Brown AND Caldwell

EREF Environmental Research & Education Foundation
Lighting a path to sustainable waste management practices

Environmental Research and Education Foundation

Leachate 201
Treatment Issues/Challenges

Course Overview

- Review of Leachate 101
- Leachate 201
  - Considerations for Disposal
  - Off-site Disposal - Issues for POTWs
  - Leachate Treatment Technologies & Application
  - Emerging Issues

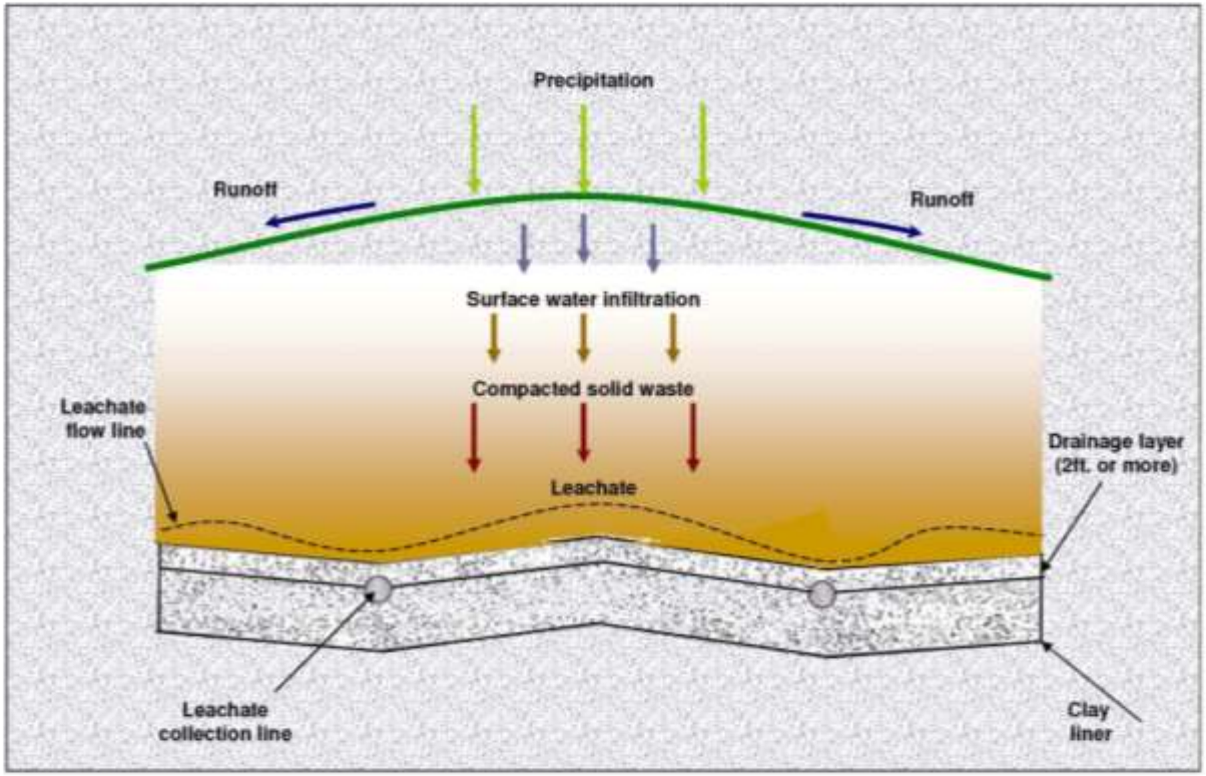
Review of Leachate 101

General Concepts Covered

1. **Leachate generation**
2. **Leachate Composition**
3. **Impacts of climate on leachate**
4. **Management and Storage**

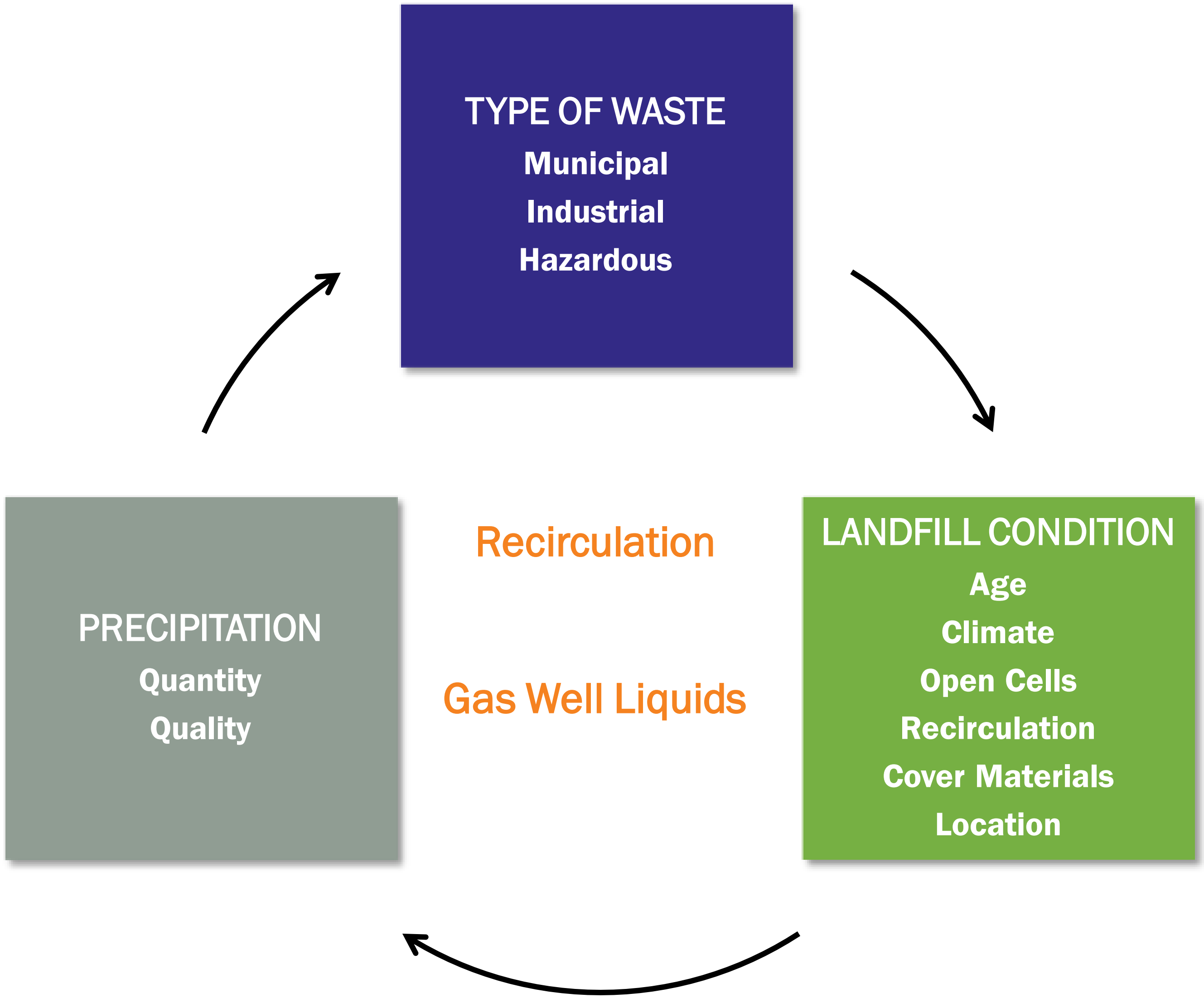
Leachate Generation

- Rainfall (climate)
- Infiltration (cover)
- Moisture content (waste)
- Additional liquids (recirculation)



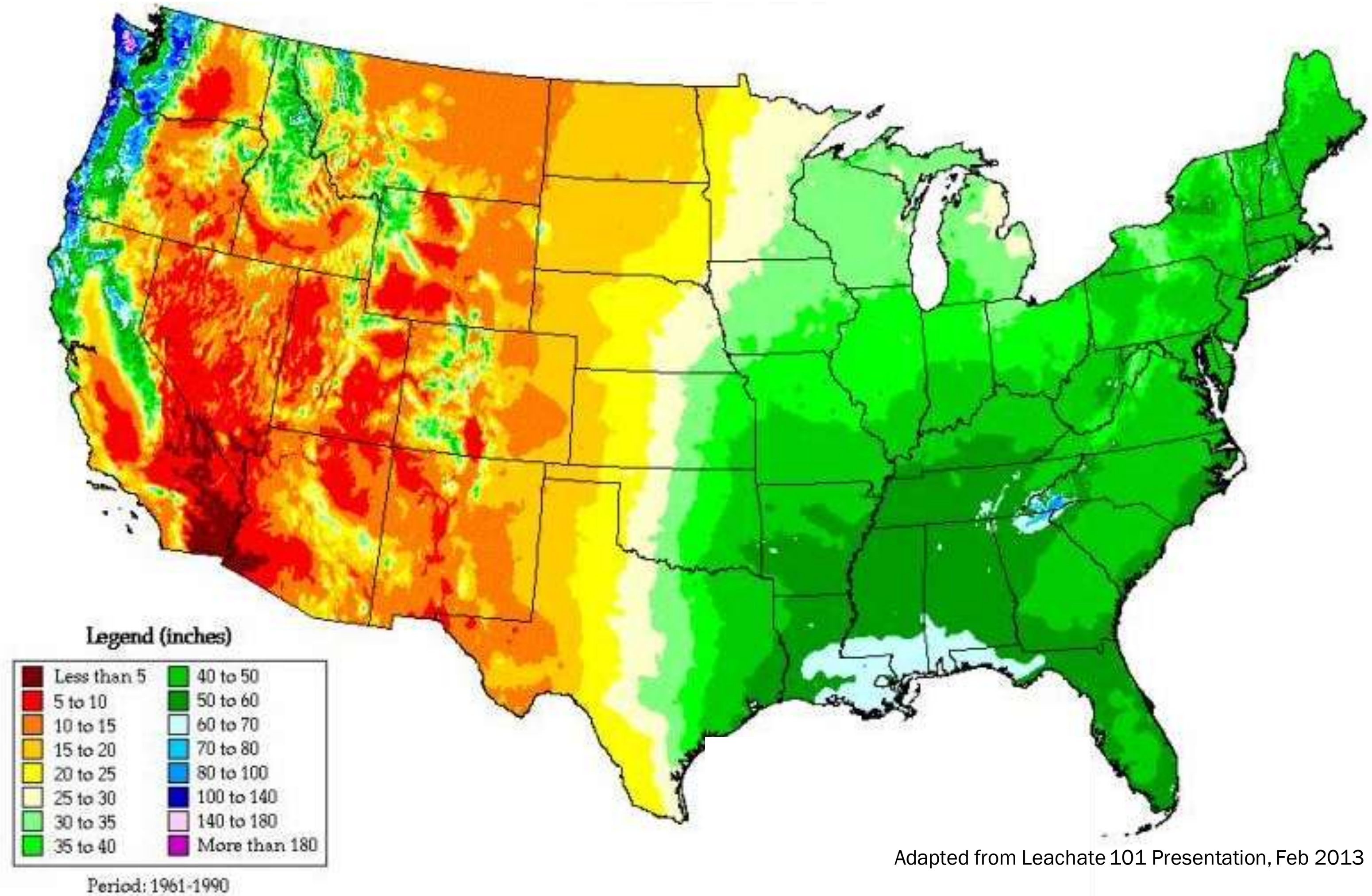
Adapted from Leachate 101 Presentation, Feb 2013

Factors Affecting Leachate Composition



Impacts of Climate Change on Leachate

Average Annual Precipitation in the US



Adapted from Leachate 101 Presentation, Feb 2013

Leachate Composition

Leachate

Organics
- BOD
- TOC
- COD
- NITROGEN
- VFA
- PESTICIDES
- EDC
- PPCP
- HUMIC SUBSTANCES

Inorganics
- LIGHT METALS
- CHLORIDES
- AMMONIA
- NOX
- SULFATES
- TDS
- OTHER ANIONS AND CATIONS

Heavy Metals
- ARSENIC
- CADMIUM
- CHROMIUM
- COPPER
- IRON
- LEAD
- MERCURY
- NICKEL
- ZINC

Others
- XENOBIOTIC ORGANICS
- DIOXINS
- BORATE
- ORGANIC ARSENIC
- FURANS
- TRITIUM
- SURFACTANTS
- FECAL COLIFORM
- ANYTHING IN TRASH

MSW Leachate Composition vs. Landfill Age

Leachate Constituent	Concentration (mg/L)			
	Transition Phase 0 – 5 Yrs	**Acid - Formation Phase 5 – 10 Yrs**	**Methane - Formation Phase 10 – 20 Yrs**	**Final Maturation Phase > 20 Yrs**
BOD	100 – 11,000	1,000 – 57,000	100 – 3,500	4 – 120
COD	500 – 22,000	1,500 – 71,000	150 – 10,000	30 – 900
CBOD/COD Biodegradability	0.23 – 0.87 Increasing	0.4 – 0.8 High	0.17 – 0.64 Decreasing	0.02 – 0.13 Low
TOC	100 – 3,000	500 – 28,000	50 – 2,200	70 – 260
Ammonia	0 – 190	30 – 3,000	100 - 500	100 – 500
NO_3 - N	0 – 500	0 – 20	0 – 1.5	0 – 0.6
TDS	2,500 – 14,000	4,000 – 55,000	1,100 – 6,400	1,460 – 4,640

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TDS	2,500 – 14,000	4,000 – 55,000	1,100 – 6,400	1,460 – 4,640

Leachate Minimization and Management

- Leachate management system
  - Drainage layers (gravel, sand, drainage net)
  - Collection piping
- Stormwater separation
  - Geosynthetic rain cover
  - Separation berms
  - Pipe connections

Adapted from Leachate 101 Presentation, Feb 2013

Leachate Storage Systems

Above ground

- Steel tanks
  - Bolted, welded, glass lined, stainless, epoxy coated, lined
- Plastics
  - Tanks, impoundments

Storage lagoons and ponds

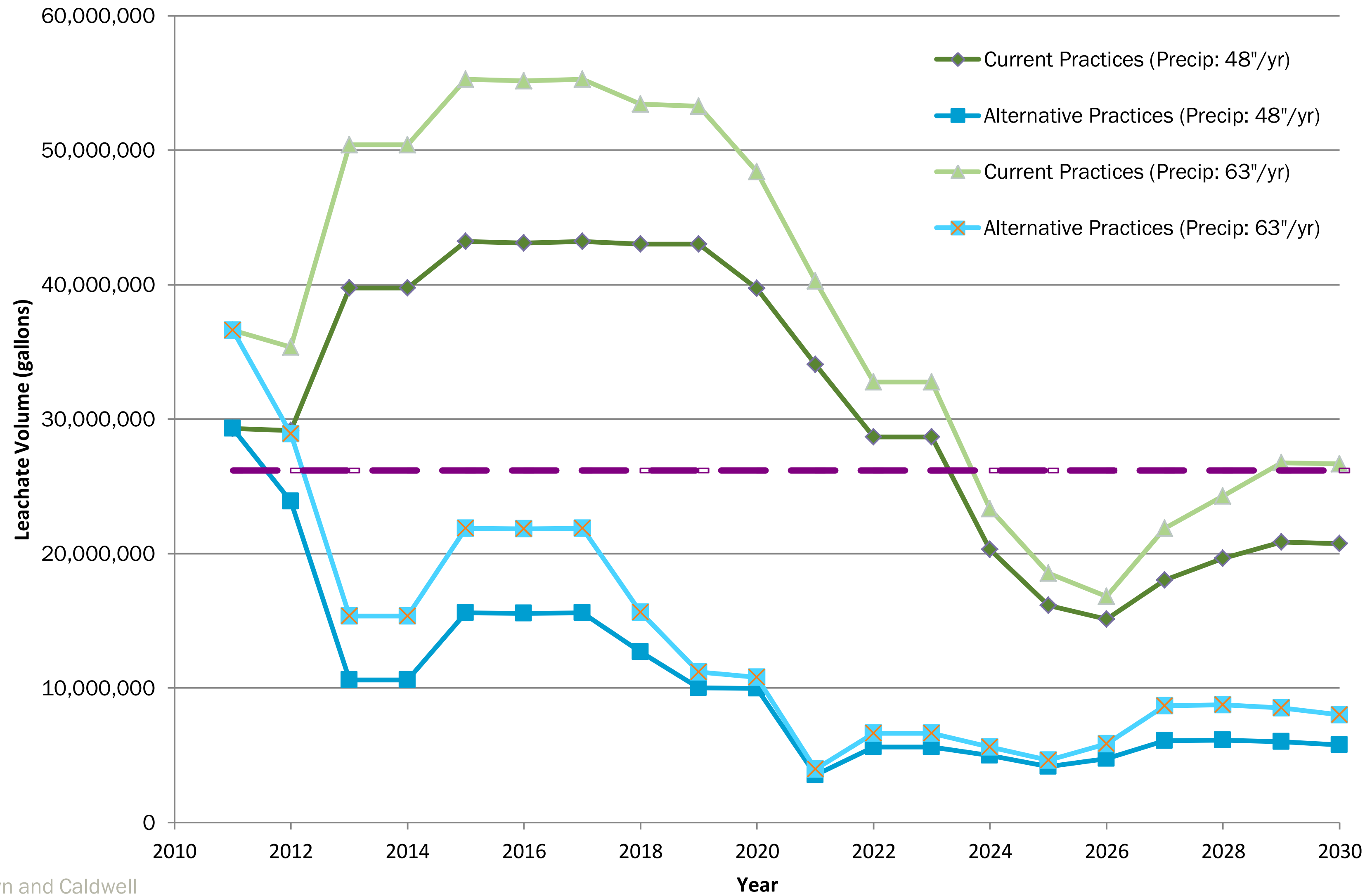
- Geosynthetic, concrete

Leachate 201

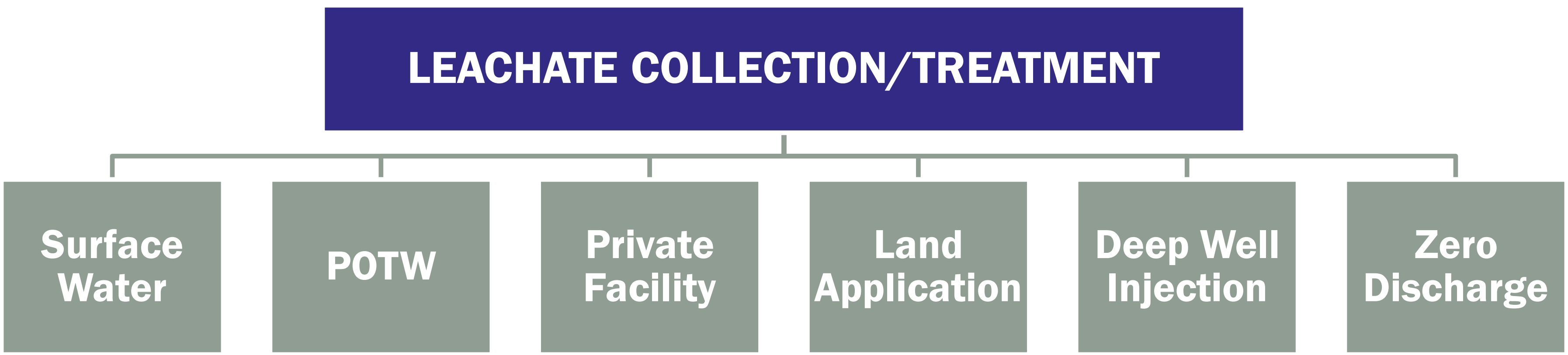
Considerations for Disposal

Minimization Example:

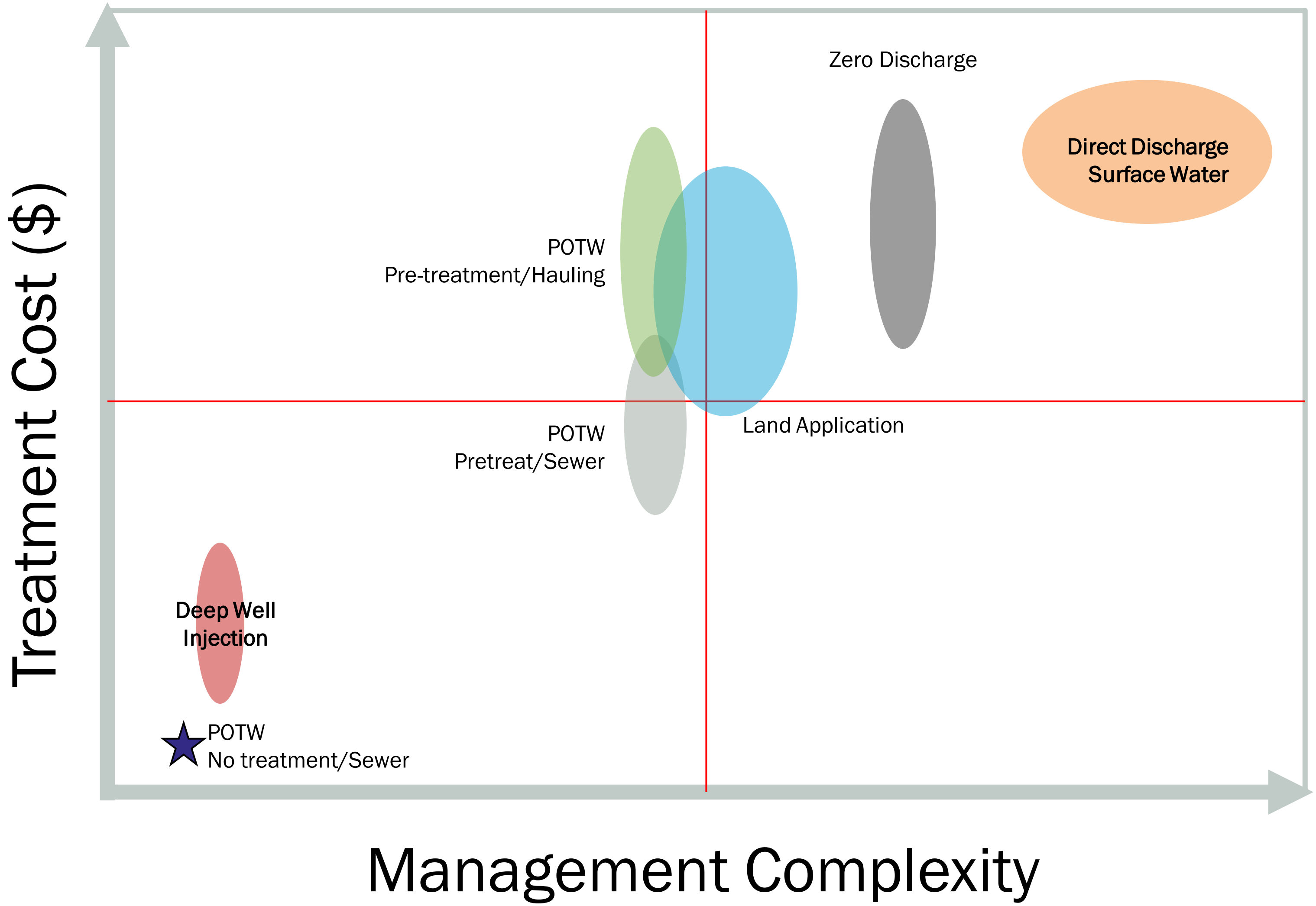
Annual Projected Leachate Volume Generation



Leachate Disposal Options



Comparative Treatment Cost



Selection Criteria and Key Considerations

- Leachate quality/quantity
- Land availability
- Disposal route
- Discharge limits
- Climate
- LFG availability
- Site operations capabilities
- Site preferences
- Landfill life
- Air emissions
- POTW Capacity
- POTW Processes
- Energy Costs
- Residual disposal
- Site preferences
- Minimization potential
- Etc.

Direct Discharge to Surface Water

TBEL's

- Best available technology
- Established based on best professional judgment
- Federal ELGs (40 CFR Part 403)

TMDL

- Impaired water bodies where water quality standards are not expected to be met after implementation of technology-based effluent limitations on point sources

WQBEL

- Established when TBEL's are not stringent enough to meet State WQS
- Based on designated water body use
- Mass balance (does not apply for some pollutants)
- Mixing zone rules and limitations

WET

- Acute toxicity limit
- Chronic toxicity limit

Basis for Limits
Indirect Discharge to POTWs

Industrial Pretreatment Program

- Local discharge limits issued by local municipality or sewer agency
  - Same limit apply to all industrial users
  - Specific limits for each industrial user
- Categorical Pretreatment Standards (Federal) specific to defined categories of industries, 40 CFR 405 – 499
  - Treatment technology based limits
- Surcharges for compatible pollutants

Comparison of Effluent Limitations

Parameter	Unit	Monthly Daily Concentrations		
		Typical POTW Pretreatment[1]	Direct Discharge[2]	
		Average	Average	Maximum
BOD_5	mg/L	200 – 500	37	37
TSS	mg/L	100 – 1,000	27	27
Ammonia	mg/L	25 – 300	4.9	4.9
Zinc	mg/L	Site specific	0.11	0.11
Alpha Terpineol	mg/L	Site specific	0.016	0.016
Benzoic Acid	mg/L	Site specific	0.071	0.071
p-Cresol	mg/L	Site specific	0.014	0.014
Phenol	mg/L	Site specific	0.015	0.015
pH	std. units		6.0 – 9.0	

Notes

1. General range of POTW is compiled based on project experience
2. Table 2-2 Non-Hazardous Landfill Subcategory , EPA-821-R-99-019
3. Site specific discharge permits will likely require additional parameter monitoring and/or impose additional parameter limitations

Other Regulatory Considerations

- Air emission
  - Storage
  - Treatment/Pretreatment
  - Zero discharge
  - Land application?
- Groundwater protection/quality
  - Land application
  - Deep well injection
- Residuals management
  - Treatment/Pretreatment
  - Zero discharge
  - Land application?
  - Deep well injection?
- OSHA-Virtually all

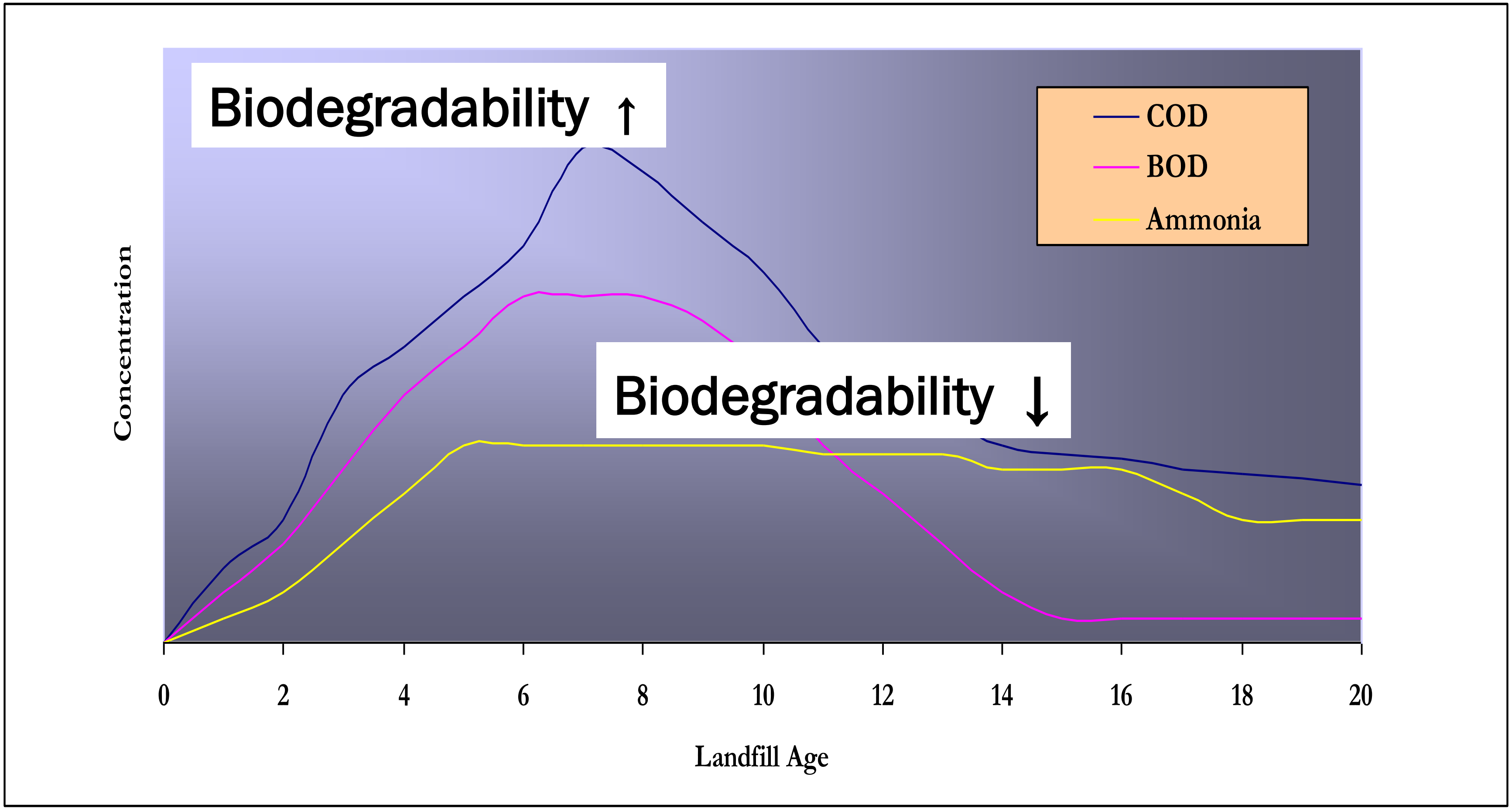
Leachate Disposal Costs Example

Landfill	Management	Costs	Notes
A	**Option 1:** Raw leachate discharged to a POTW –X through sewer connection	$0.02/gal (1) typical range: $0.02 to $0.05	Annual savings > $200,000/yr Compared to Option 2
	Option 2: Hauling raw leachate to a POTW-Y	$0.055/gal	
B	Direct discharge to surface water	$0.05/gal (2) typical range: $0.02 - $0.05 $0.02 (less stringent limits) $0.05 (very stringent limits)	Membrane Bioreactor (MBR) Technology

Notes
1. Includes surcharges for NH3-N, TSS, and BOD on a mass basis ($/lb); analytical, sampling and sewer connection costs.
2. Includes amortized capital costs for equipment purchase and installation, O&M costs over a 20-year period.

Offsite Disposal - Issues for POTWs

Leachate Characteristics vs. Landfill Age



MSW Leachate vs. Domestic Wastewater Composition

Parameter	Unit	Domestic Wastewater[1]		Landfill Leachate		
		Weak/Medium	Strong	MSW	Ash-fill[3]	C&D[4]
BOD	mg/L	110 – 190	350	500 – 3,300	4 – 100	
COD	mg/L	250 – 430	800	1,800 – 4,350	500 – 2,000	150 - 700
TOC	mg/L	80 – 140	260	-	10 - 80	20 - 625
Ammonia	mg/L	12 – 25	45	150 – 2,250	25 – 90	
NO_2/NO_3	mg/L	0	0	0		
Total P	mg/L	4 – 7	12	3 - 10		
TSS	mg/L	120 – 210	400	50 - 150	15 - 60	

Notes
1. Adapted from Table 3-15 from Metcalf & Eddy, 4th Edition
2. Observations from onsite storage tanks
3. Observations from with segregated leachate streams
4. Townsend et al. 2000.

MSW Leachate vs. Domestic Wastewater
MSW Leachate is 10 – 70 times the strength of domestic sewage and reacts differently in treatment

Parameter	Unit	Domestic Wastewater[1]		Landfill Leachate		
		Weak/Medium	Strong	MSW[2]	Ash-fill[3]	C&D[4]
BOD	mg/L	110 – 190	350	500 – 3,300	4 – 100	
COD	mg/L	250 – 430	800	1,800 – 4,350	500 – 2,100	150 - 700
TOC	mg/L	80 – 140	260	-	10 – 80	20 - 625
Ammonia	mg/L	12 – 25	45	150 – 2,250	25 – 100	
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		Weak/Medium	Strong	MSW	Ash-fill[3]	C&D[4]
pH	mg/L	-	-	6.8 – 7.5		6.0 – 8.0
TDS	mg/L	270 – 500	860	5,000 – 20,000	25,000 – 50,000	1,000 – 6,000
Alkalinity as $CaCO_3$	mg/L	50 - 100	200	850 – 8,000	50 - 100	-
Hardness as $CaCO_3$	mg/L			-		-
Chloride	mg/L	30 – 50	100	750 – 1,200	15,000 – 25,000	10 – 6,000
Sulfate	mg/L	20 – 30	50	150 - 500	600 – 1,000	30 – 2,100
VOC/SVOC	mg/L					

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Alkalinity as $CaCO_3$	mg/L	50 - 100	200	850 – 8,000	50 - 100	-
Hardness as $CaCO_3$	mg/L			-		-
Chloride	mg/L	30 – 50	100	750 – 1,200	15,000 – 25,000	10 – 6,000
Sulfate	mg/L	20 – 30	50	150 - 500	600 – 1,000	30 – 2,100
VOC/SVOC	mg/L			BRL – 0.5		

Notes
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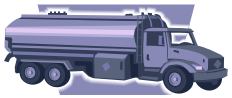
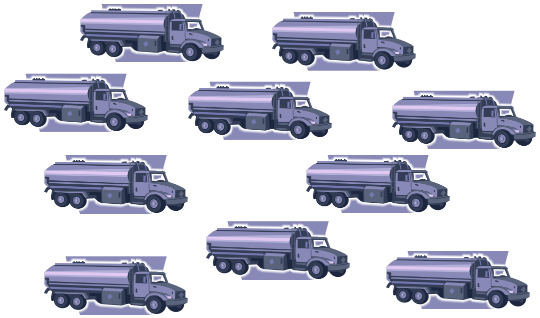
2. Observations from onsite storage tanks
3. Observations from with segregated leachate streams
4. Townsend et al. 2000.

MSW Leachate vs. Gas Well Condensate

Parameter	Unit	Landfill Leachate	Condensate
		Typical	Observed
BOD	mg/L	500 – 3,300	1,000 – 10,000 +
COD	mg/L	1,800 – 4,350	3,000 – 20,000+
Ammonia	mg/L	150 – 2,250	500 – 10,000
NO_2/NO_3	mg/L	0	-
VOC/SVOC	mg/L	Varied	5x – 10x, possibly free product
TDS	mg/L	500 – 5,000	3,000 – 50,000+

Comparative Waste Loadings (Rule of Thumb)





Domestic WW
1 Equivalent

MSW Leachate
10 Equivalents

Condensate
30 Equivalents

Potential Impacts to POTWs

- Ammonia removal inhibition
- Biological treatment upset
- Metals (e.g., arsenic)
- Color
- UV transmittance (POTW issue)
- TDS/Chlorides (e.g. deflocculation, pass through into effluent)
- Refractory dissolved organic nitrogen (rDON)
- Non-degradable COD
- Odors
- Foaming
- Sulfate (sewer odor)

Most Common Problematic Parameters

Ammonia

COD/BOD

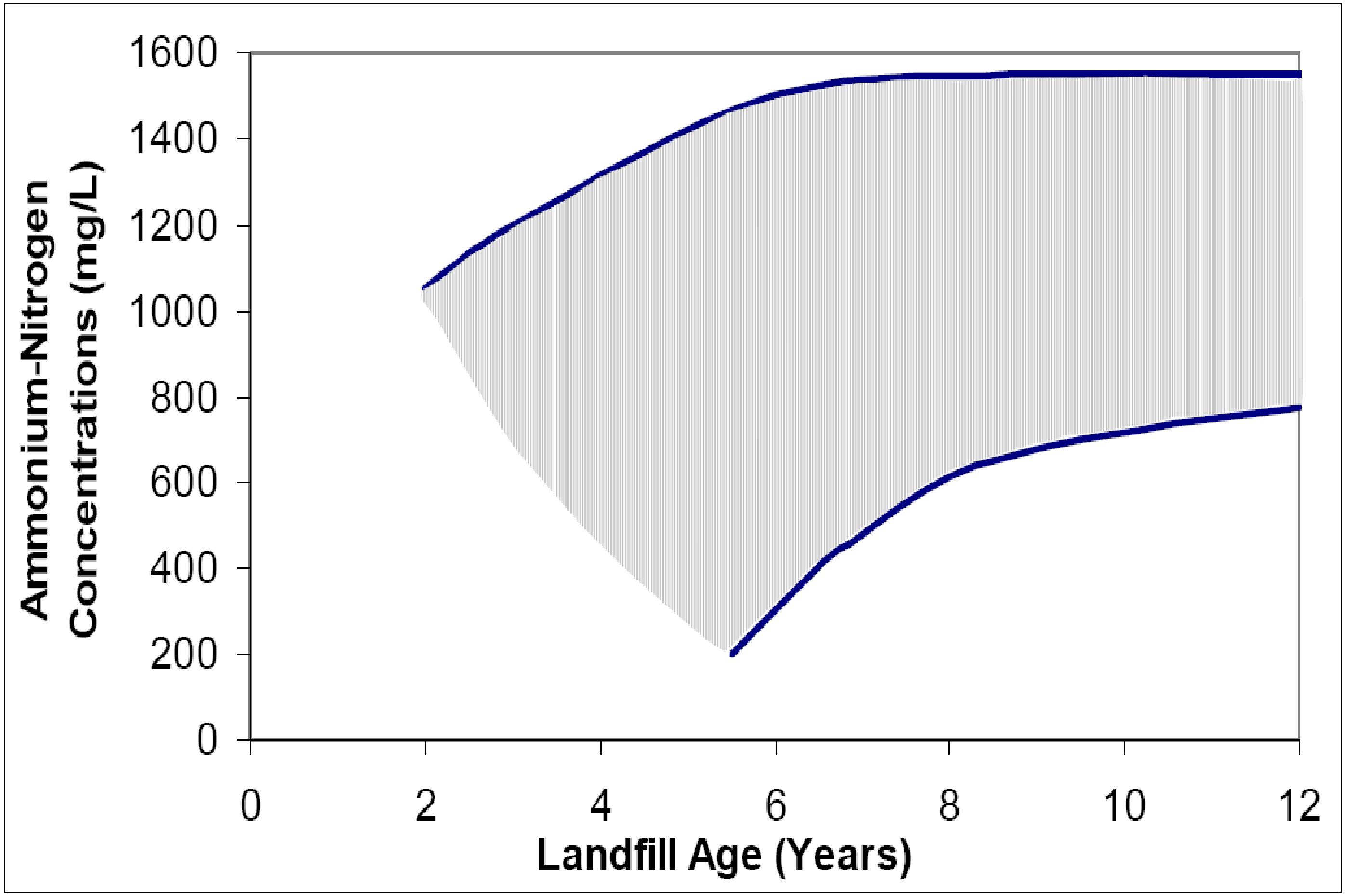
Metals

Total nitrogen (TN) limits are becoming more common in discharge permits (POTW and Discharge – NPDES) requiring advanced treatment

Why Nitrogen?

- **Toxicity** (unionized ammonia is gaseous, and toxic to fish)
- **Oxygen Depletion** (adversely affects aquatic life)
- **Eutrophication** (algal growth)
- **Reduced Chlorination Efficiency** (during disinfection, i.e. chloramines)
- **Corrosion** (ammonia)
- **Blue Baby Syndrome** (blood cannot carry oxygen to cells)
  - NO_x and ammonia

Ammonia-N vs. Landfill Age



Aerobic Biological Treatment

- Commonly used (landfill bioreactor, constructed wetland, onsite WWTF, POTW)
- Most operators are cognizant of operational requirements

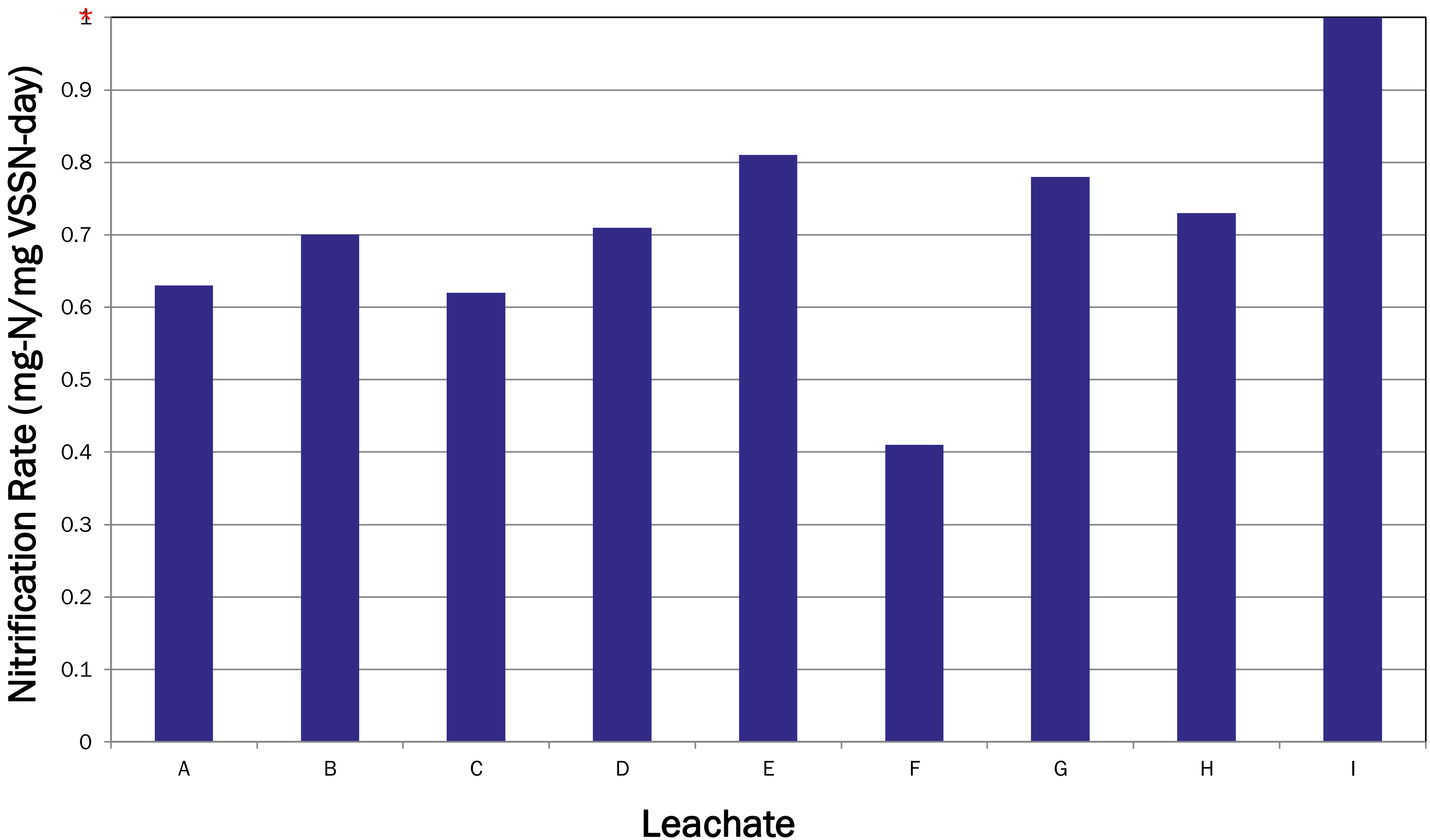
BOD/COD and Ammonia Interaction

- Heterotrophs faster growing bacteria than nitrifiers
- Nitrification rates tend to drive the size of sludge age and size of basin
- Once ammonia removal accomplished, carbonaceous organic concentrations general significantly lowered
- Typically not concerned about BOD removal rates but they can be inhibited in similar fashion to nitrifiers

Nitrification Considerations

- Nitrifiers are slow growers (define reactor size/sludge age)
- Nitrification tends to be an “all-or-none” phenomenon (on or off)
- Nitrifier floc don’t settle well--need heterotrophs or BOD consuming bacteria to form a good settling floc or a robust solids/liquid separation process
- Kinetics of growth are very sensitive to:
  - Temperature (10 Deg C > range < 32 Deg C, significant decrease in rate beyond this range)
  - Alkalinity (3.7 g of CaCO3 / g N removed); pH (optimal 7.5 - 8.6 s.u.)
  - Dissolved oxygen (> 2 mg/L)
  - Prone to toxicity (i.e. metals, unionized ammonia)

Nitrogen: Range of Nitrification Rates



*uninhibited removal rate

Leachate Treatment Technologies & Application

Brown AND Caldwell

When Selecting a Technology, Consider…

1. **Is it flexible?**

   Able to meet current and future stringent limits

2. **Is it consistent and reliable?**

   Able to adapt to various situations

3. **Does it offer ease of use and lowest life cycle costs?**

   Low on capital and O&M

Treatment Approaches

Physical/Chemical

Biological

Physical/Chemical Technologies

Physical Treatment Examples

- Precipitation/flocculation/sedimentation
- Media filtration
- Membrane filtration
- Ion exchange/adsorption
- Air/Ammonia stripping
- Flash distillation
- RO

Chemical Treatment Examples

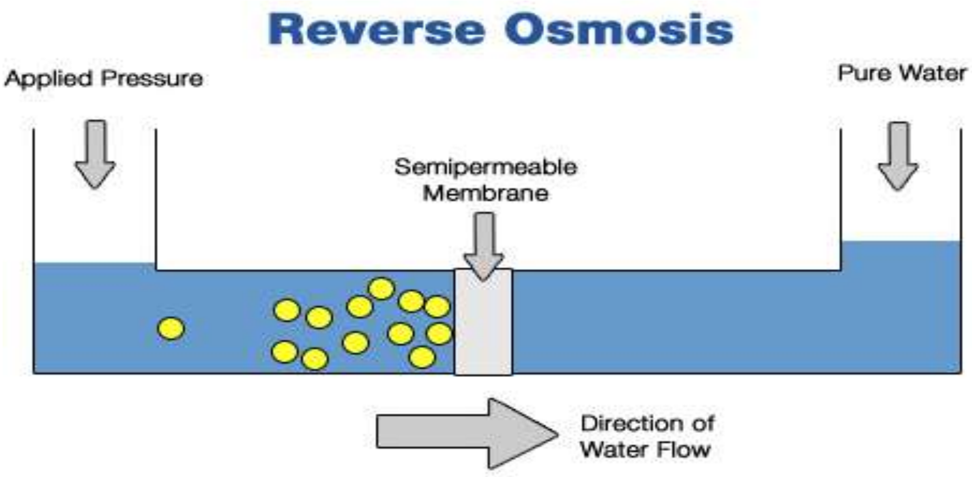
- Chemical/advanced oxidation
  - Break point chlorination
  - Fenton oxidation
  - Ozone/hydrogen peroxide
  - UV based processes not applicable
- **Evaporation (volume reduction)**

General Observations: Non-Biological Processes

- **Non-destructive, phase transfer (liquid to solid or vapor)**
- None are generally capable of serving as a stand alone technology for direct discharge (e.g. surface water)
- Most are mechanically simple but may be operationally intensive (backwashing, media change outs, etc.)
- Leachate composition makes selective removal unlikely
- RO possible but may require upfront pre-treatment (solids and colloidal organics) and post treatment (ammonia, organics, pH, ion supplementation)
- **Residuals management can be problematic**

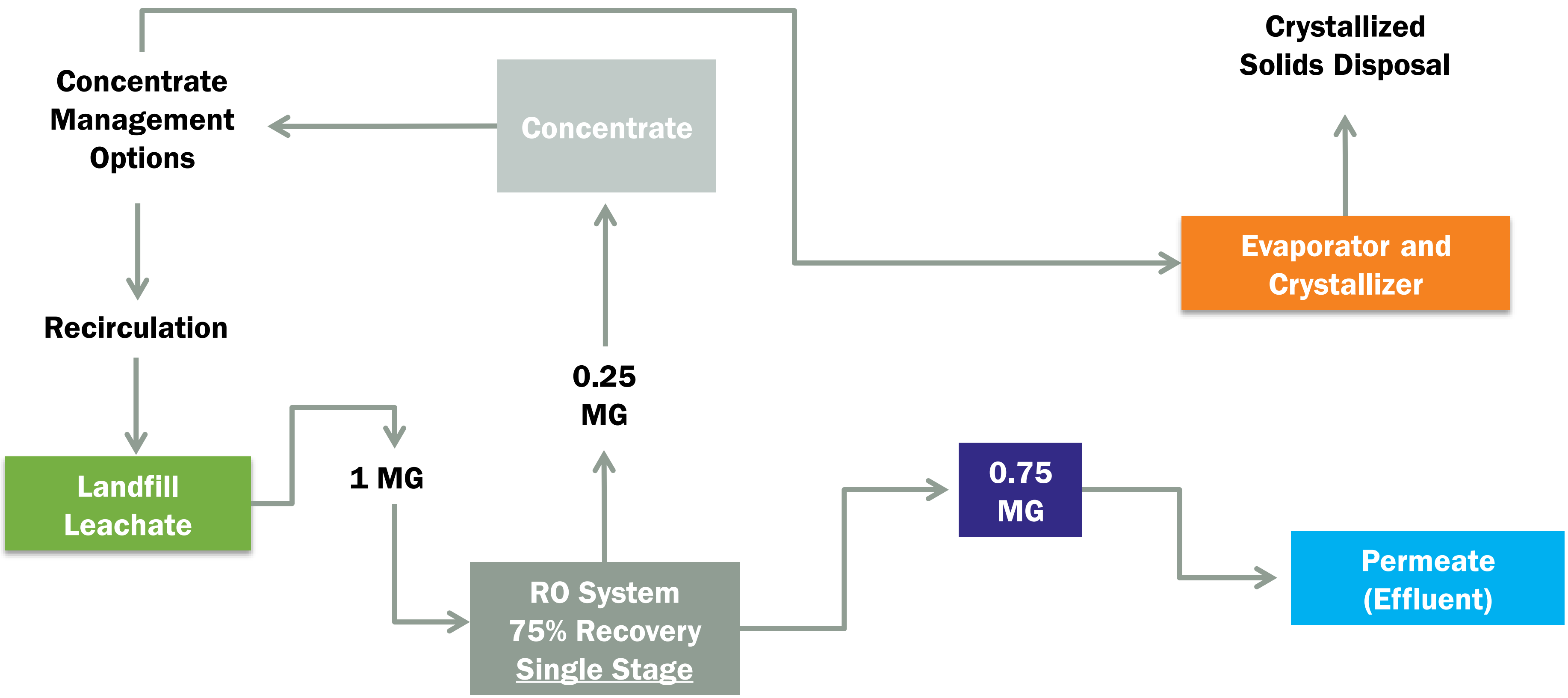
Reverse Osmosis (RO)

- Membrane technology
- Highest level of treatment
- Physical barrier < 0.001 micron-meter
- Performance expressed in MWCO
  - *Lower MWCO means tighter membrane*
- Future application: TDS, color, ECOC: EDCs and PPCPs removal

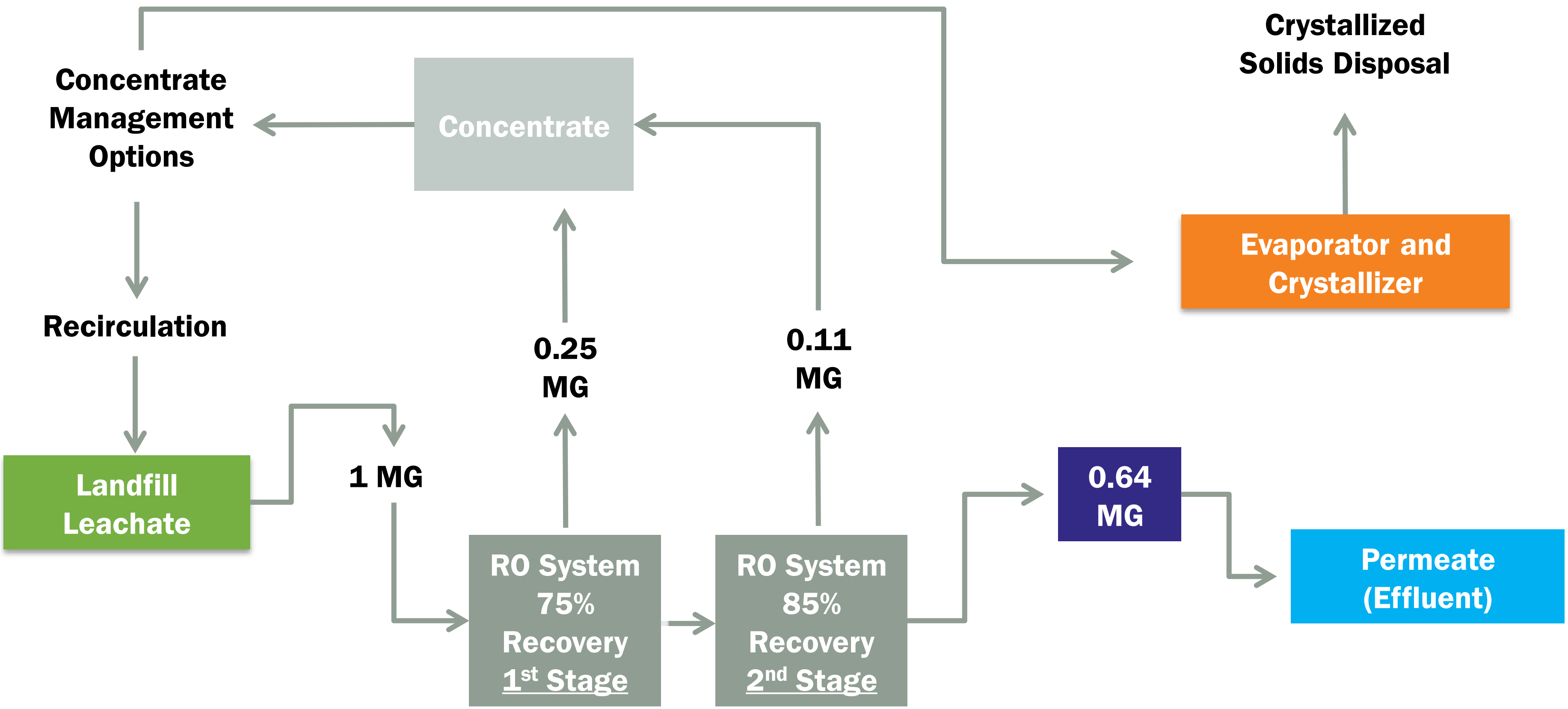


Example RO Processes

RO: Process Flow Single Stage Process



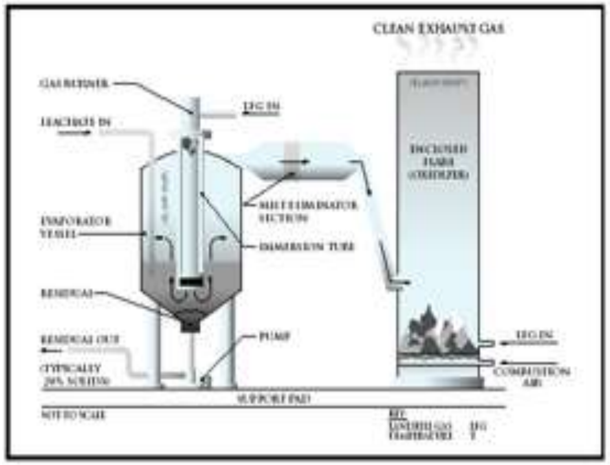
RO: Process Flow Two Stage Process



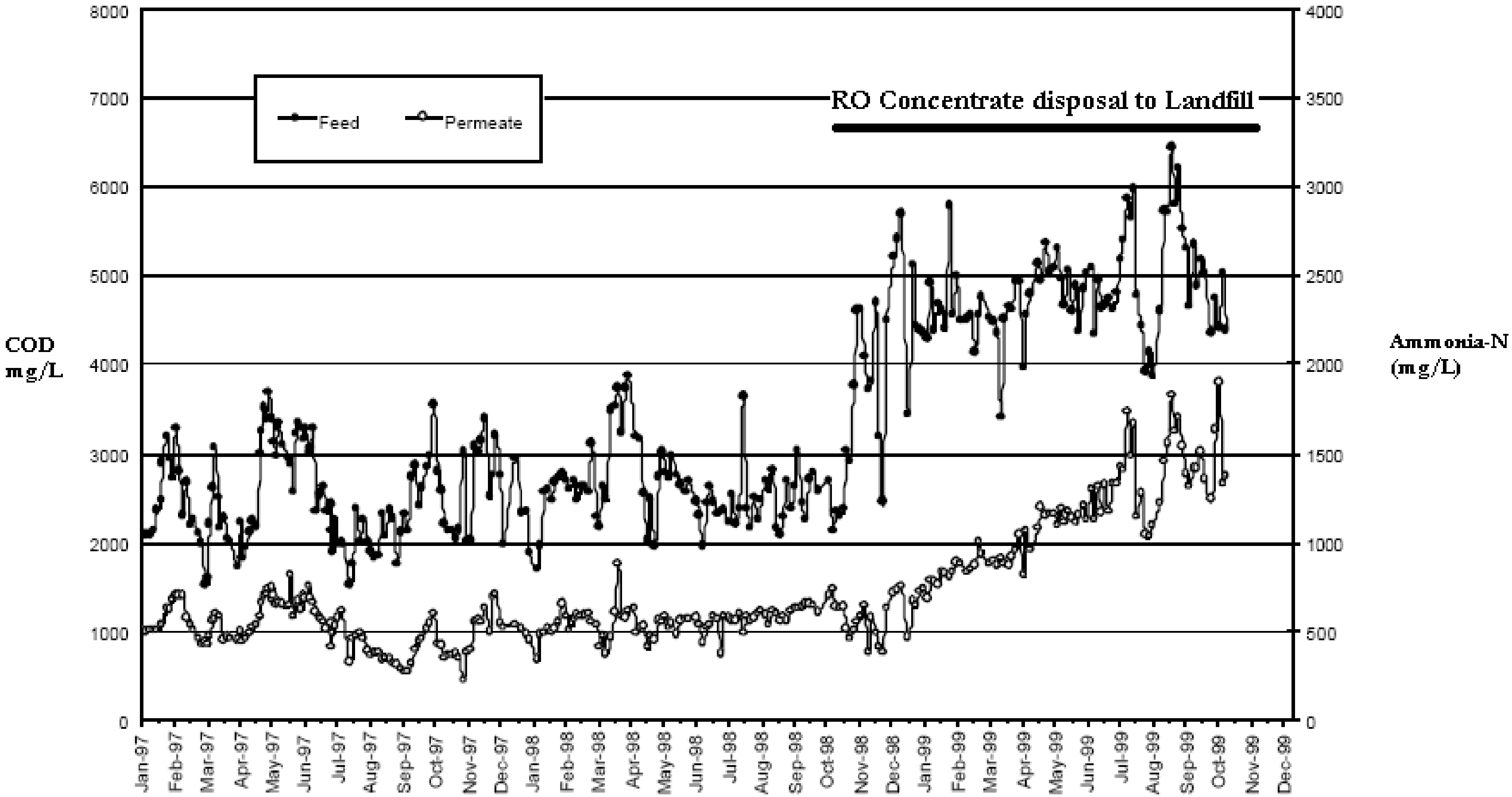
More RO Stages will Reduce Overall System Recovery!!
Multiple Stages are Required to meet Effluent NH_3-N Quality

Evaporation

- Typically 80-90% volume reduction
- Small footprint
- Flexible fuel source (waste heat, LFG, NG, LP)
- Air emission
- Residuals management



Impacts of RO Concentrate Recirculation – COD and NH3-N



Biological Removal: General Observations

- Constituents are removed, destroyed or transformed
- Most commonly applied treatment strategy
- Can operate as stand alone treatment systems
- Can operate over a wide variety of leachate conditions
- Leachate inhibits nitrification (factor into design)
- Operational/labor requirements vary widely
- Treatment costs tend to be lower than the physical removal strategies

Biological Strategies

Natural Systems

- Lagoons
- Constructed/engineered wetlands
- Phytoremediation
  - Poplar and Willow Trees
  - Vertiver grass
  - Shrubs

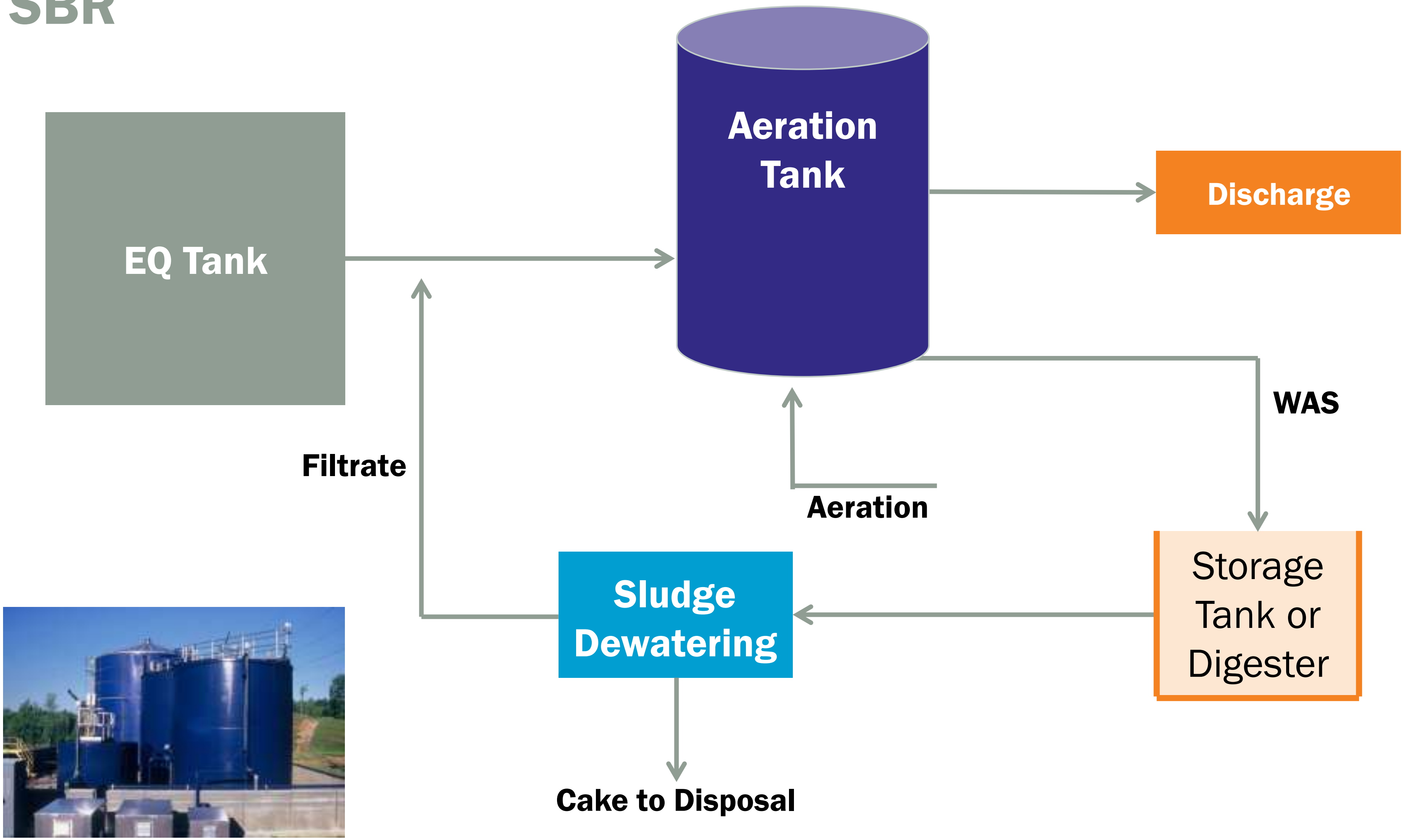
Biological Strategies

Tank Based Biological

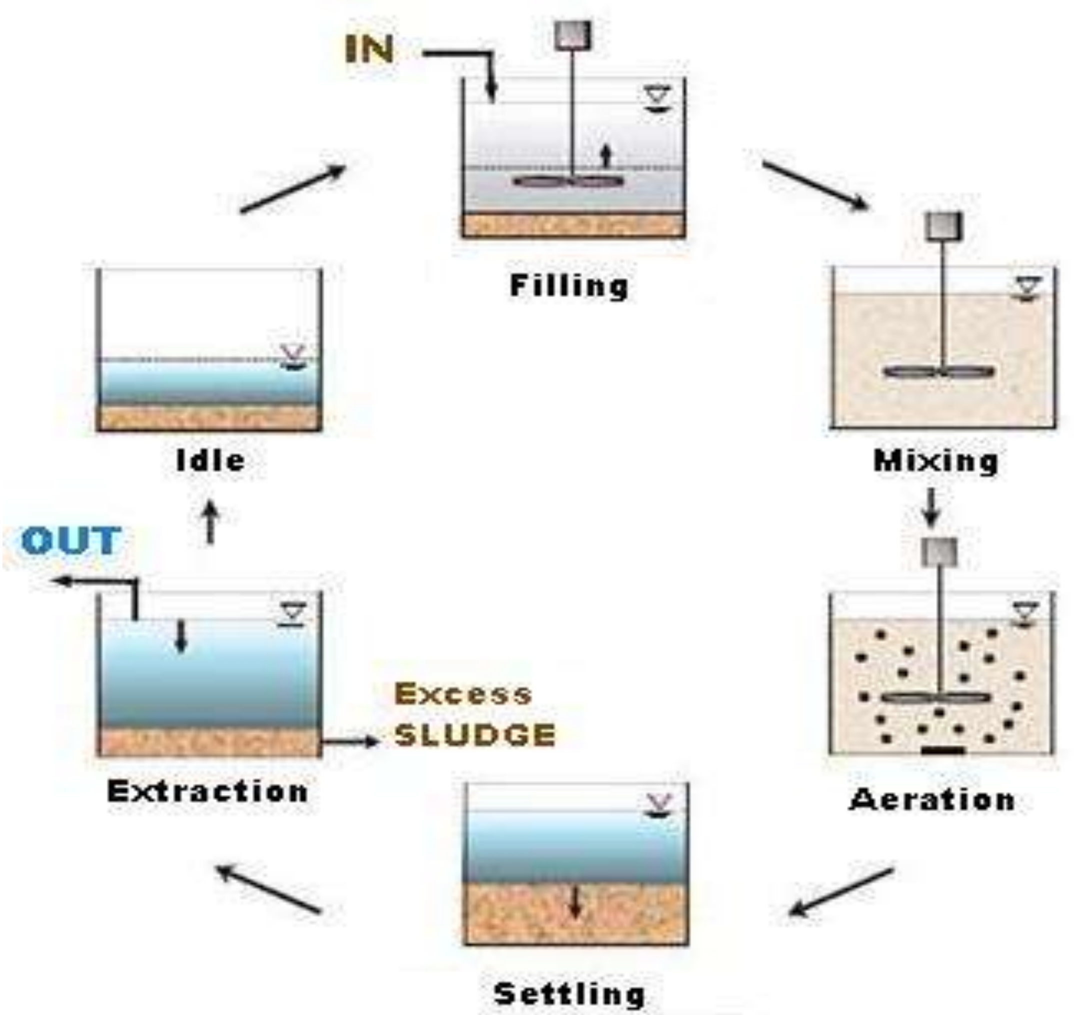
- Sequencing batch reactors (SBR)
- Membrane bioreactors (MBR)
- Conventional activated sludge (AS)
- Powdered activated carbon treatment (PACT)
- Moving bed biofilm/biological reactor (MBBR)
- Integrated fixed-film activated sludge (IFAS)
- Fixed film

Sample Treatment System Configurations

SBR



SBR Process Single Tank Operation Steps

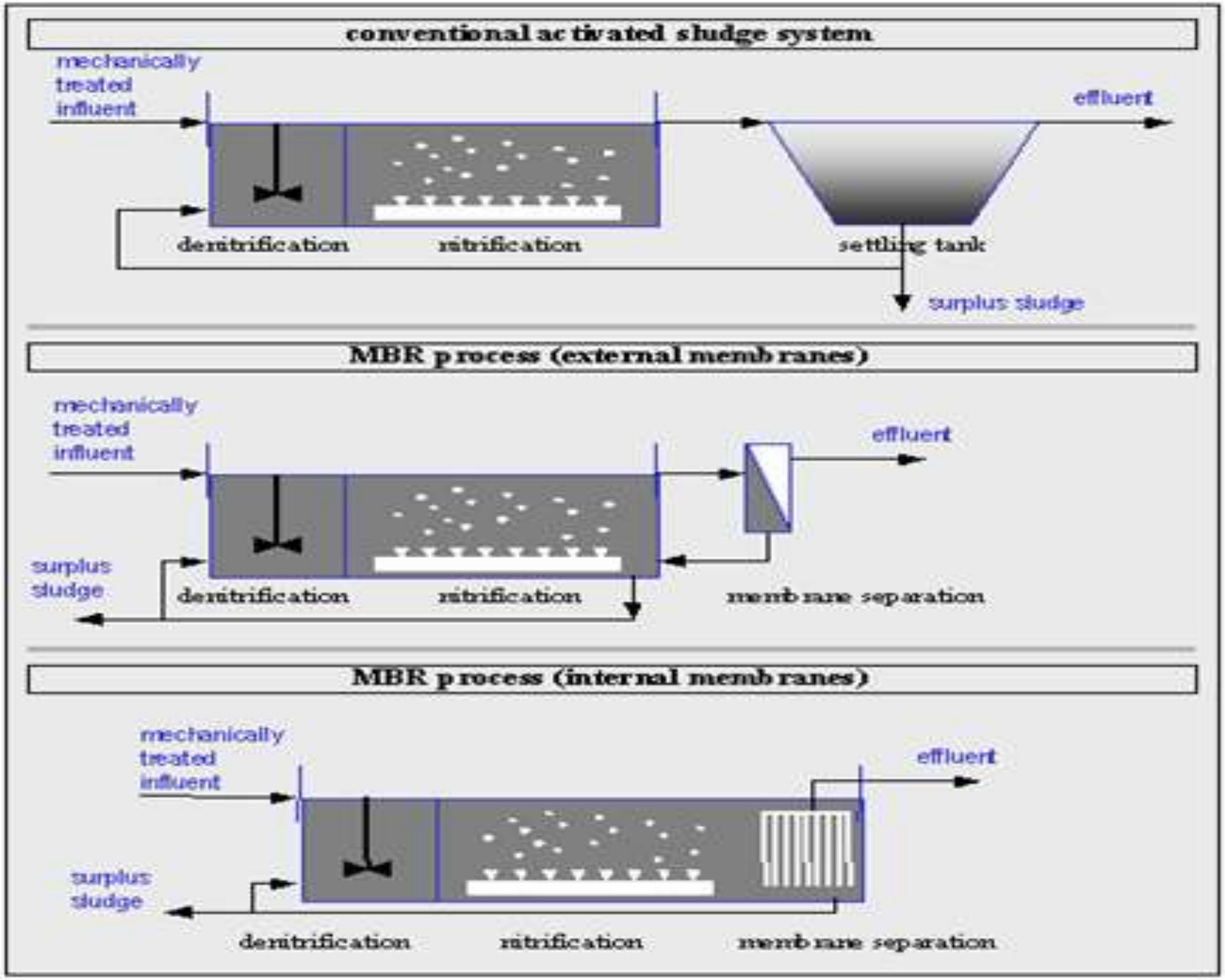


Membrane BioReactor Treatment

MBR: Activated Sludge Followed by Ultrafiltration

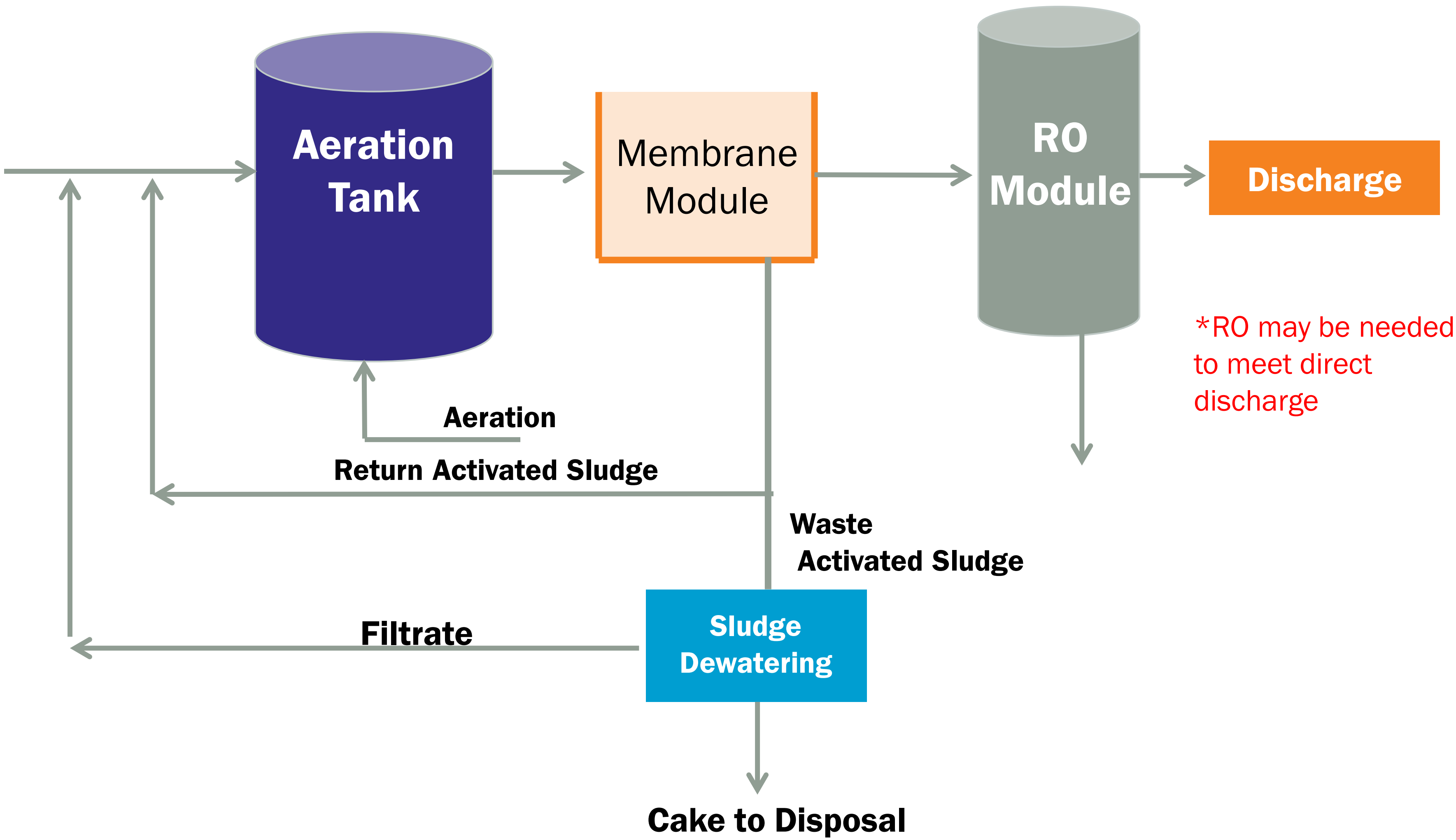
- Physical Barrier
  - 0.01 – 0.05 um nominal pore size (RO is 2 orders of magnitude smaller than UF)
  - Current disc filter nominal pore size is 10 um (2-3 orders of magnitude larger than UF)
- Replaces conventional clarifier thus avoiding sludge settling and contaminant carryover issues
- Eliminates need for additional filtration
- Uses automated cleaning and back-pulsing for membrane maintenance

MBR Process Comparison



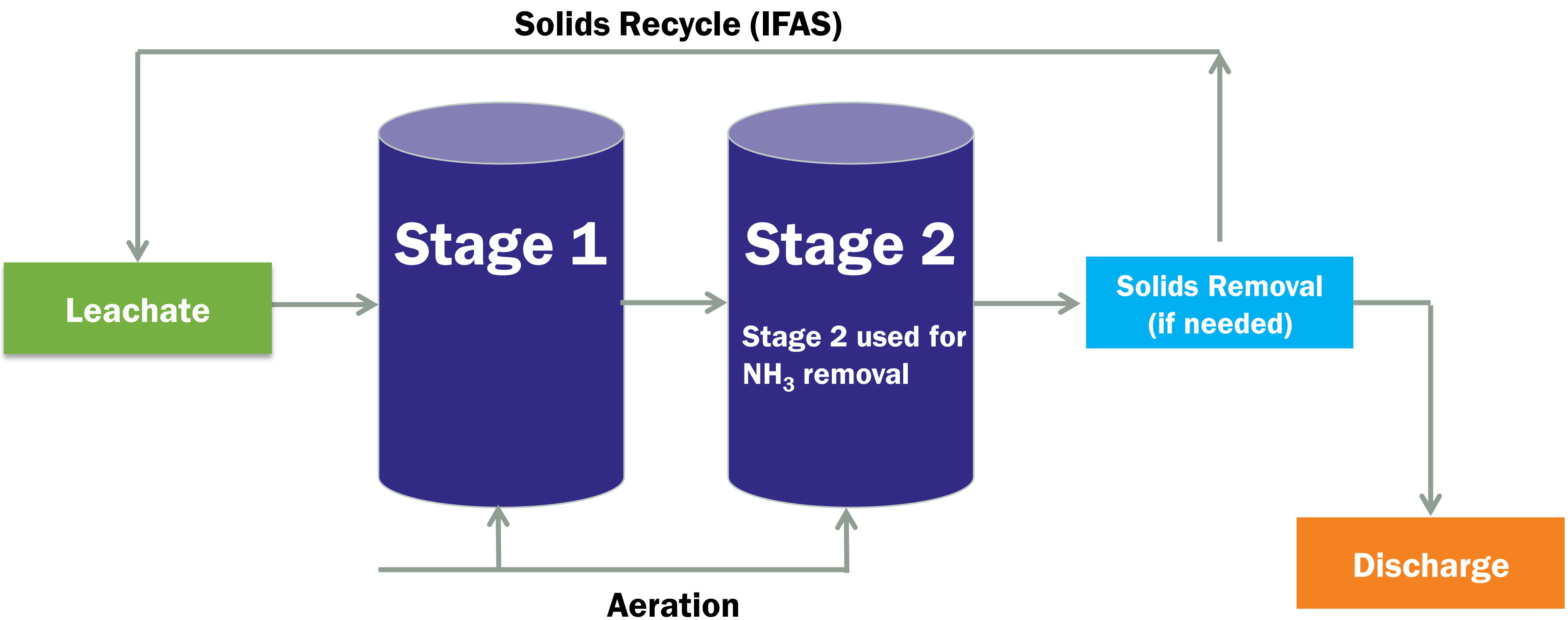
Sample Treatment System Configurations

MBR/MBR-RO



*RO may be needed to meet direct discharge

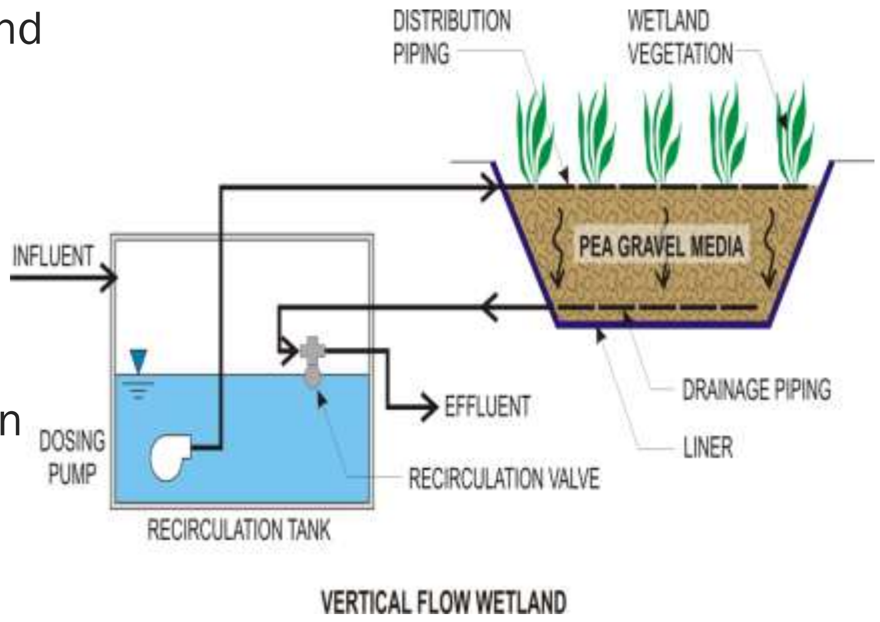
MBBR/IFAS


Solids Recycle (IFAS)
Leachate
Stage 1
Stage 2
Stage 2 used for NH_3 removal
Solids Removal (if needed)
Discharge
Aeration

Moving Bed Bioreactor (MBBR)

Constructed Wetlands

- Plants and bacteria use ammonia-N as a nitrogen source
  - Plants: hyacinth
- Nitrification
- Surface flow (SF), subsurface flow (SSF), and hybrid wetlands
- SSF
  - Horizontal and vertical flow
  - Higher efficiency than SF
  - More temperature resistance than SF (freezing)
- Fill Material
  - Plants, sand , gravel, wood chips (carbon source)
- SSF = horizontal flow wetlands
  - Denitrification (wood chips)
- SSF = vertical flow wetlands
  - Ammonia removal
  - Facilitates oxygen transfer from the atmosphere



Issues on the Horizon

Near Term

- Color
- UV transmittance (POTW)
- Nutrients
- Refractory Dissolved Organic Nitrogen
- Total Dissolved Solids/ chlorides

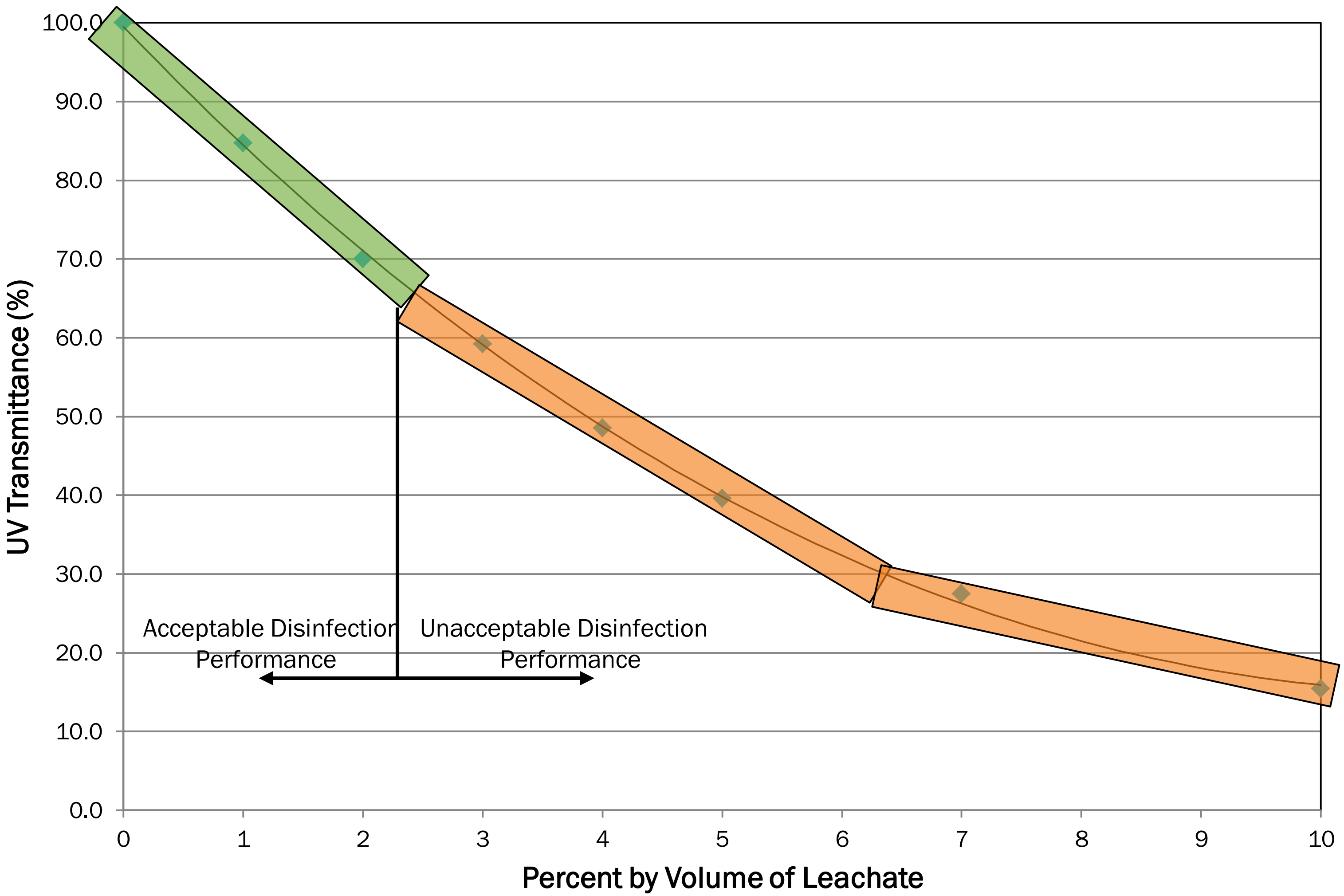
Longer Term

- Emerging contaminants
  - Boron, PFCs, future unknowns
- Pharmaceutical and Personal Care Products
- Nano-particles

Emerging Contaminants: EDC & PPCP

- A recent study by the MaineDEP showed that PPCPs were present in landfill leachate
- Raw leachate samples from three MSW landfills were analyzed for 135 individual pharmaceutical and health care products
- The analytical results showed that the samples contained approximately 40 pharmaceutical compounds
- Pharmaceuticals are discarded in household waste and appear in landfill leachate
- Regulatory agencies may try to regulate the release of pharmaceuticals to receiving streams from POTWs because of the toxic impacts to aquatic life (e.g. sex changes in fish)
- Drive to educate public to eliminate sewering of unused pharmaceuticals. Anticipate higher volumes of pharmaceuticals being directed to landfills

UVT: Effect of Leachate on UVT at POTW



UVT and Color: No Clear Correlation

Matrix Treatment	True Color (PCU)	UVT (%)
Raw Leachate	1950	0
Perozone (2,000 ppm) with 12 Minute Contact Time	105	0.2
Chlorination (1,000 ppm) with 1 Hour Contact Time	100	0.1
Chlorination (1,000 ppm) with 18 Hour Contact Time	50	0.1

Color/UV Transmittance

Landfill A

- Raw leachate color = 4,000 – 4,500 PCU
- Current LTP limit = 1,500 PCU was reduced to 100 PCU for future new LTP
- BAT: Emphasis on costs and other non environmental factors
- Waiver request to 2,000 PCU (in progress)

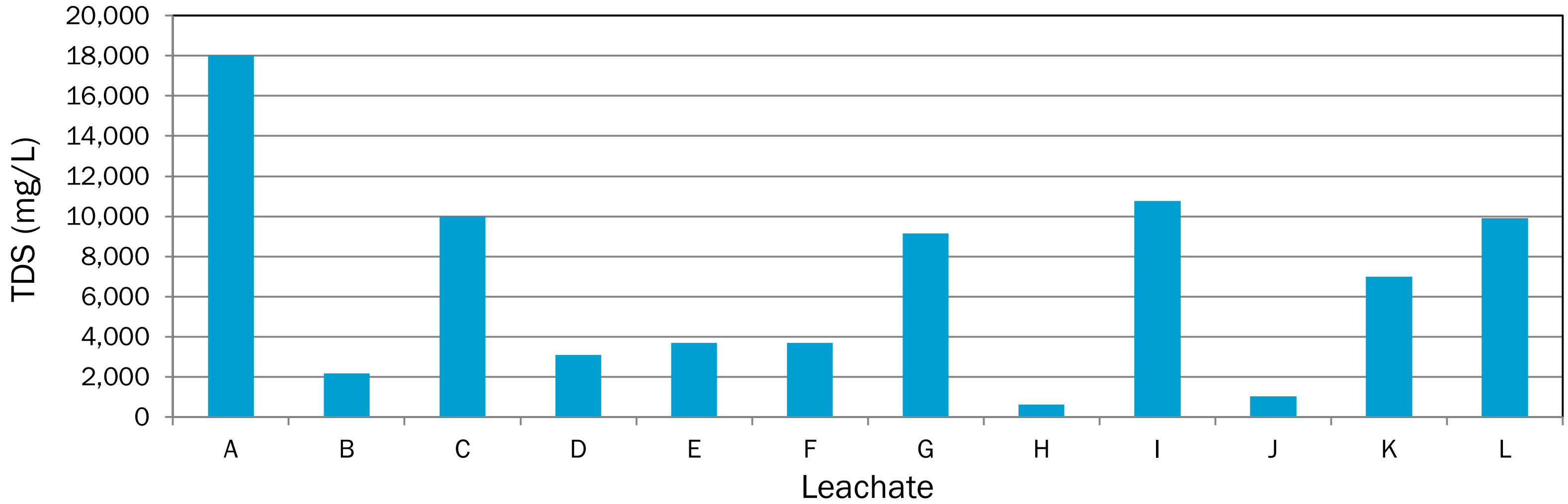
Landfill B

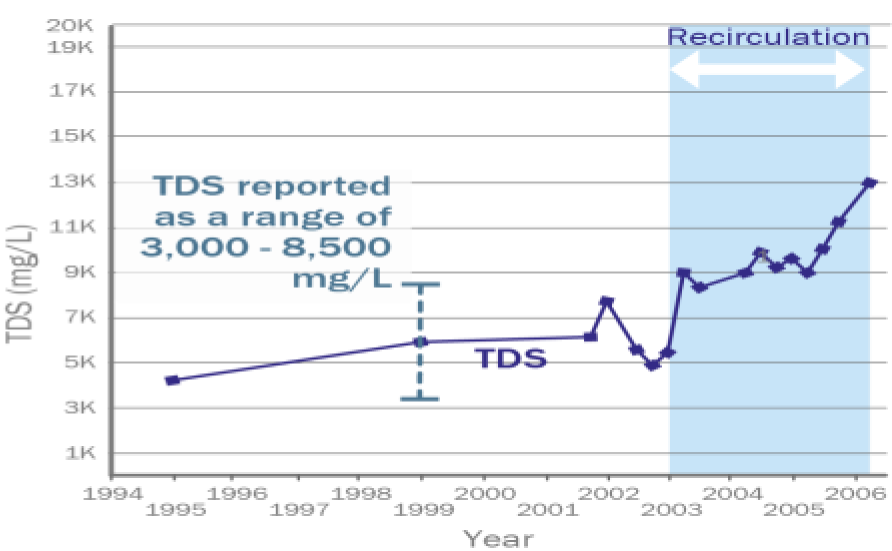
- Concerns of Leachate Color impacting UV Performance at POTW
- Treatability
  - Chlorination: 95% Removal (currently adopted to meet Antrim discharge requirements)
  - PerOzone: 90%
  - Ozone: 86 %
  - Ozone and PAC: 80%
  - PAC: 75%
  - Coagulation: 68%
- No Relationship between Color and UV transmittance
- Leachate Flow > 1% of POTW impacted UV performance (< 63% transmittance needed for adequate disinfection)

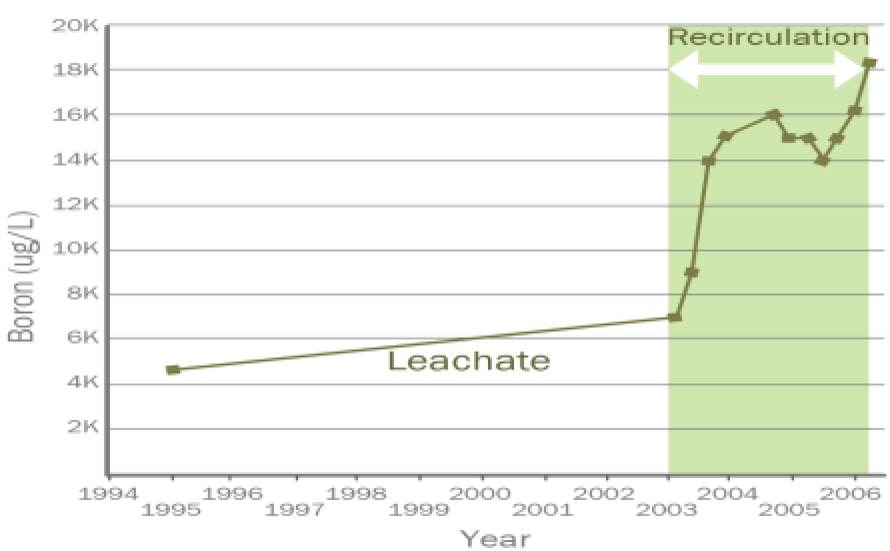
Technology	Removal (%)
$Metals_R$ /MBR	50
GAC	80.3
Ozone and GAC	82.3
PerOzone	89.7
RO	95.4

Color (PCU)	UV Transmittance (%)
900	0
105	0.2
100	0.1
50	0.1

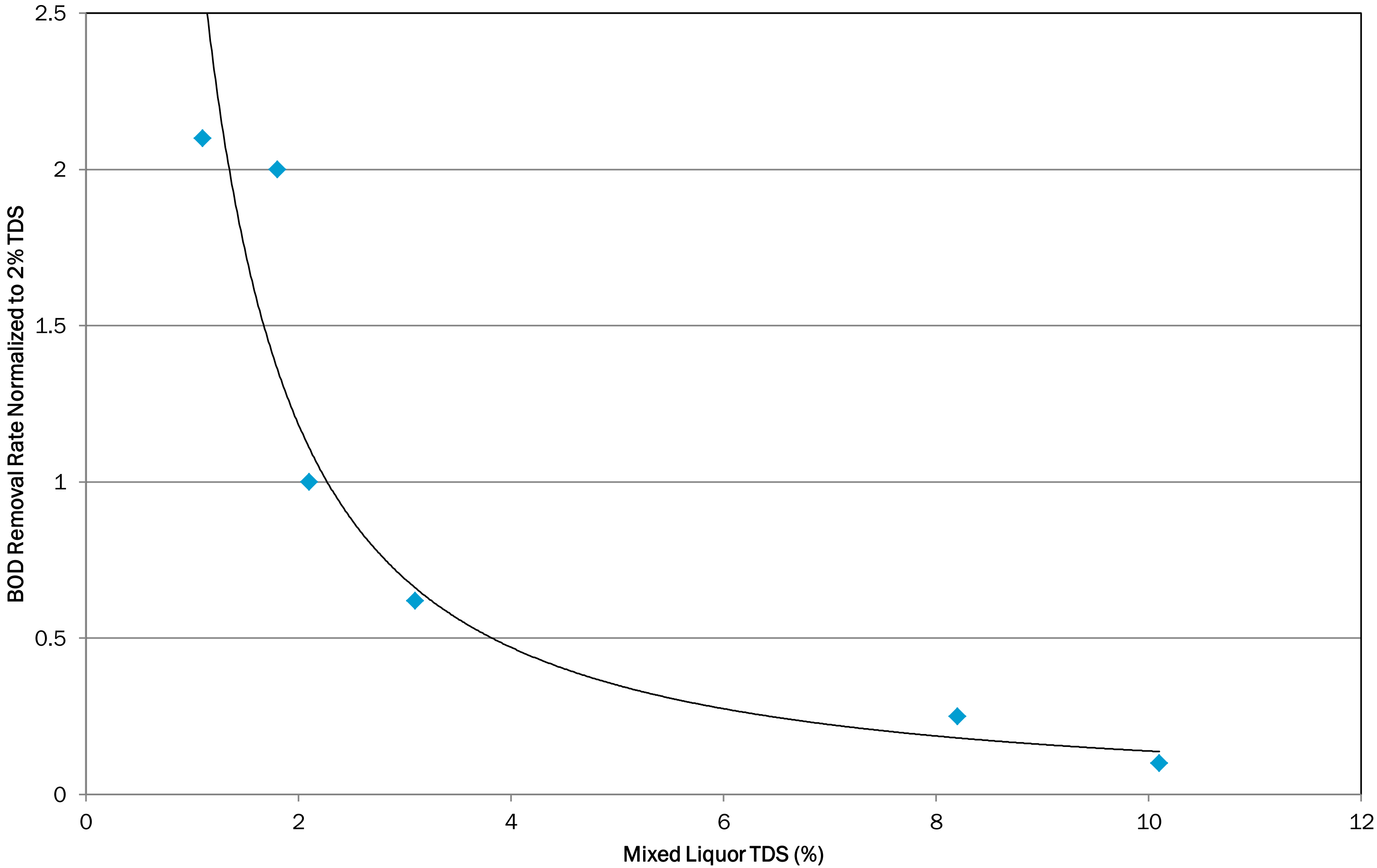
TDS: Typical Range



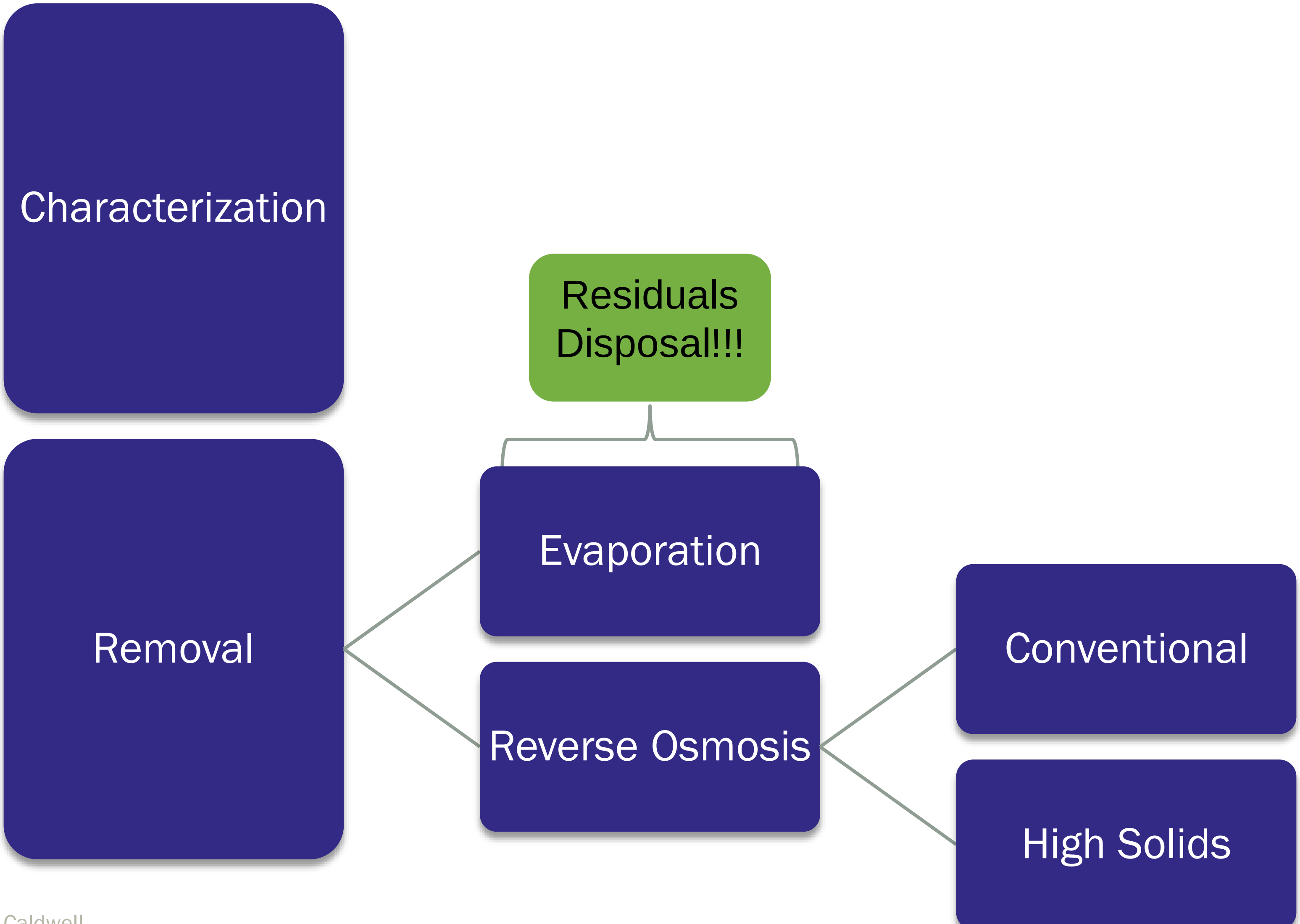




TDS: Effect on Organics Removal



Inorganic TDS/Cl Removal



Refractory Dissolved Organic Nitrogen - rDON

What is rDON?

Comprises of the following:

- Humic substances (humic acids, fulvic acids, and humins)
- Polymerized organic compounds
  - Endogenous decay of biomass and release of intracellular material
  - Released during high substrate utilization rate

rDON Example

- Discharge to POTW which discharges to the Chesapeake Bay Watershed (CBW)
- rDON load to POTW:
  - 18% or 1.45 mg/L @ avg flow
  - 36% or 2.9 mg/L @ peak flow
  - POTW Discharge Allocation for TN = 8 mg/L
- Treatability: GAC, H2O2, Hypochlorite, and High pH were evaluated (no removal observed)
- Per CBW Program : variance could be achieved if the permittee can demonstrate that the constituent is not bioavailable in the plant and in the watershed (consistent with CBW models). Submit a preliminary design report identifying technologies and operational changes implemented

Technologies on the Horizon

- Anaerobic treatment
- Nitrogen removal alternatives
  - Biological
  - Physical/chemical
- Contaminant specific sorbents
- Thermophilic (select wastes)

Thank You!

Brown AND Caldwell

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Lighting a path to sustainable waste management practices

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