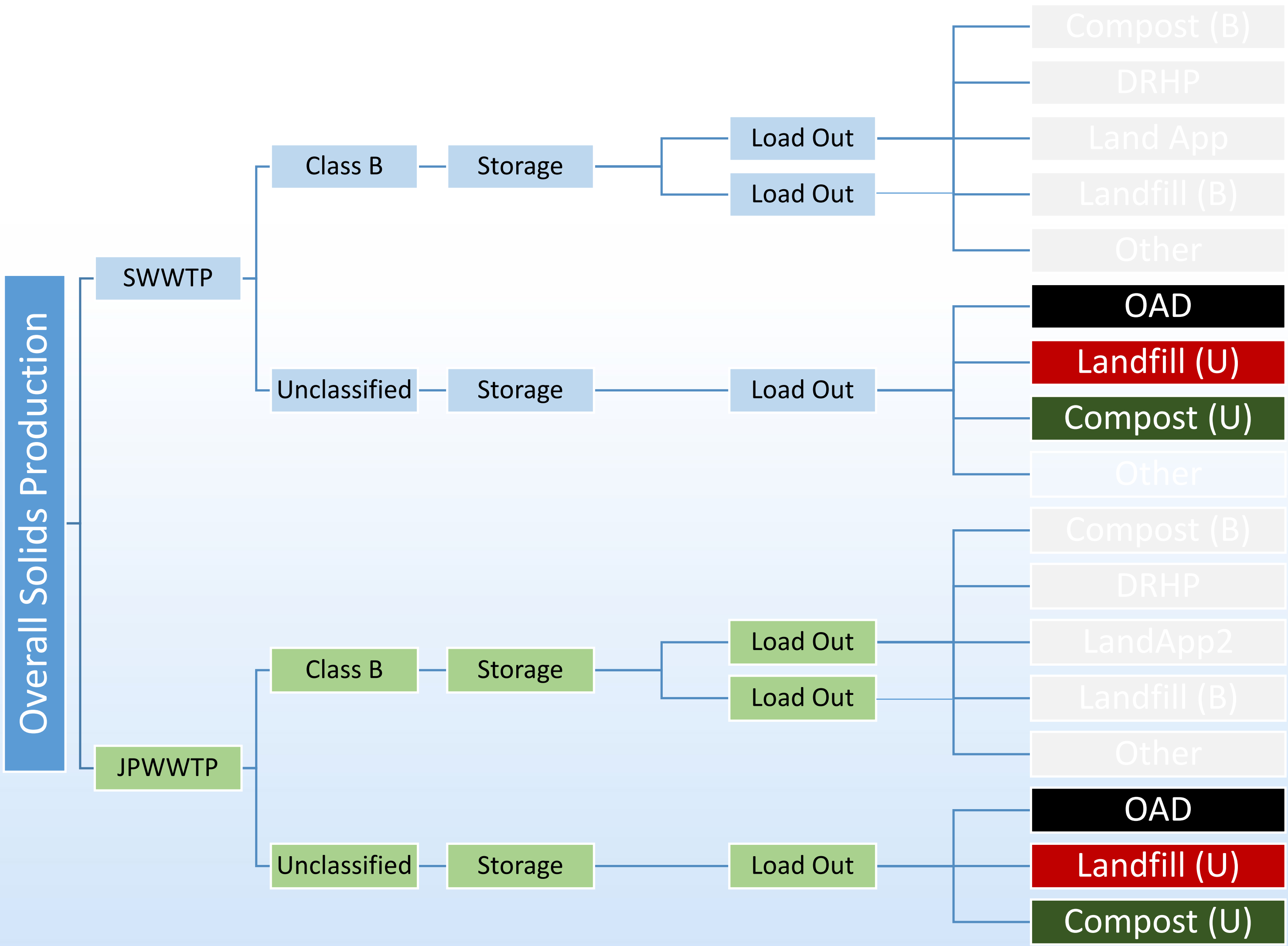

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Modeling Digested (Class B) Solids Handling

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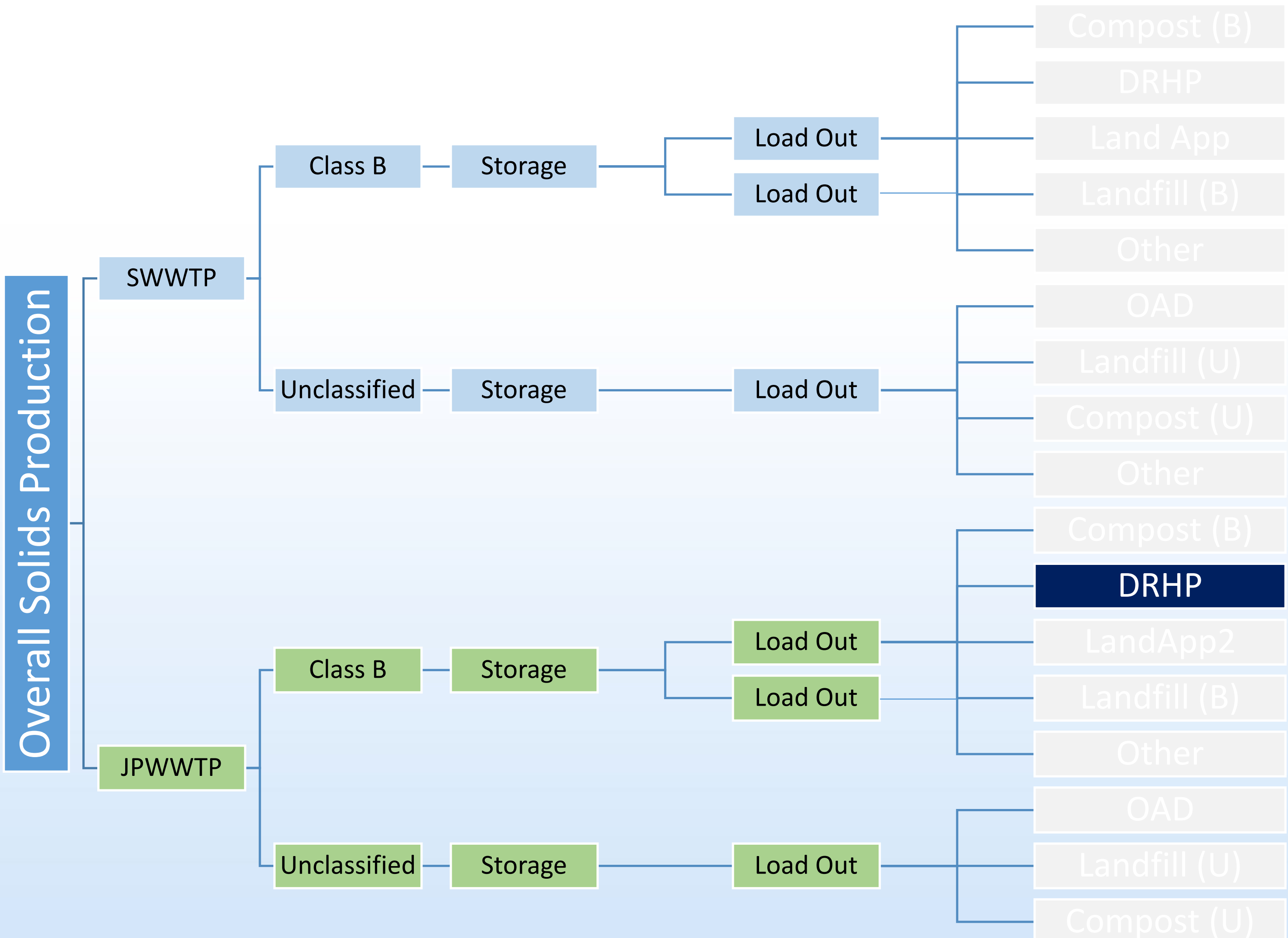

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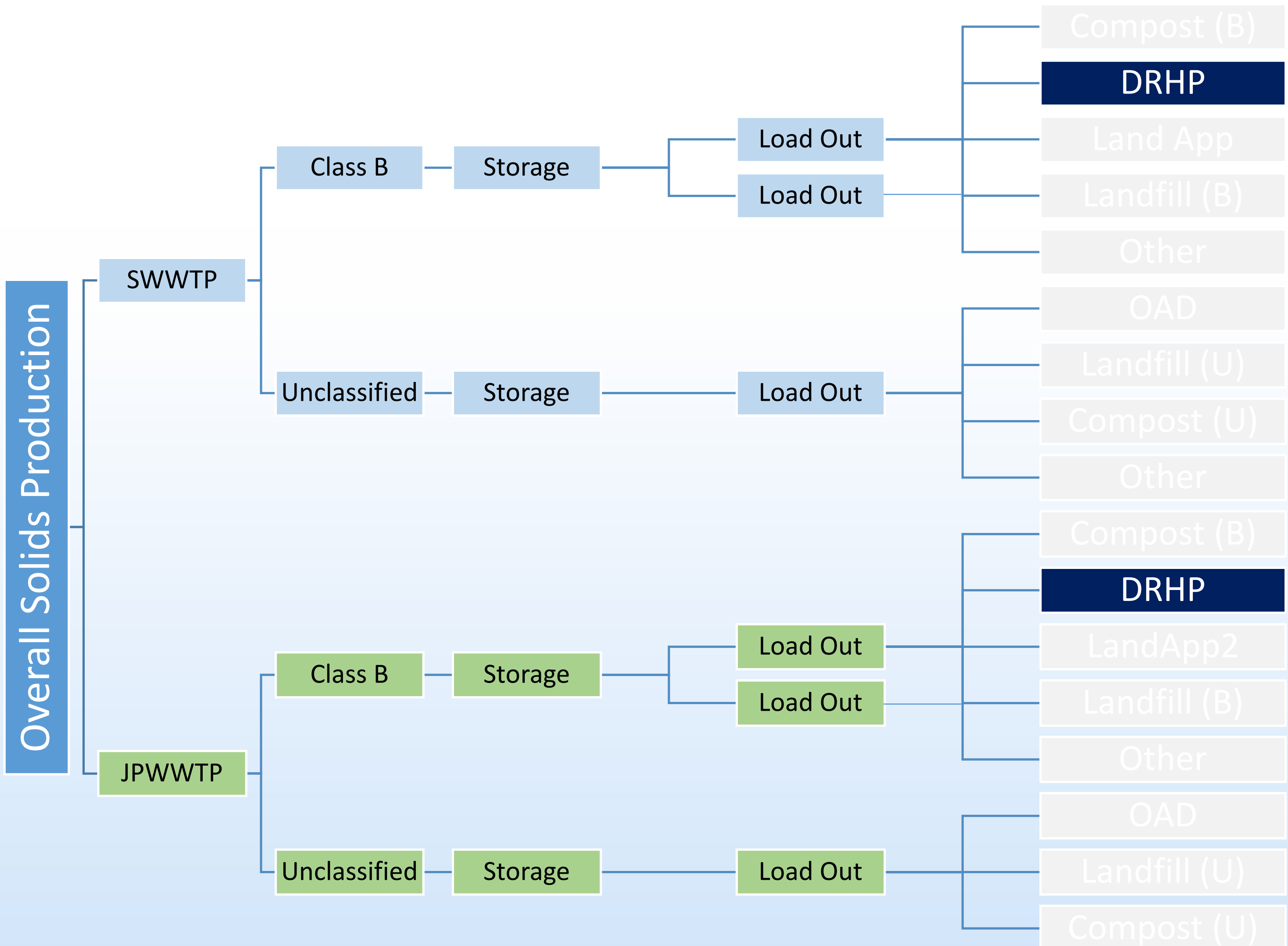

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Class B Solids to DRHP

Baseline Circumstances	If available storage at SWWTP < JP
DRHP capacity dedicated to JP Class B first	DRHP capacity is shared equally

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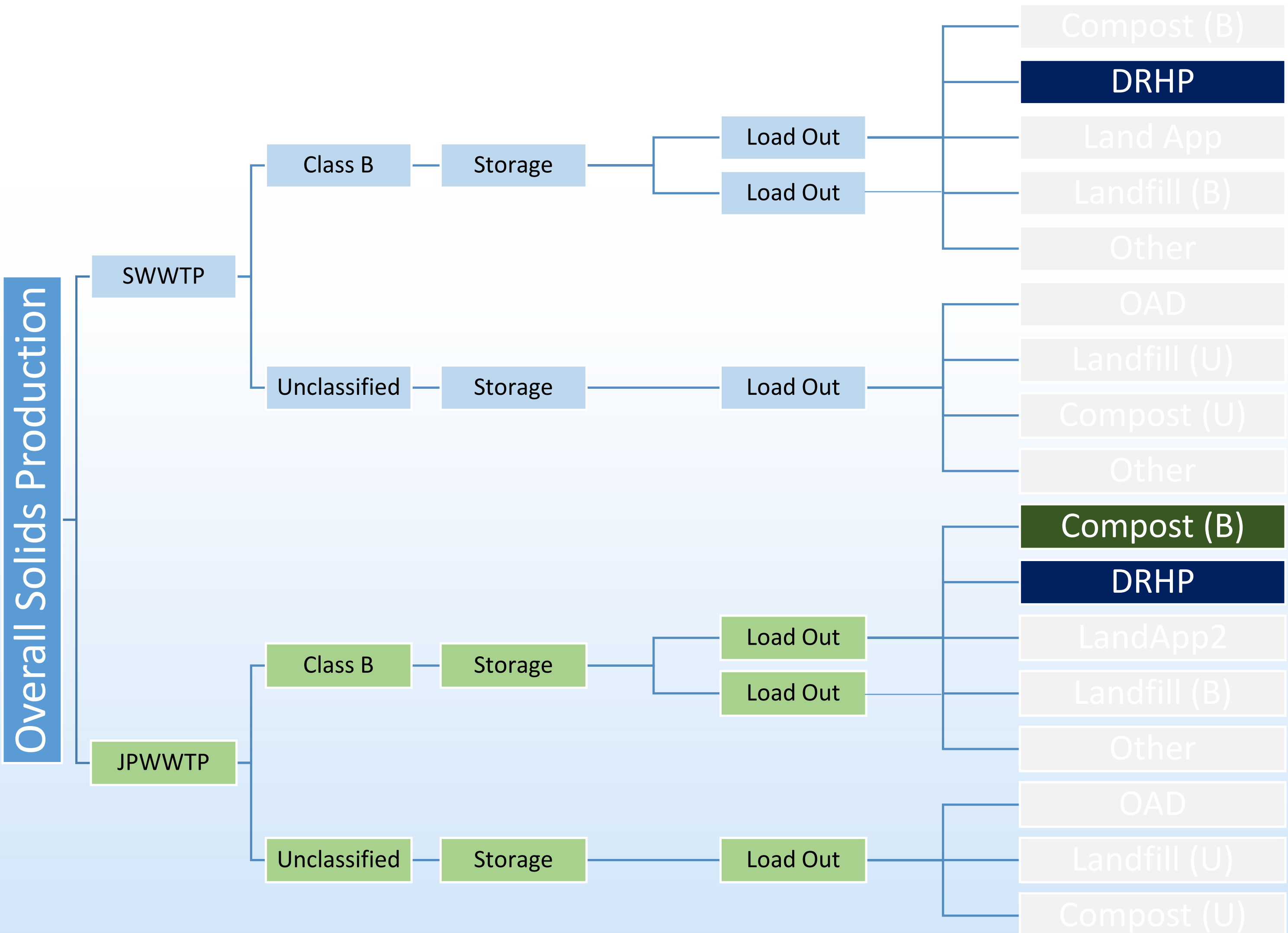

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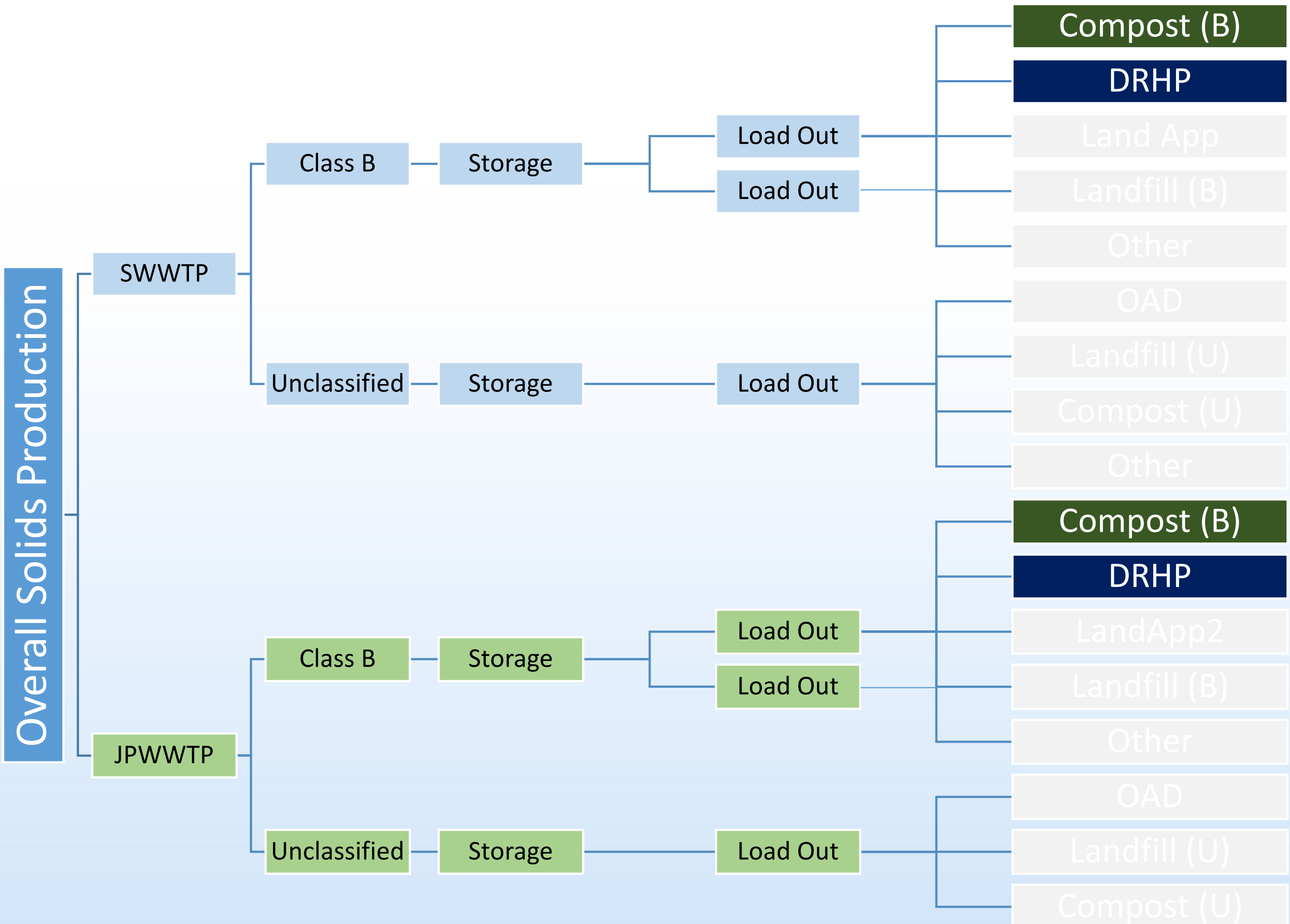

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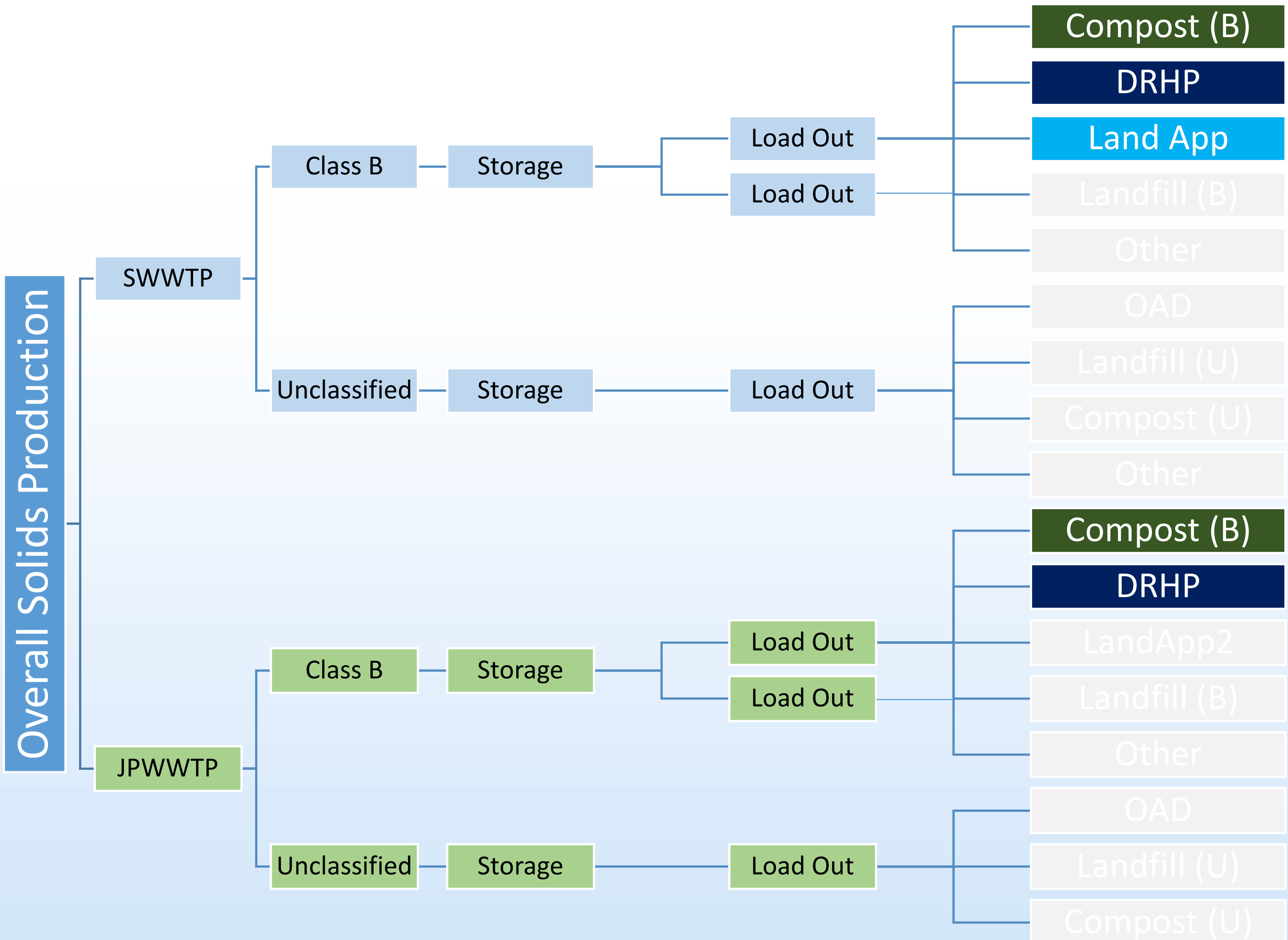
Class B Solids to Compost

Baseline Circumstances	If available storage at SWWTP < JP
Compost capacity dedicated to JP Class B first	Compost capacity dedicated to SWWTP Class B first



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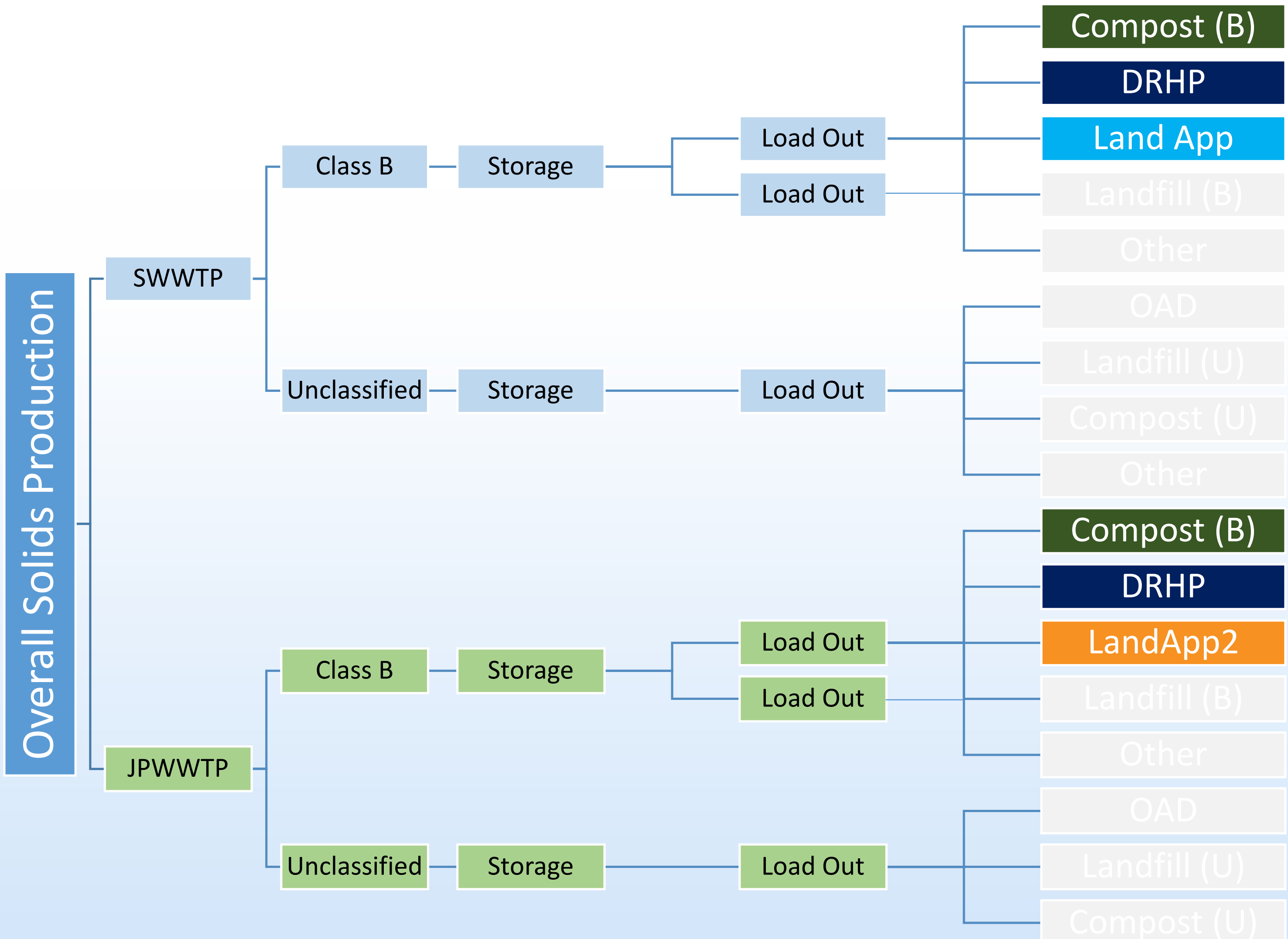

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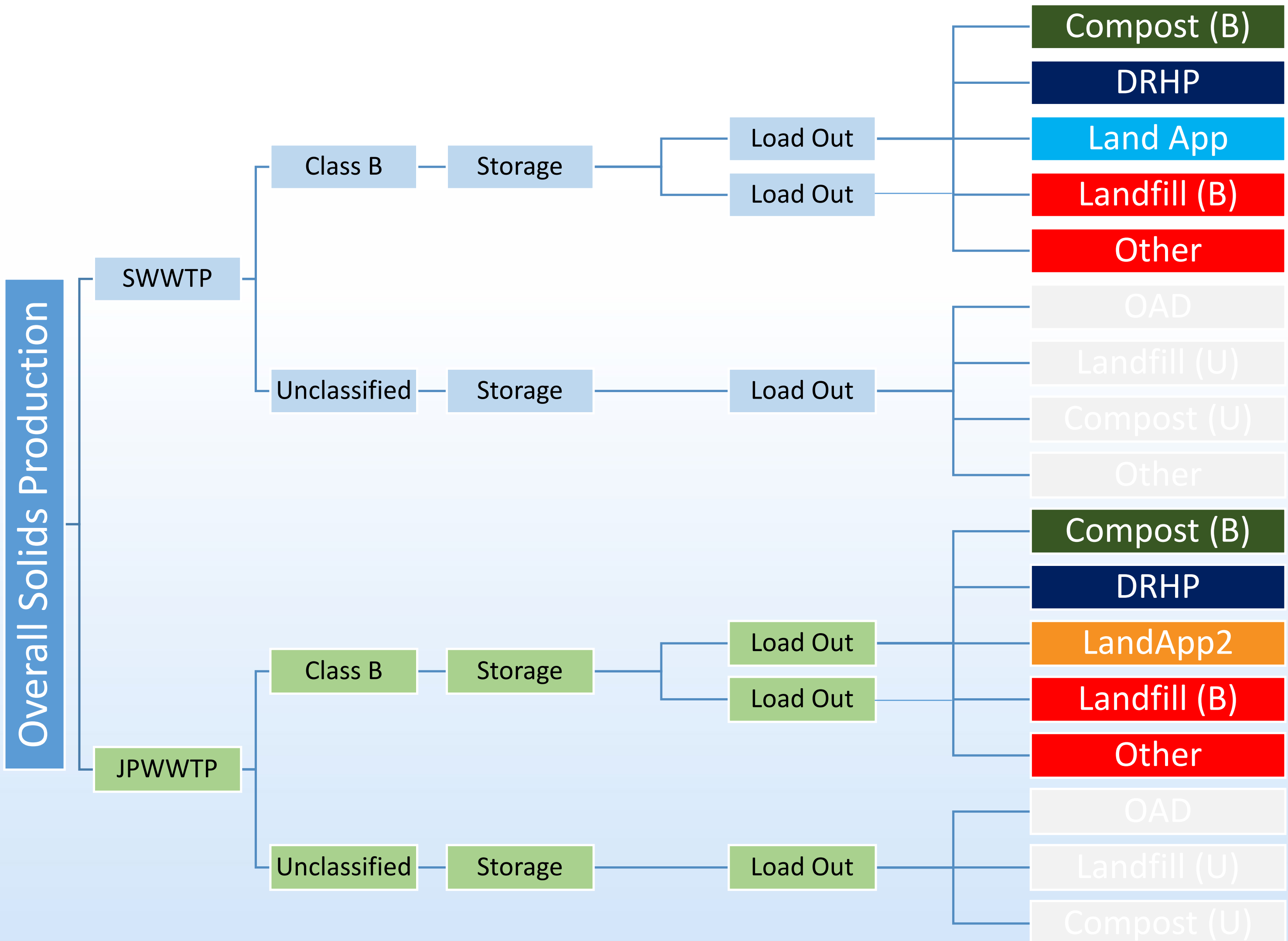

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Modeling Methods

Conventional Static Design Scenarios vs. Monte Carlo

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Static Design v. Monte Carlo?

- Static Modeling involves the user to define discrete scenarios
  - Average (Solids Production, Digester Reliability, Outlet Availability)
  - Worst Case / Worst Year

But what is a hypothetical worst year?

Defining the Worst Case

Compost production is down due to construction

It won't stop raining and I can't land apply

Solids production is high at both plants

Digesters reliability is down

My primary outlet went out of business

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Defining the Worst Case

Why Apply Monte Carlo?

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Some benefits of Monte Carlo

Monte Carlo not only answers these questions, it eliminates the need to ask the questions in the first place, saving time and money.

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With MC: JP Class B Solids Production
9,700
9,200
8,700
8,200
7,700
7,200
SOLIDS, DT
0
10
20
30
40
50
60
70
80
90
100
PERCENTILE %

What About the Output?

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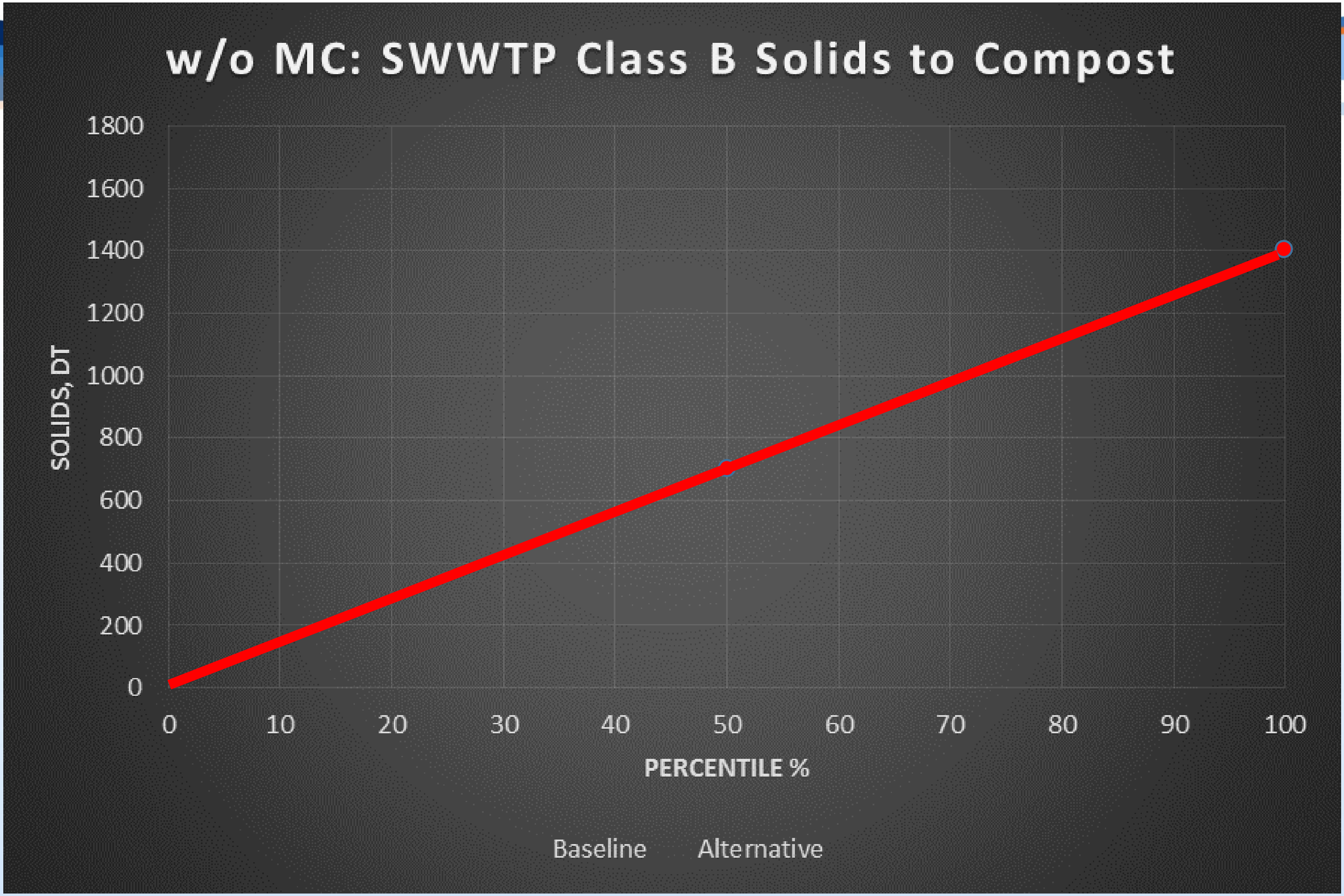
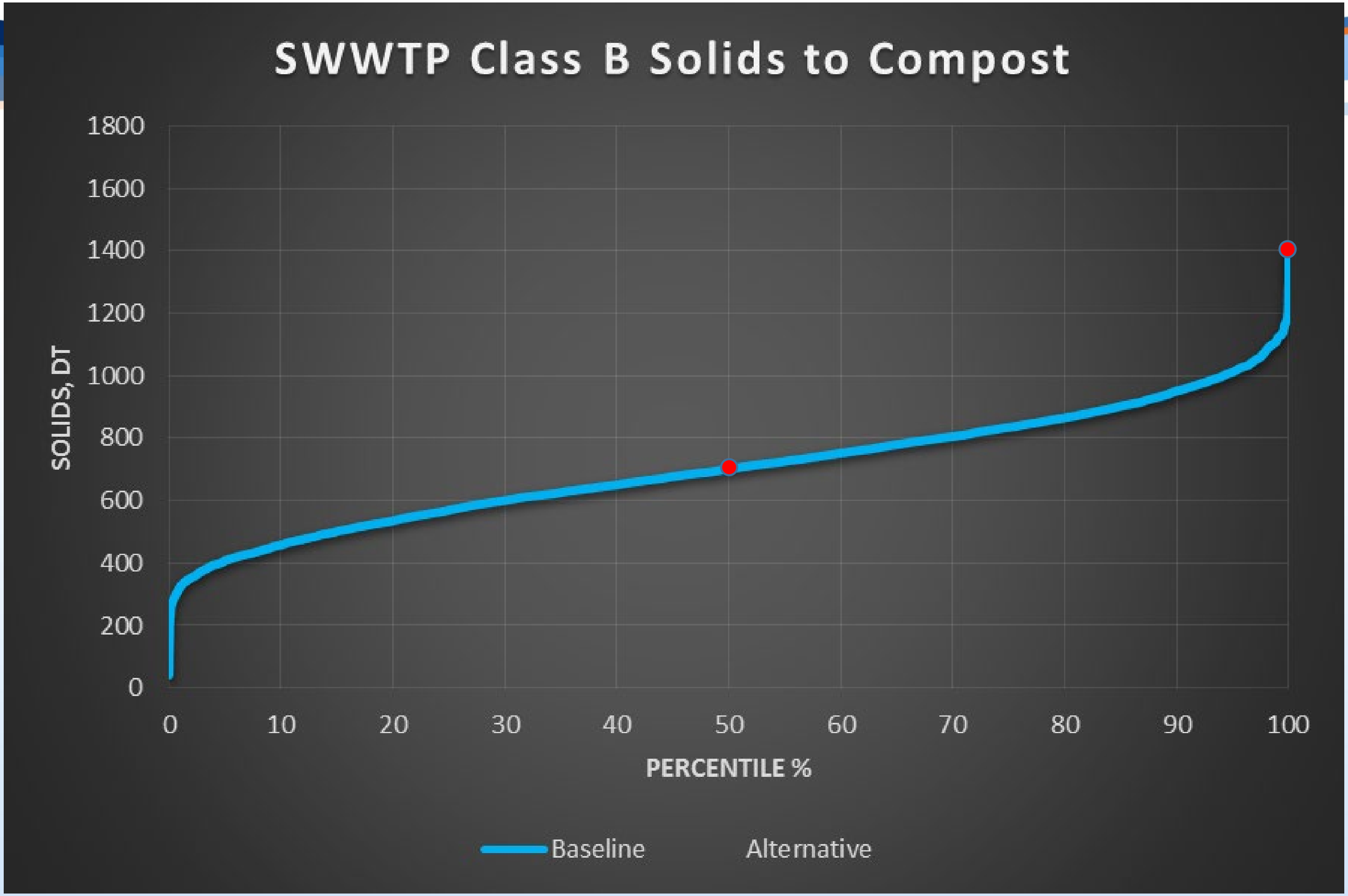

w/o MC: SWWTP Class B Solids to Compost
1800
1600
1400
1200
1000
800
600
400
200
0
SOLIDS, DT
0
10
20
30
40
50
60
70
80
90
100
PERCENTILE %
Baseline
Alternative



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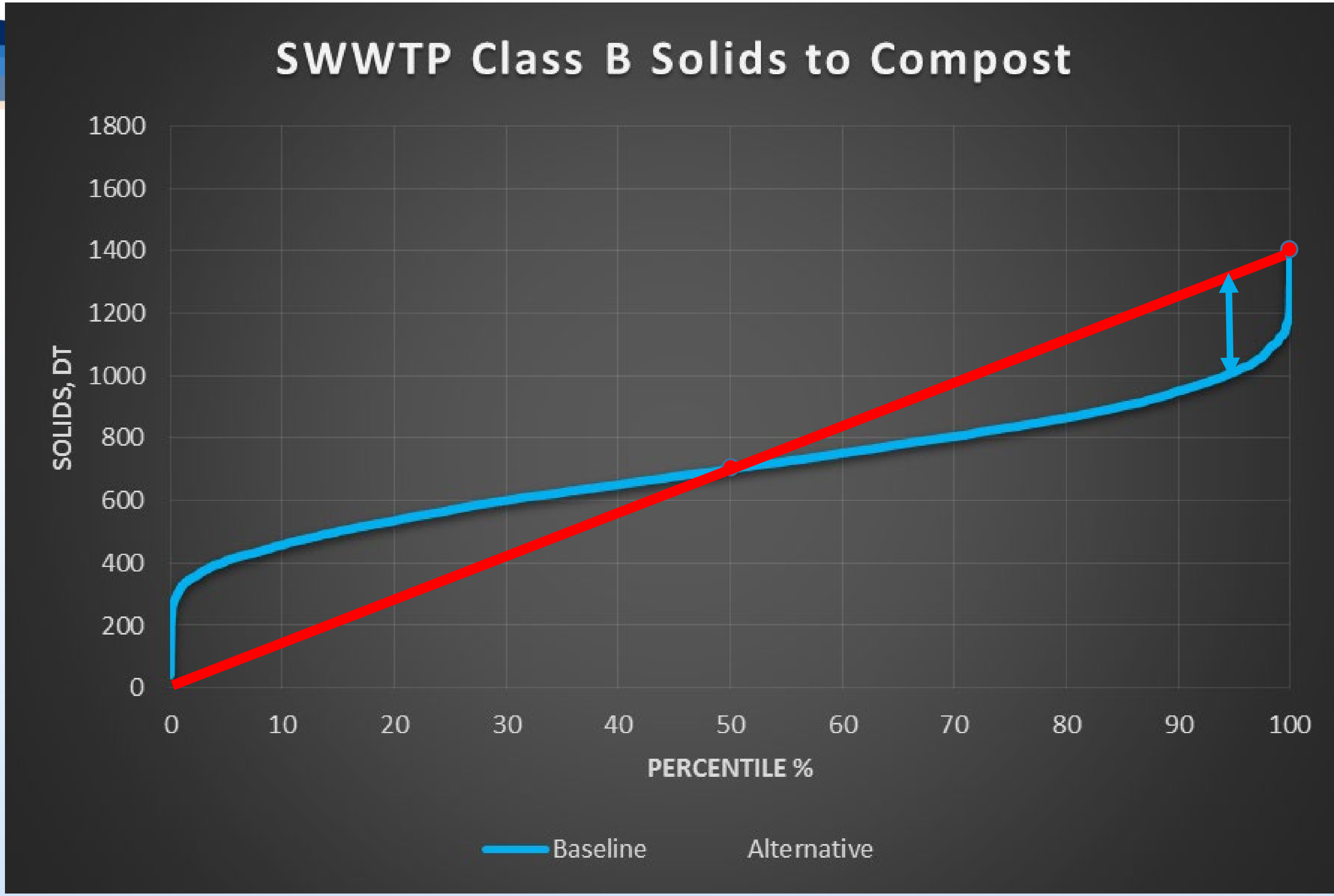
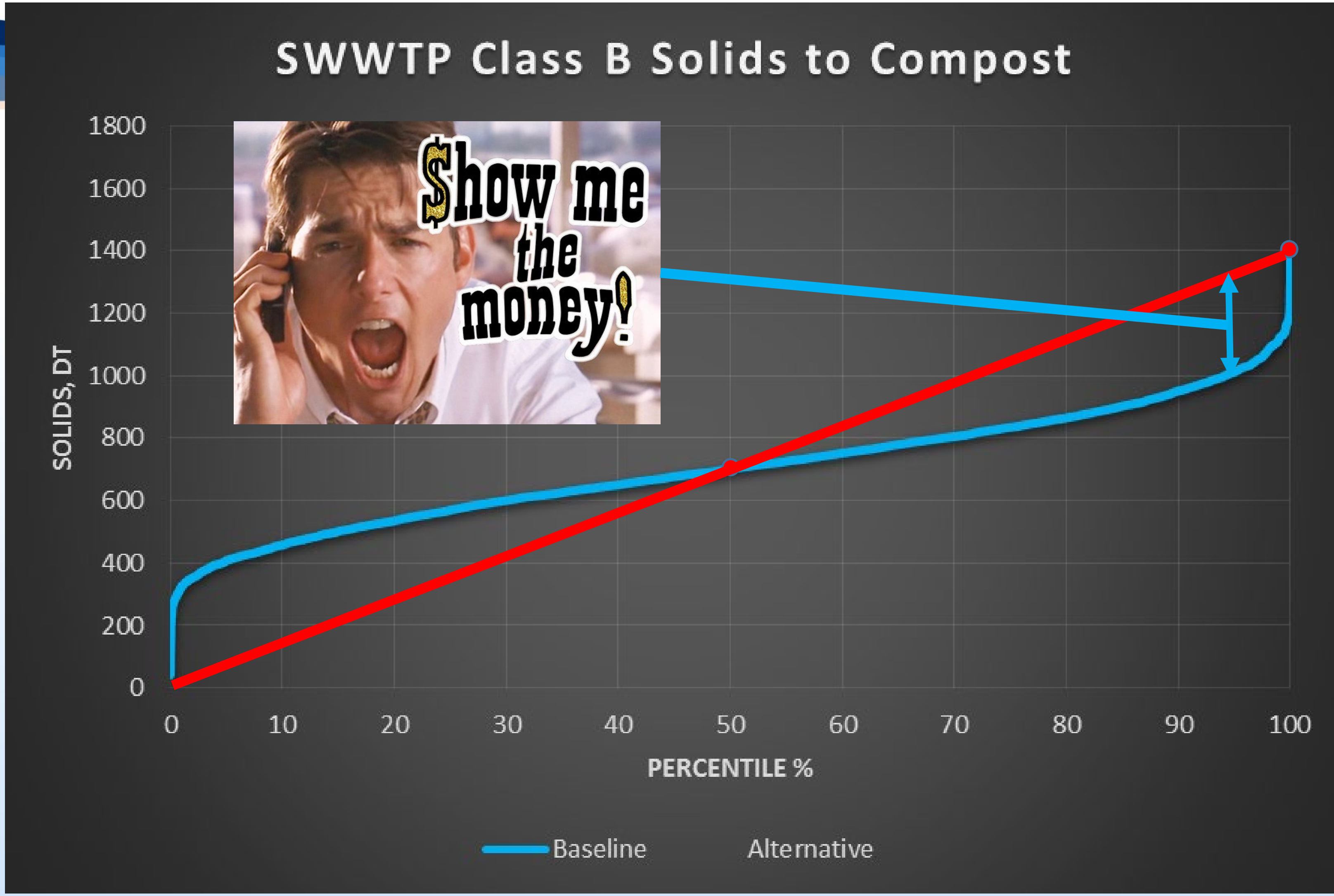

SWWTP Class B Solids to Compost
1800
1600
1400
1200
1000
800
600
400
200
0
SOLIDS, DT
0
10
20
30
40
50
60
70
80
90
100
PERCENTILE %
Baseline
Alternative


SWWTP Class B Solids to Compost
$how me the money!
1800
1600
1400
1200
1000
800
600
400
200
0
SOLIDS, DT
0
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20
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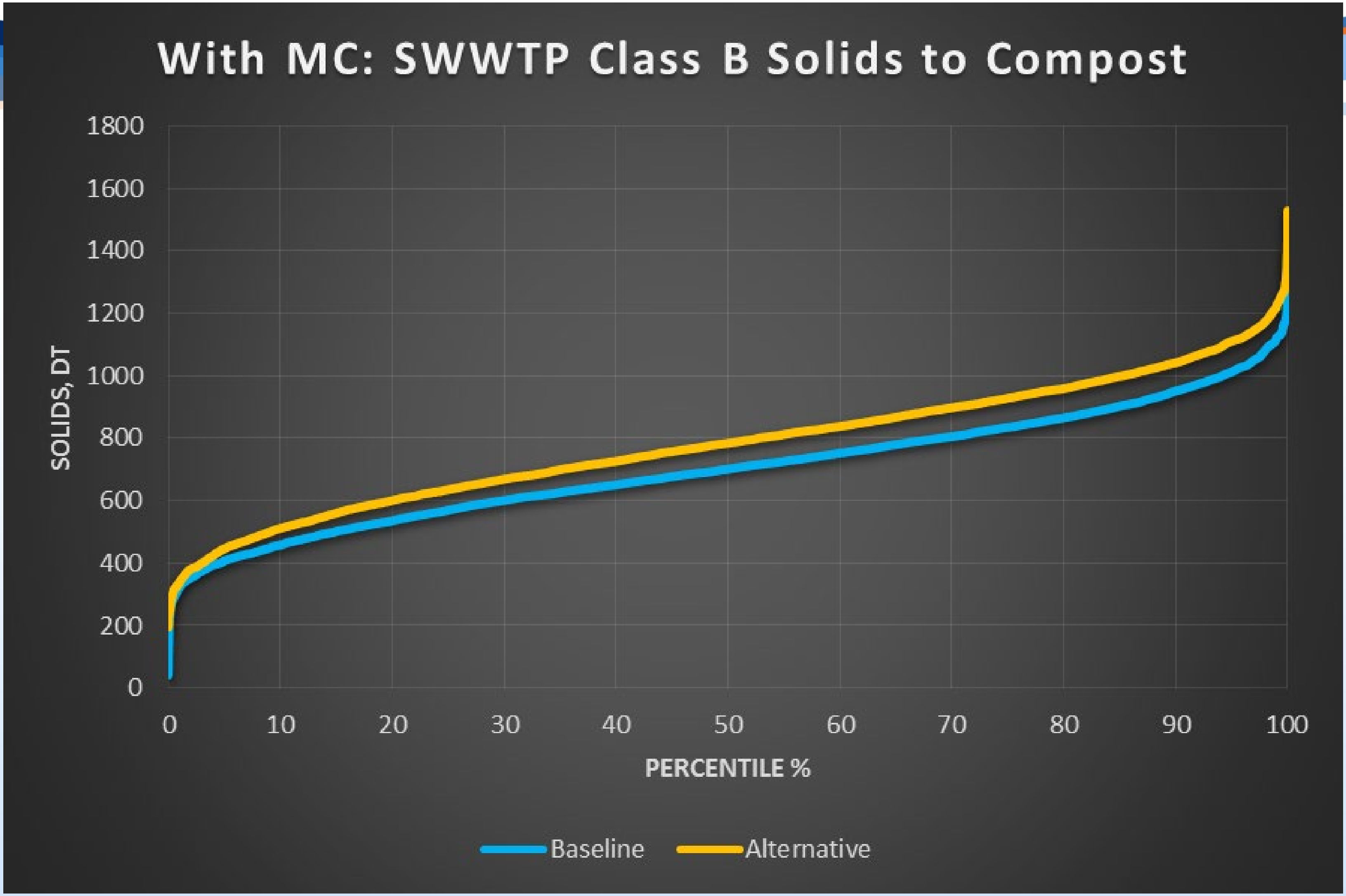
40
50
60
70
80
90
100
PERCENTILE %
Baseline
Alternative



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How Does Monte Carlo Work?

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Rolling Two Dice

Known Dice Role Probabilities		
Dice Roll	# of Ways to Roll	Probability
2	1	0.028
3	2	0.056
4	3	0.083
5	4	0.111
6	5	0.139
7	6	0.167
8	5	0.139
9	4	0.111
10	3	0.083
11	2	0.056
12	1	0.028

What if you didn't know?

Die Role Probabilities

Die Roll	Probability
1	0.167
2	0.167
3	0.167
4	0.167
5	0.167
6	0.167

Monte Carlo - 1000 Simulations			
Iteration	Die 1	Die 2	Sum
1			0
2			0
3			0
4			0
5			0
6			0
7			0
8			0
9			0
10			0

Monte Carlo Results			
Dice Roll	Frequency	Probability	Deviation from Known
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			

Die Role Probabilities

Die Roll	Probability
1	0.167
2	0.167
3	0.167
4	0.167
5	0.167
6	0.167

Probability Bins

0	1
0.1666667	2
0.3333333	3
0.5	4
0.6666667	5
0.8333333	6
1	

0.39027	random number1
0.9489769	random number2

Monte Carlo - 1000 Simulations

Iteration	Die 1	Die 2	Sum
1	3	6	9
2	4	2	6
3	5	1	6
4	2	1	3
5	6	1	7
6	5	4	9
7	2	5	7
8	1	3	4
9	6	5	11
10	2	2	4
11	6	4	10
12	4	2	6
13	1	6	7
14	6	3	9
15	5	4	9
16	6	1	7
17	4	2	6
18	1	6	7
19	1	3	4
20	1	2	3
21	1	1	2
22	3	4	7
23	1	1	2
24	1	3	4
25	1	4	5
26	1	5	6
27	3	2	5
28	6	2	8
29	4	5	9
30	6	5	11
31	6	1	7
32	5	5	10
33	5	1	6

Monte Carlo Results

Dice Roll	Frequency	Probability	Deviation from Known
2	31	0.031	0.32%
3	58	0.058	0.24%
4	68	0.068	-1.53%
5	123	0.123	1.19%
6	149	0.149	1.01%
7	152	0.152	-1.47%
8	139	0.139	0.01%
9	112	0.112	0.09%
10	66	0.066	-1.73%
11	66	0.066	1.04%
12	36	0.036	0.82%

Monte Carlo Analysis Elements and Structure

Models

Daily
- Production of solids (2 plants, 2 types), based on empirical data
- Solids outlet capacity based on empirical data
- Distribution of solids to six outlets
- BLAF storage utilization at both plants

Monthly
- Digester Reliability/ Catastrophic Failures

Annually
- Costs

Allows for **User-Defined** scenarios

Simulates a full calendar year → **5,000** times

Monte Carlo Analysis for DOSD Solids Disposal

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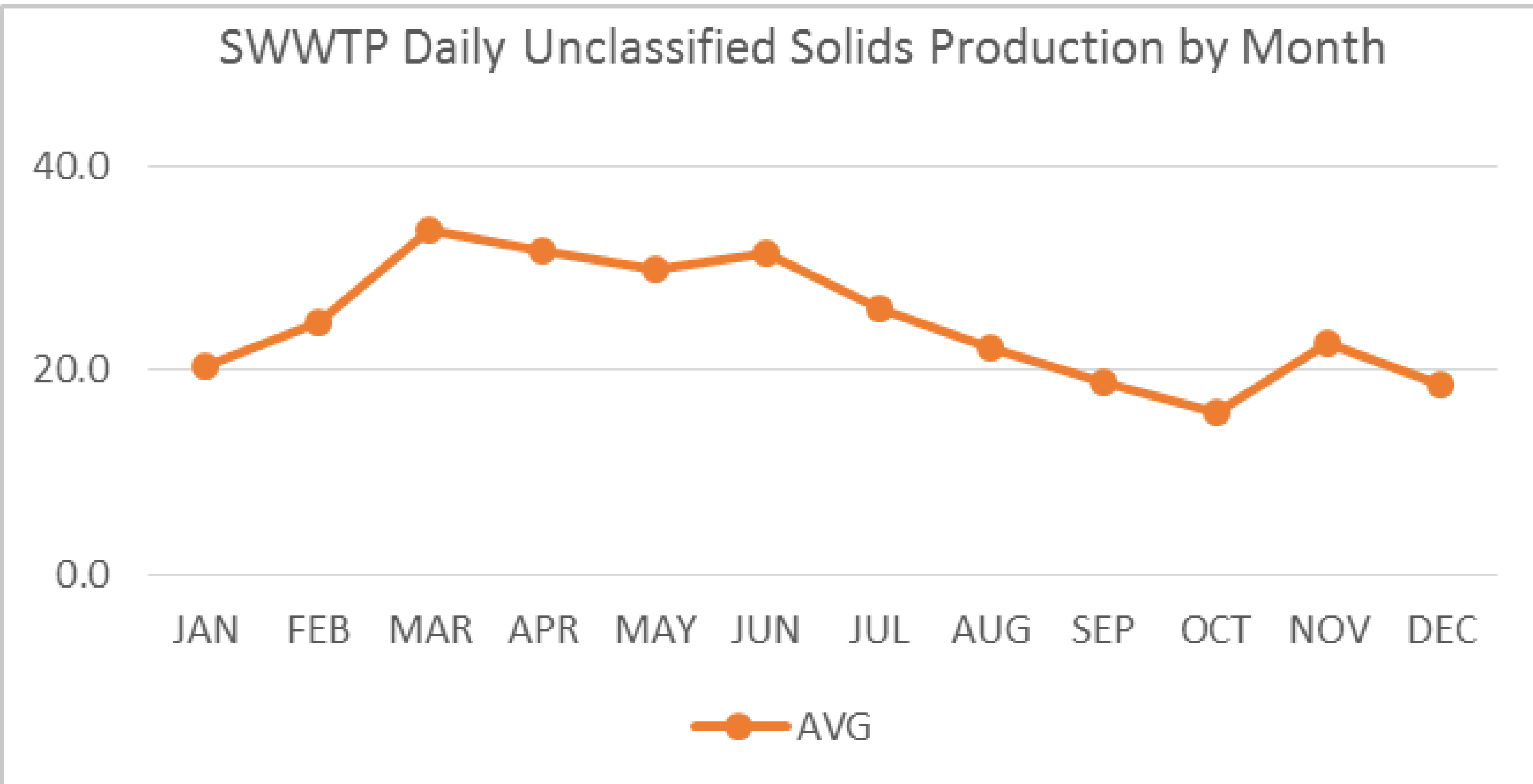
Solids Production



Daily Solids Production Data 2013-2017

JACKSON PIKE Daily UNCLASSIFIED solids production - historical											
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	2	3	4	5	6	7	8	9	10	11	12
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

JACKSON PIKE Daily CLASS B solids production - historical											
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	2	3	4	5	6	7	8	9	10	11	12
18.57	20.64	14.14	17.22	28.28	28.70	27.68	20.89	17.82	24.53	21.54	9.63
18.54	24.98	15.55	19.33	29.31	27.08	25.76	20.56	19.28	26.72	21.47	9.63
13.55	28.45	13.43	19.59	22.70	20.65	17.76	21.04	19.39	30.32	22.37	13.06
17.65	25.96	15.40	22.57	17.88	18.98	22.28	20.29	23.87	26.73	21.22	16.63
21.67	16.75	6.01	22.58	16.93	23.23	18.30	20.13	27.28	42.76	21.41	15.23
19.83	21.60	22.19	22.12	18.32	19.63	19.02	19.85	21.35	34.39	16.22	10.76
26.43	35.23	15.39	18.06	18.30	18.40	2.81	14.42	27.42	31.76	14.15	12.31
25.44	30.61	11.17	16.79	18.31	23.39	20.02	19.25	27.55	33.06	14.43	10.50
25.05	28.15	13.93	16.14	16.17	20.01	34.38	27.71	27.77	31.63	17.44	17.72
19.93	28.15	11.12	22.68	18.34	15.90	35.44	29.15	27.61	21.57	19.83	18.42
12.82	26.05	12.84	19.58	18.89	16.92	33.94	29.57	6.14	19.92	19.95	20.43
6.55	26.07	26.52	11.07	18.34	17.73	28.10	31.50	11.34	14.12	19.13	17.84
14.21	25.02	26.36	13.21	18.85	15.83	23.36	30.46	20.73	2.46	9.24	18.04
17.24	25.01	23.28	17.44	18.31	16.00	23.19	32.62	0.00	12.02	0.00	18.04
18.19	24.60	22.26	16.16	21.76	14.84	22.13	17.44	0.00	13.52	0.00	18.89
18.94	26.04	23.26	22.47	28.18	15.53	20.39	13.86	0.00	15.20	0.00	18.03
14.68	26.04	22.25	28.05	26.06	14.97	12.41	12.35	0.00	18.61	4.65	21.96
14.12	24.99	12.32	22.39	26.19	19.47	0.00	0.00	0.00	17.70	16.21	22.27
18.20	25.00	10.10	0.00	20.21	27.48	11.96	0.00	0.00	12.39	14.14	20.54
23.00	14.88	12.56	22.54	18.88	27.23	17.95	8.71	0.00	19.56	28.26	19.69
23.74	10.10	16.01	19.39	17.92	37.09	19.06	18.28	0.00	17.93	19.10	8.99
14.74	9.65	23.85	17.58	19.62	44.21	19.85	31.66	0.00	16.01	12.61	12.05
18.12	10.12	24.78	38.49	21.25	61.37	14.84	34.56	18.28	16.52	8.81	19.36
30.25	10.58	20.36	17.88	19.90	0.00	10.65	19.05	24.00	18.31	14.91	20.12
26.26	13.31	17.18	17.37	19.43	0.00	31.76	38.27	19.80	17.61	21.57	13.64
20.36	14.88	37.44	14.47	22.04	0.00	28.62	19.98	20.86	18.09	24.17	6.87

Modeling Daily Solids Production using MC

G4 =HLOOKUP($C4,JPClassBProduction,RANDBETWEEN(2,187))

	A	B	C	D	E	F	G	H	I	J
1										
2						Baseline Solids Production Data (assuming Digesters operational)				
3	Day of the week	Count of Days	Month	Week	Date	Overall Solids Production (DT)	JP Class B Solids Productio n (DT)	SWWTP Class B Solids Production (DT)	JP Unclassified Solids Production (DT)	SWWTP Unclassified Solids Production (DT)
4	Sunday	1	1	1	1/1/2017	73.50	25.31	28.32	0	19.87
5	Monday	2	1	1	1/2/2017	65.13	21.67	30.03	0	13.43
6	Tuesday	3	1	1	1/3/2017	72.09	20.97	29.00	0	22.12
7	Wednesday	4	1	1	1/4/2017	53.59	15.95	24.21	0	13.43
8	Thursday	5	1	1	1/5/2017	70.65	28.90	22.68	0	19.06
9	Friday	6	1	1	1/6/2017	60.89	18.25	24.21	0	18.43
10	Saturday	7	1	1	1/7/2017	79.25	31.56	27.29	0	20.40

Daily Solids Production Lookup Tables

JACKSON PIKE Daily UNCLASSIFIED solids production - historical											
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

JACKSON PIKE Daily CLASS B solids production - historical											
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
18.57	20.64	14.14	17.22	28.28	28.70	27.68	20.89	17.82	24.53	21.54	9.63
18.54	24.98	15.55	19.33	29.31	27.08	25.76	20.56	19.28	26.72	21.47	9.63
13.55	28.45	13.43	19.59	22.70	20.65	17.76	21.04	19.39	30.32	22.37	13.06
17.65	25.96	15.40	22.57	17.88	18.98	22.28	20.29	23.87	26.73	21.22	16.63
21.67	16.75	6.01	22.58	16.93	23.23	18.30	20.13	27.28	42.76	21.41	15.23
19.83	21.60	22.19	22.12	18.32	19.63	19.02	19.85	21.35	34.39	16.22	10.76
26.43	35.23	15.39	18.06	18.30	18.40	2.81	14.42	27.42	31.76	14.15	12.31
25.44	30.61	11.17	16.79	18.31	23.39	20.02	19.25	27.55	33.06	14.43	10.50
25.05	28.15	13.93	16.14	16.17	20.01	34.38	27.71	27.77	31.63	17.44	17.72
19.93	28.15	11.12	22.68	18.34	15.90	35.44	29.15	27.61	21.57	19.83	18.42
12.82	26.05	12.84	19.58	18.89	16.92	33.94	29.57	6.14	19.92	19.95	20.43
6.55	26.07	26.52	11.07	18.34	17.73	28.10	31.50	11.34	14.12	19.13	17.84
14.21	25.02	26.36	13.21	18.85	15.83	23.36	30.46	20.73	2.46	9.24	18.04
17.24	25.01	23.28	17.44	18.31	16.00	23.19	32.62	0.00	12.02	0.00	18.04
18.19	24.60	22.26	16.16	21.76	14.84	22.13	17.44	0.00	13.52	0.00	18.89
18.94	26.04	23.26	22.47	28.18	15.53	20.39	13.86	0.00	15.20	0.00	18.03
14.68	26.04	22.25	28.05	26.06	14.97	12.41	12.35	0.00	18.61	4.65	21.96
14.12	24.99	12.32	22.39	26.19	19.47	0.00	0.00	0.00	17.70	16.21	22.27
18.20	25.00	10.10	0.00	20.21	27.48	11.96	0.00	0.00	12.39	14.14	20.54
23.00	14.88	12.56	22.54	18.88	27.23	17.95	8.71	0.00	19.56	28.26	19.69
23.74	10.10	16.01	19.39	17.92	37.09	19.06	18.28	0.00	17.93	19.10	8.99
14.74	9.65	23.85	17.58	19.62	44.21	19.85	31.66	0.00	16.01	12.61	12.05
18.12	10.12	24.78	38.49	21.25	61.37	14.84	34.56	18.28	16.52	8.81	19.36
30.25	10.58	20.36	17.88	19.90	0.00	10.65	19.05	24.00	18.31	14.91	20.12
26.26	13.31	17.18	17.37	19.43	0.00	31.76	38.27	19.80	17.61	21.57	13.64
20.36	14.88	37.44	14.47	22.04	0.00	28.62	19.98	20.86	18.09	24.17	6.87

Digestion

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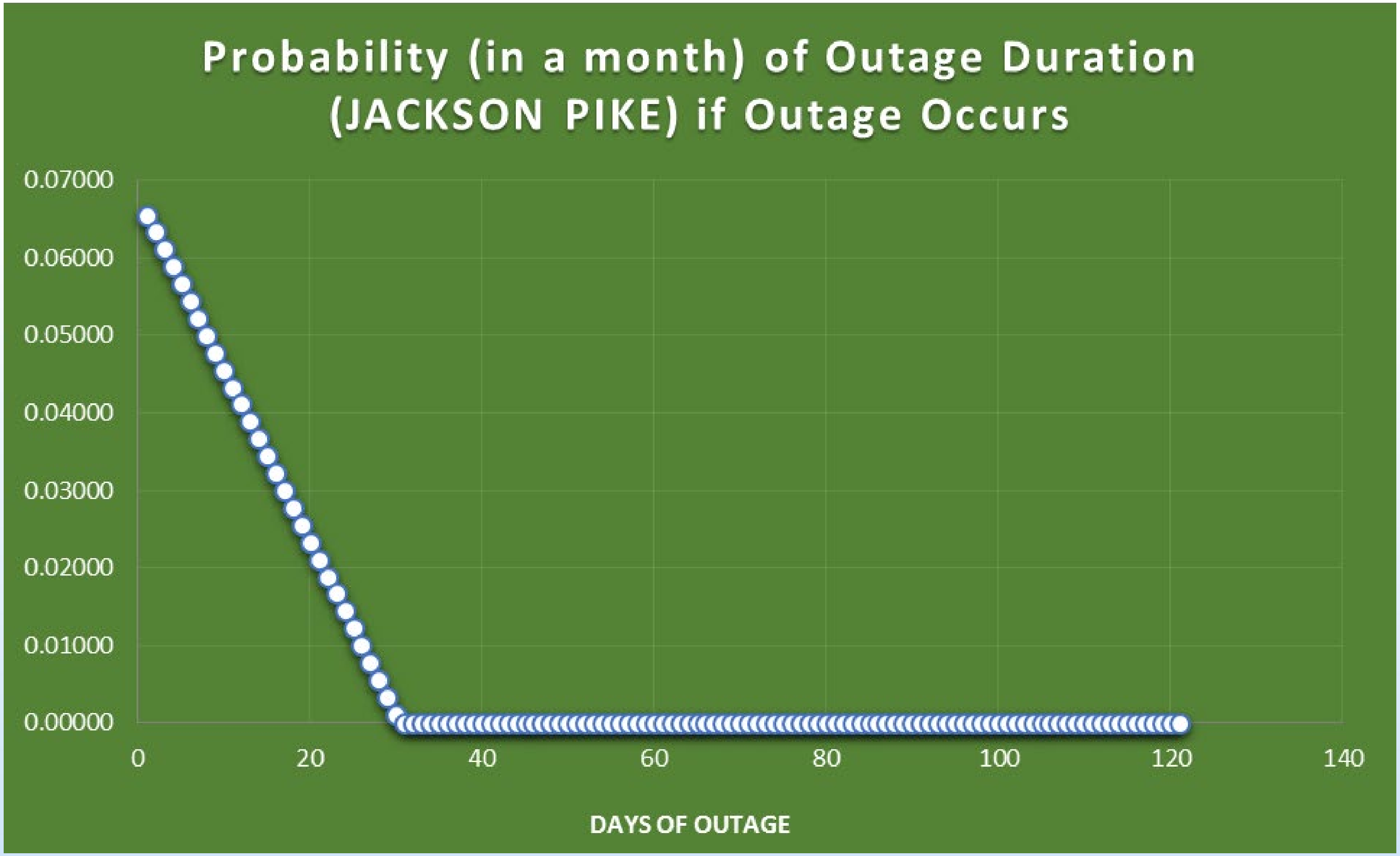
Why Model Digestion?

10 DT Unclassified → Digestion → 6 DT Class B

User Inputs

Days to recover from digester failures (max)	30
Solids reduction	40%
Avg. Duration Between Failures	36

Assumptions for Digester Outage Probabilities



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Probability Table for Digester Outages

Mothly Probability Bin	x = number of days of outage	y - likelihood of duration (given an outage)	Cumulative Probability of Duration (if outage)
0	0		0.000
0.97222	1	0.06556	0.066
0.97404	2	0.06333	0.129
0.97580	3	0.06111	0.190
0.97750	4	0.05889	0.249
0.97914	5	0.05667	0.306
0.98071	6	0.05444	0.360
0.98222	7	0.05222	0.412
0.98367	8	0.05000	0.462
0.98506	9	0.04778	0.510
0.98639	10	0.04556	0.556
0.98765	11	0.04333	0.599
0.98886	12	0.04111	0.640
0.99000	13	0.03889	0.679

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Sample Results for Digester Outages

Failures (days/ month)			
	Month	Jackson Pike	Southerly
January	1	0	0
February	2	0	0
March	3	0	0
April	4	0	0
May	5	0	0
June	6	0	0
July	7	0	0
August	8	0	5
September	9	0	0
October	10	0	0
November	11	0	0
December	12	0	0

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Land Application

Weather Forecasting

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Forecasting Land App Spreadable Days

RELIABILITY OF LAND APPLICATION MODELED BELOW

		Likelihoods of Spreadable Days (Wet year to Dry Year)				
		Probability Bin	Spring Days	Fall Days	Annual Disposal Capacity (DT)	Incremental Probability
VERY WET	0	0	12	20	5990	5%
WET-WET	1	0.05000	16	25	7675	10%
DRY-WET	2	0.15000	24	25	9173	20%
AVG-AVG	3	0.35000	20	30	9360	30%
WET-DRY	4	0.65000	16	35	9547	20%
DRY-DRY	5	0.85000	24	35	11045	10%
VERY DRY	6	0.95000	30	45	14040	5%
	7	1.00000				

ADAPTED from DOSD Evaluation

0.75746556 random number between 0 and 1 (15 decimals)

Spring Days	**Fall Days**
16	**35**

Modeling Costs

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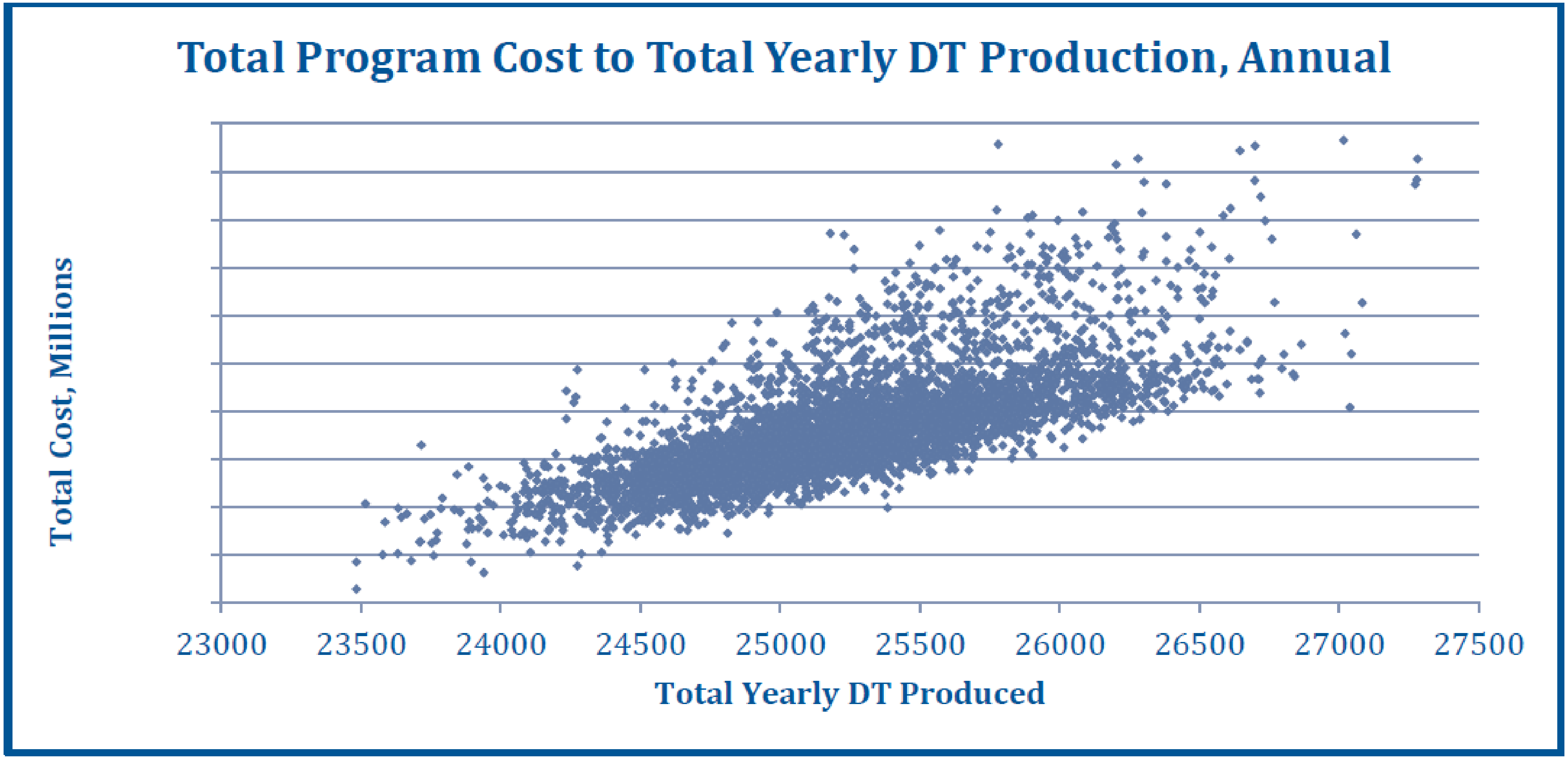
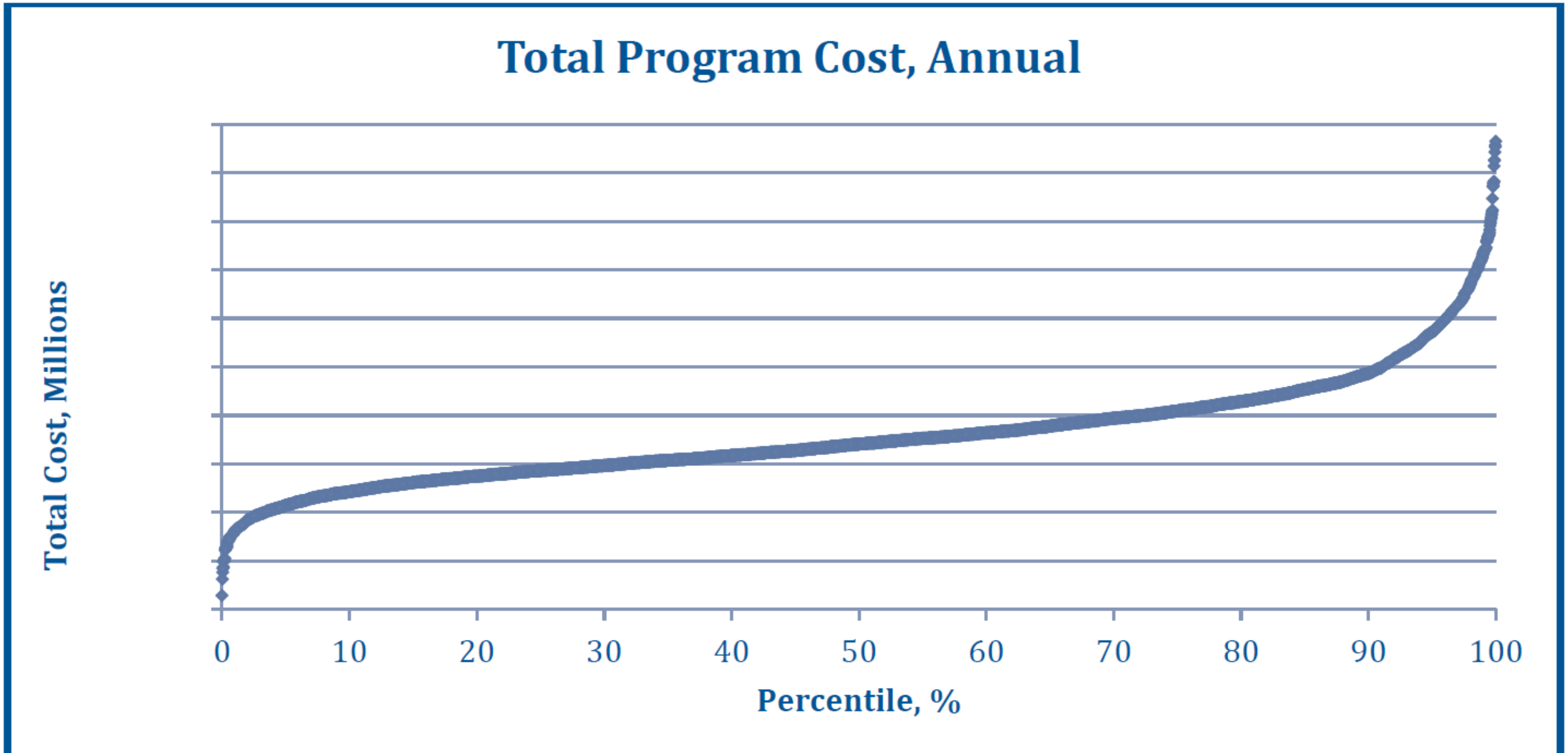
Cost per DT Solids Produced



Cost Probability



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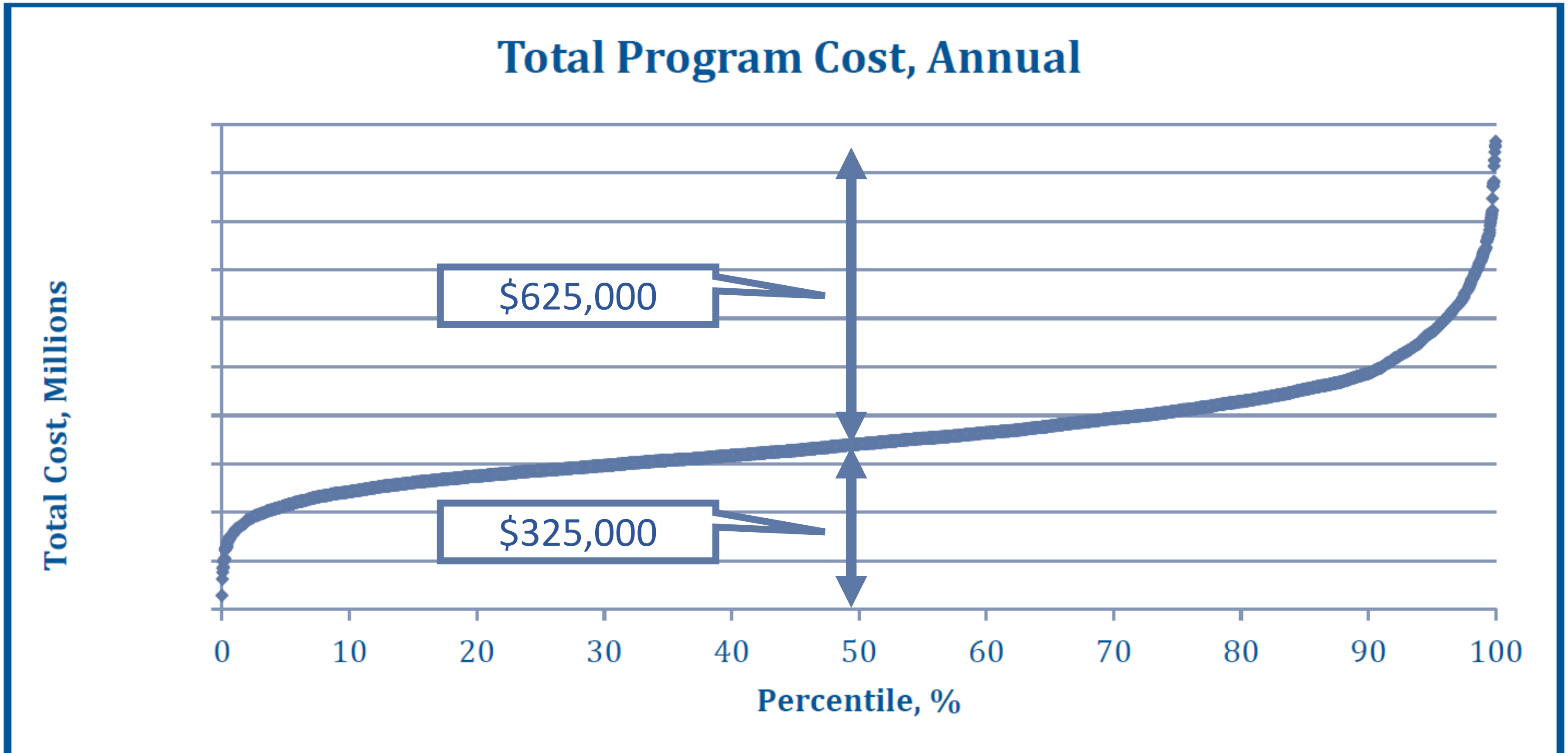
Cost Probability



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Other Benefits of Monte Carlo

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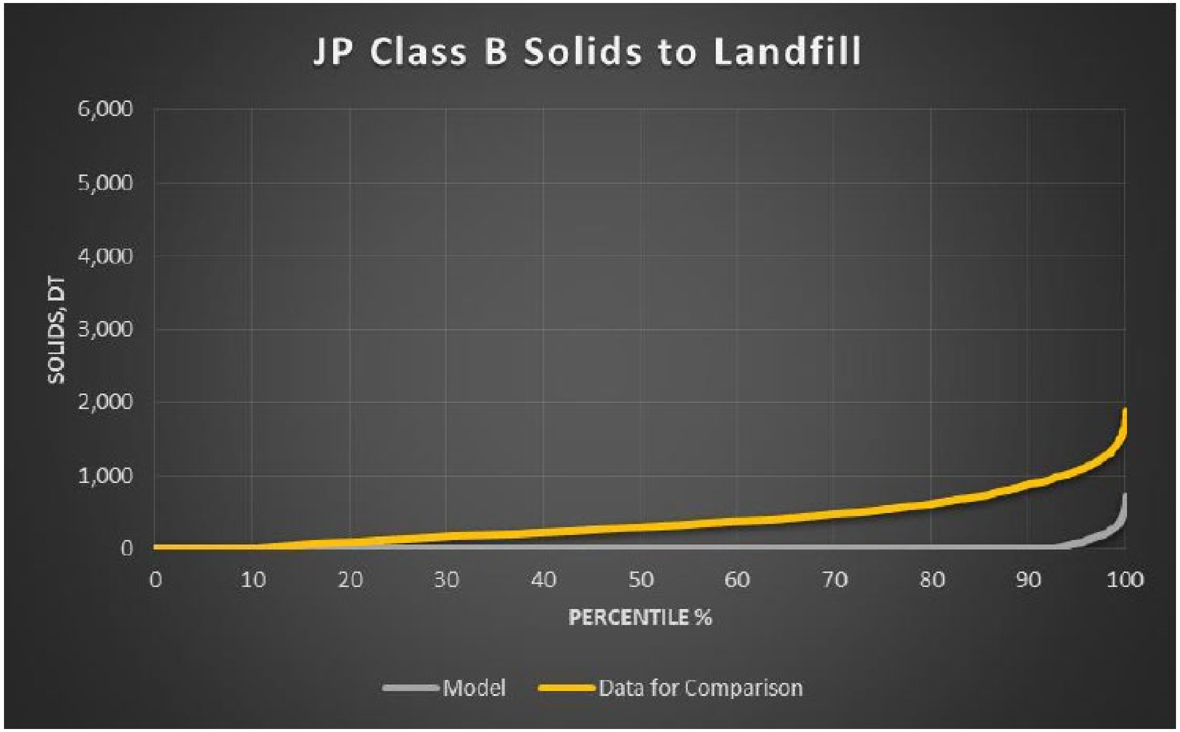
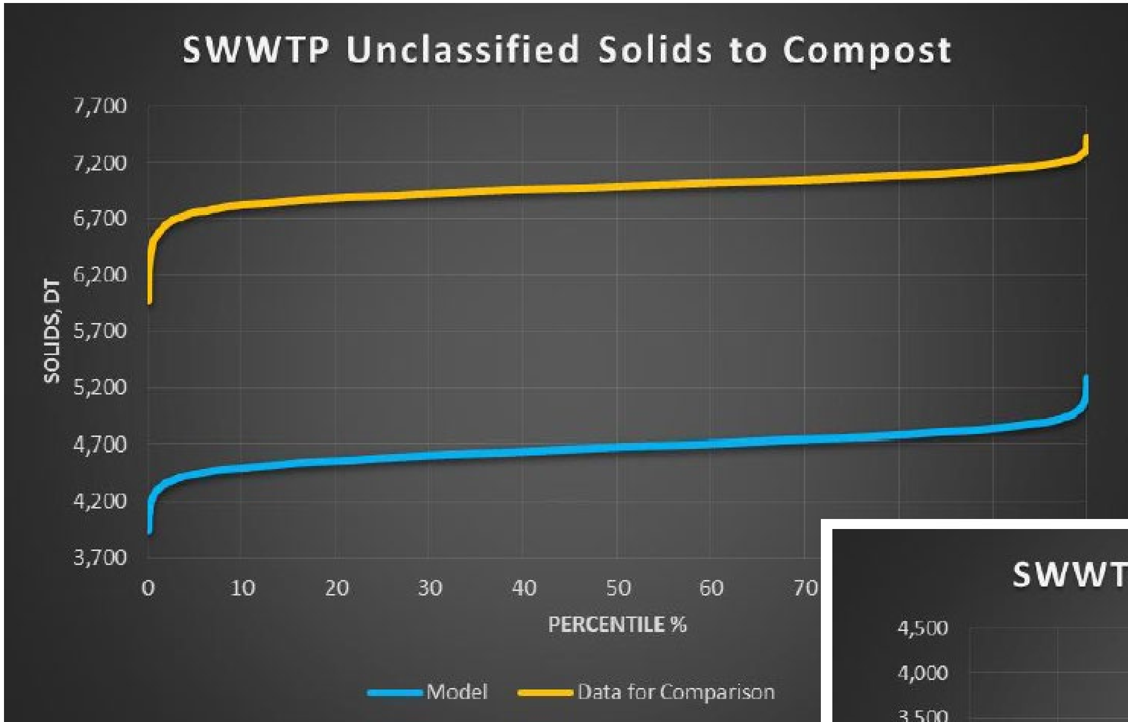
What if…..? Monte Carlo Knows…

- What if I lose an outlet?
- Should I expand my portfolio to mitigate that risk?
- Should I increase staff at Compost in the summer?
- What if an outlet's capacity increases by 15%?
- What if digester reliability improves by 50%?
- What are my long-term costs if I design storage for the 90^{th} percentile solids production?...80^{th} percentile?

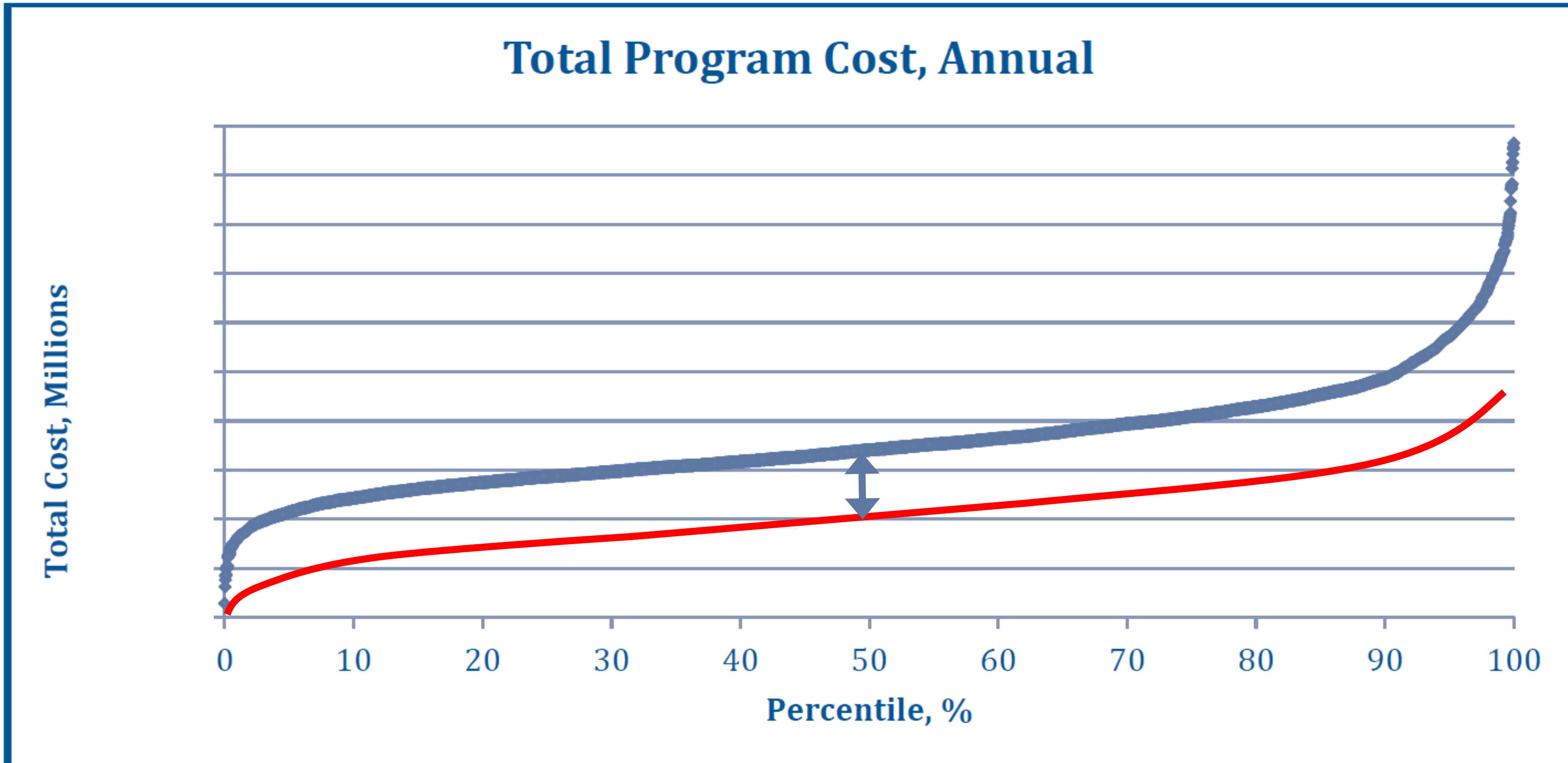
What if DRHP Disappeared?



What if Anaerobic Digestion contract is not renewed?



Cost Probability



Conclusion

- Monte Carlo provide benefits with
  - Model diversity of scenarios, not discrete conditions
  - Understand issues involving many complex variables
  - Answer a wide range of “what if” scenarios quickly
  - Manage risks and optimize costs
- Other applications – optimizing investments
  - Sizing pipelines, treatment systems, storage facilities

Questions?

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