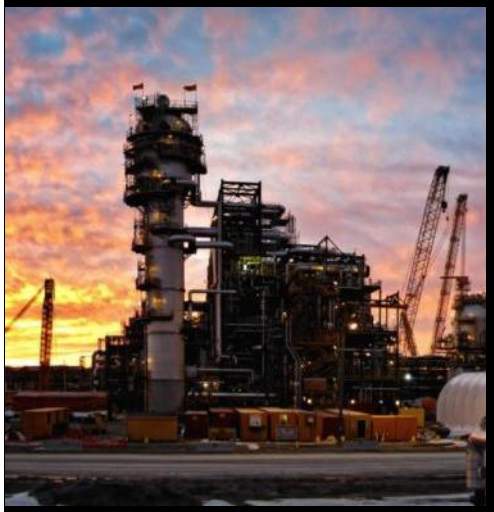


Kiewit Engineering & Design Co.

Prepared for McIlvaine Webinar | March 12, 2015

Discussion Overview

- Water Chemistry
- Water Users
  - Demineralized Water Production
  - Cooling
- Water Reducing Strategies
  - Treat
  - Recycle
  - High pH Processes
- ZLD Options
- Thermal ZLD Details
  - Energy Supply Alternatives
  - Maintenance
  - Contingencies
- Conclusions

Kiewit Corporation / Brian Clarke, P.E.

- 130-year history
- Engineering News-Record (ENR) (May 2014)
  - 1st Domestic heavy contractors
  - 2nd Power
  - 2nd Transportation
  - 3rd Top 400 contractors
  - 7th Petroleum
- 30,000 employees
  - 11,500 staff and 18,500 craft
- 93 offices in the US, Canada & Australia
  - Power / OGC / Water / Wastewater

- Brian Clarke
  - Kiewit Engineering and Design Office
    - Lenexa, KS
    - 1,000 employees
  - 8 years performing industrial water treatment
    - Primarily Natural Gas Power Applications
  - PE Licensed in Ohio

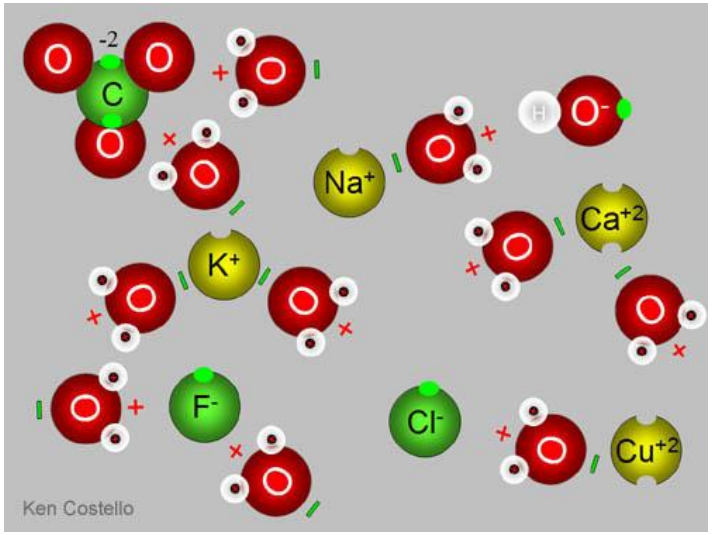
Water Contaminants and Chemistry

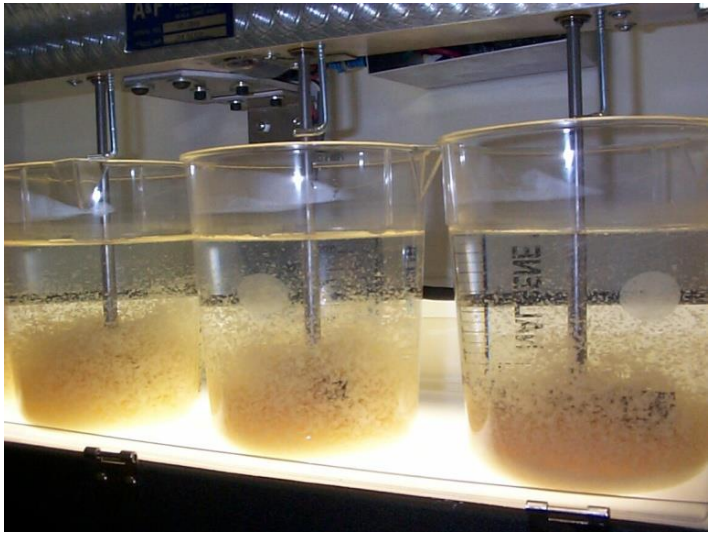
Suspended Solids (“see ums”)

- Can be filtered

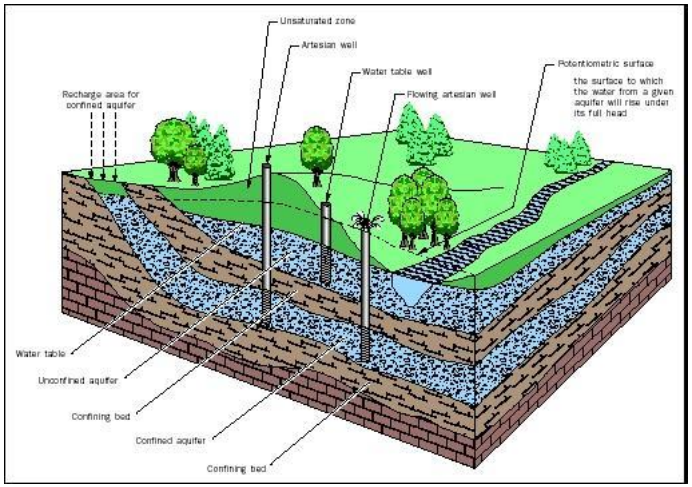
Dissolved Solids (“no see ums”)

- Formed by solids dissolving in water
  - Ex: $NaCl + water \rightarrow Na^{+} + Cl^{-}$
- Ions free to move independently in solution
- Ions are positively (cations) or negatively (anions) charged





Water Chemistry

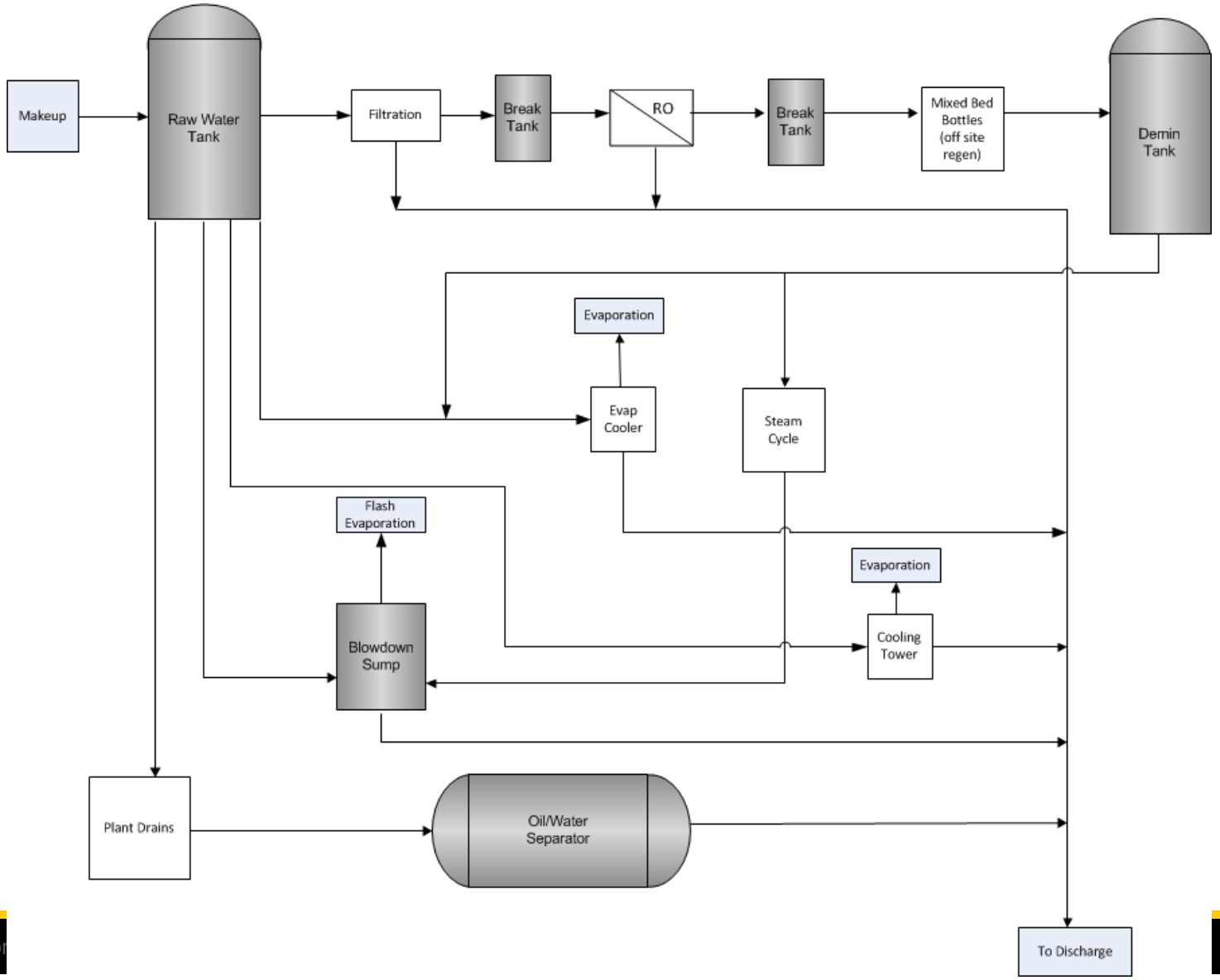


- Each water source has unique chemistry
  - Sampling plan is critical
  - Knowing your water allows you to determine the appropriate treatment
- Different water sources have different typical considerations, for example:
  - River
    - Seasonal TSS upsets
    - High Hardness
  - Groundwater Well
    - High TDS
    - High Hardness
    - High Silica (west)

Power Plant Equipment

- Typically try to concentrate the water to the extent possible in order to reduce usage
  - Use modeling software and industry standard limits to determine maximum concentrations
  - Try to concentrate each reject stream to its saturation or permit limit
- Equipment not tolerant to TSS
  - Filters remove suspended solids in concentrated waste stream
- Demineralized water required for the steam cycle
  - Remove the dissolved solids in a concentrated waste stream
- Cooling water for the cooling tower and evap cooler will concentrate due to evaporation loss

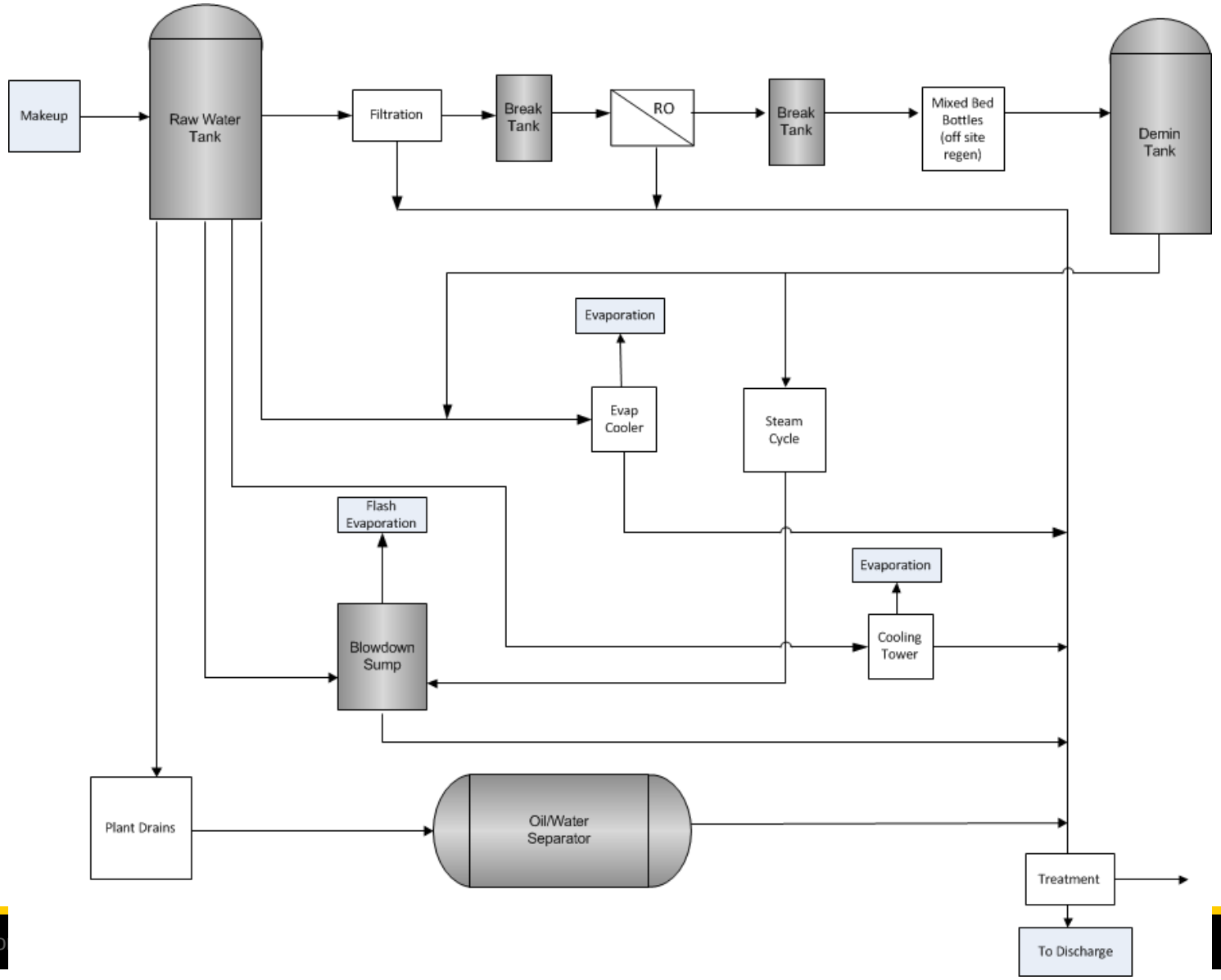
Power Plant Schematic – Simple Diagram



Power Plant Wastewater Treatment

- Two goals behind wastewater treatment
  1. Ensure wastewater meets NPDES permit limits
     - Select problem constituent(s) and add a treatment process for removal
     - Don’t concentrate wastewater as much
       - Uses more water
  2. Reduce freshwater consumption
     - Recycle
     - Treat and reuse
     - Go full ZLD

Power Plant Schematic – With Treatment



Reducing Flows Through Recycle

- Low TDS streams can be recycled to dilute inlet or cycled water
  - Temperature Concerns
  - Chemical compatibility
- Iterative evaluation checking chemistry at the different operating scenarios
- Good to do for any project
- Helps reduce fresh water usage and wastewater discharge

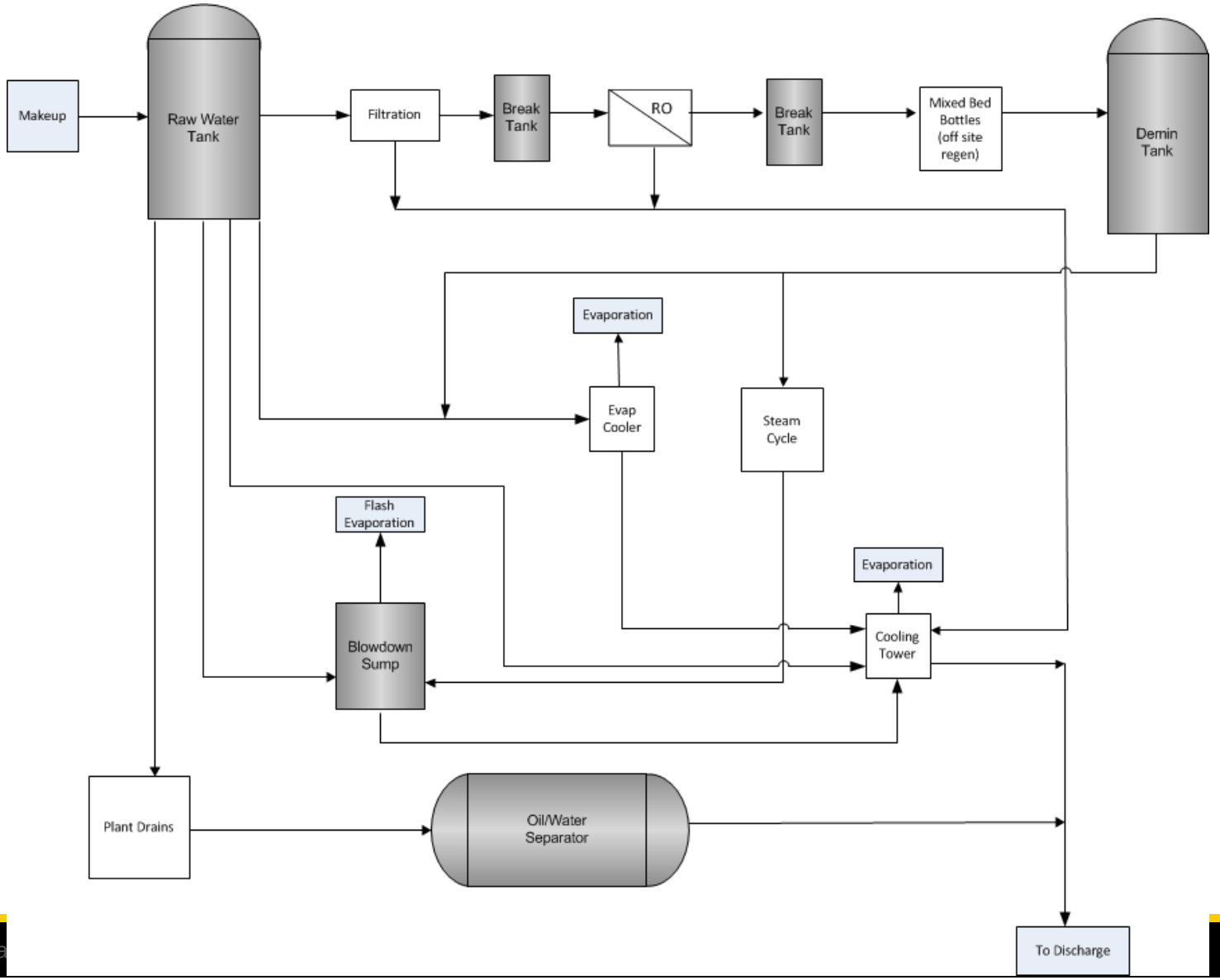
Reducing Flows Through Additional Treatment

- Can target a specific constituent for isolation and removal.
  - Different treatment for different constituent
- HIGH PH Membrane Concentration treats for multiple constituents
  - HERO™ / OPUS™
  - Takes water at saturation and concentrates it further via the following steps:
    1. Hardness and TSS removal
    2. Carbon dioxide removal
    3. Caustic injection
    4. Reverse osmosis
  - Yields a very concentrated Waste Stream (10,000 – 30,000 ppm TDS).
    - Unlikely to be permitted as discharge
    - Precursor to ZLD

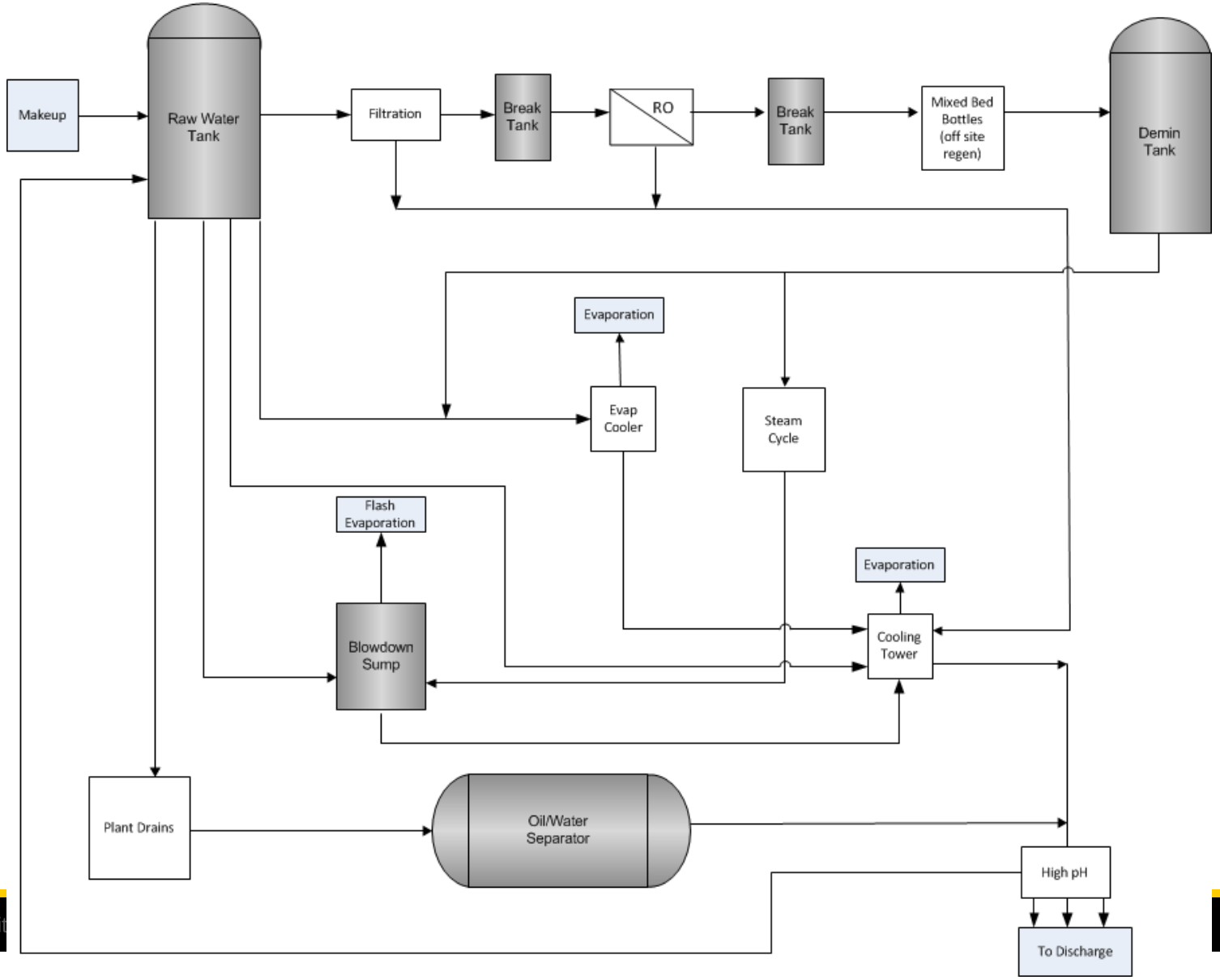
Water Treatment Processes Examples

Constituents	Treatment
Ammonia	Biological Treatment: Membrane Bioreactors (MBR) Moving Bed Bioreactors (MBBR) Biological Aerated Filters (BAF) Trickling Filters (TF)
Oil and Grease	
BOD	
COD	
TOC	
TP - P	
TSS	Clarification, Multimedia Filtration, and Microfiltration
Turbidity	
Al	Lime Softening and pH Adjustment
Fe, Mn	Aeration, Greensand Filtration, Lime Softening, pH Adjustment, Chlorination
Ca, Mg	Lime Softening
SiO_2	Supplemental Magnesium, Inhibition through high pH*

Power Plant Schematic with Recycle



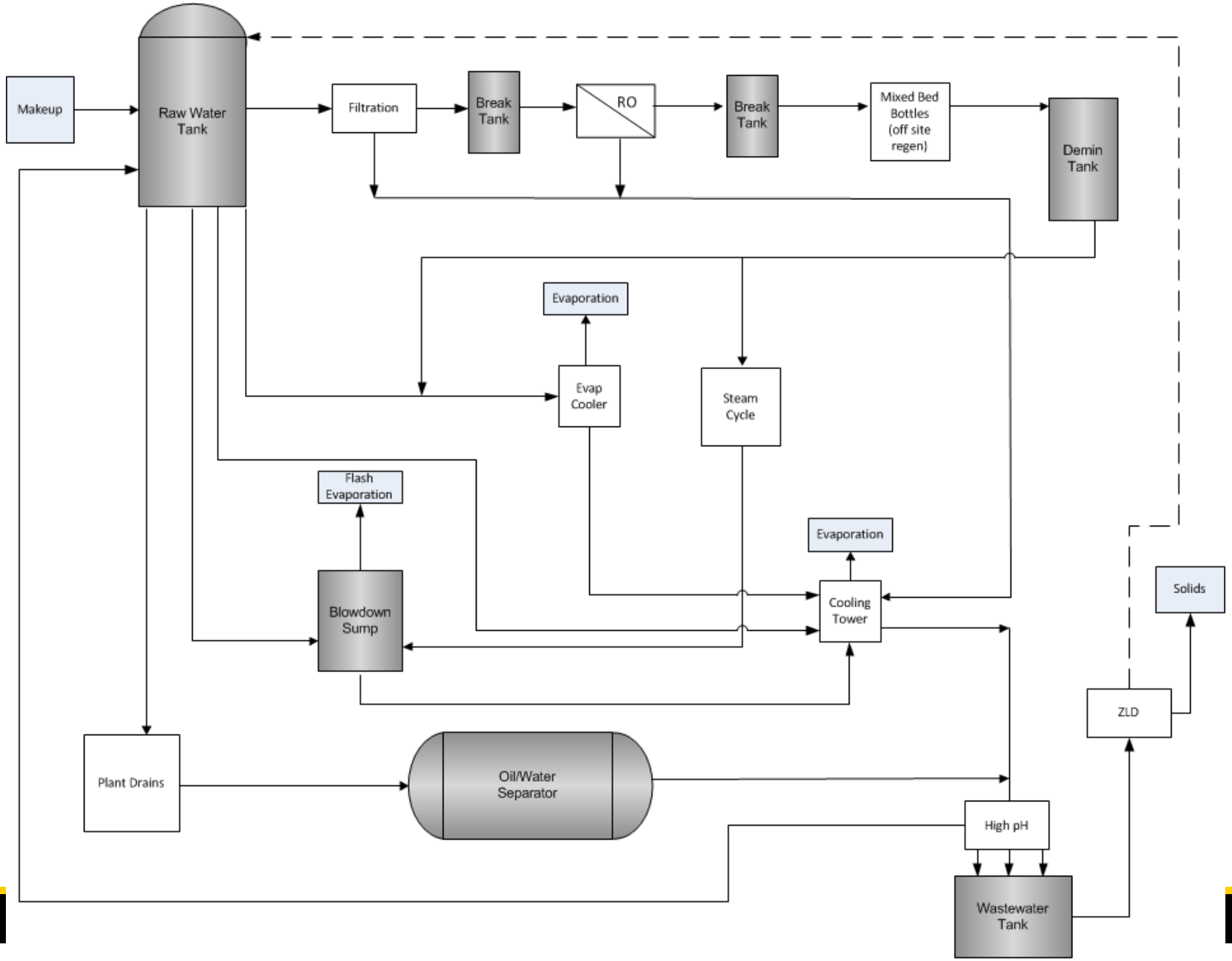
Power Plant Schematic with High pH



The Ultimate Step: Zero Liquid Discharge

- The ultimate in stream concentration – reducing wastewater to dissolved solids to suspended solids
- Several ZLD options exist
- What is there space for?
- What is there budget for?
- **What is permitted?**
- For any option:
  - At least one week volume of wastewater storage at worst case conditions
    - If the ZLD is down the plant is down
  - Spare parts for any critical / rotating equipment

Power Plant Schematic with ZLD



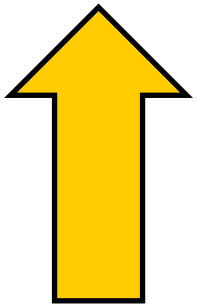
ZLD Options

- Zero Liquid Discharge – No liquid process water leaves the plant boundary
- ZLD can technically include:
  - Evaporation ponds
  - Deep well injection
  - Trucking water off site
  - Pipeline off site
- Thermal ZLD – using heat to evaporate water and concentrate wastewater to solids
  - Brine Concentrator
  - Crystallizer

Anecdotal Cost / Complexity of ZLD Options

- Brine Concentrator/Crystallizer
- Deep Well Injection*
- Spray Dryer*
- Trucking water off site*
- Evaporation Ponds*
- Pipeline off site*

Highest Cost and Complexity



Lowest Cost and Complexity

*Subject to permitting and regional limitations

Evaporation Pond

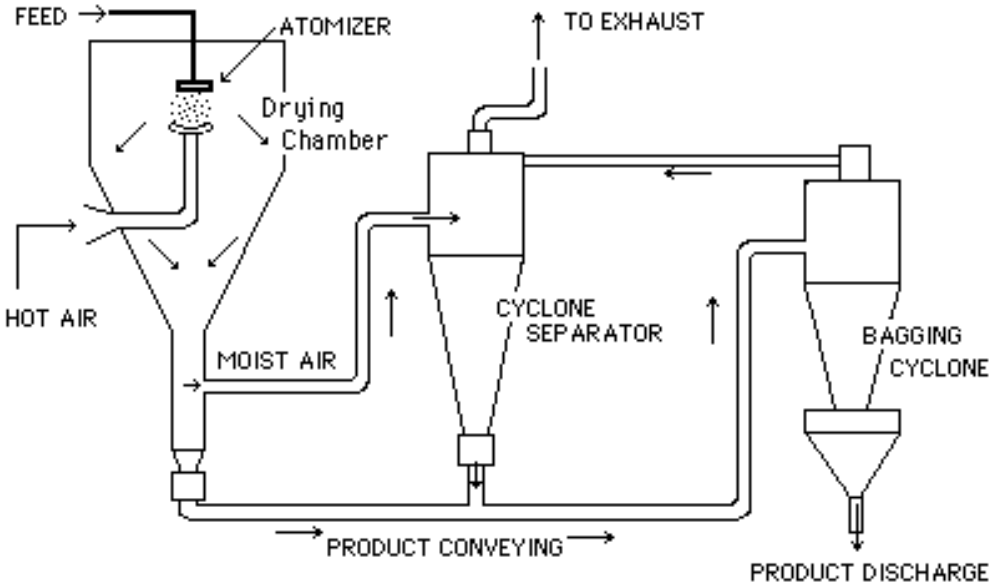
- Lined pond
  - Liner with leak detection installed to prevent percolation of water and heavy metals into soil
- Works by using solar evaporation to concentrate wastewater
- Ponds are typically used in sections and following evaporation solids sludge are periodically removed via bulldozer
- Large square footage requirement
- Aeration can be added to improve efficiency

Pipeline / Trucking Water Offsite

- Wastewater is directed to a tank where tanker trucks remove it as required or it is pumped to a nearby facility
  - Facility is generally an operation with an evap pond or thermal ZLD system
  - Wastewater trucks generally 5,000 gallons
  - A truck every 3 hours at 28 gpm wastewater
- All ZLD facilities will require trucking water offsite at some point

Spray Dryer

- Works by burning gas and adding wastewater to that gas to evaporate the water
- Dissolved solids become suspended and are removed in a baghouse
- Evaporated water is vented to a stack. Emissions / permitting always an issue



Deep Well Injection

- Wastewater is concentrated and pumped to deep aquifiers
  - Wastewater theoretically never interfaces with low TDS aquafiers
- Approximately $3-4M capex per wall
- Wells rarely take as much water as expected
  - Downhole Chemistry
  - Porous formations
- High Pressure pumps

Thermal ZLD

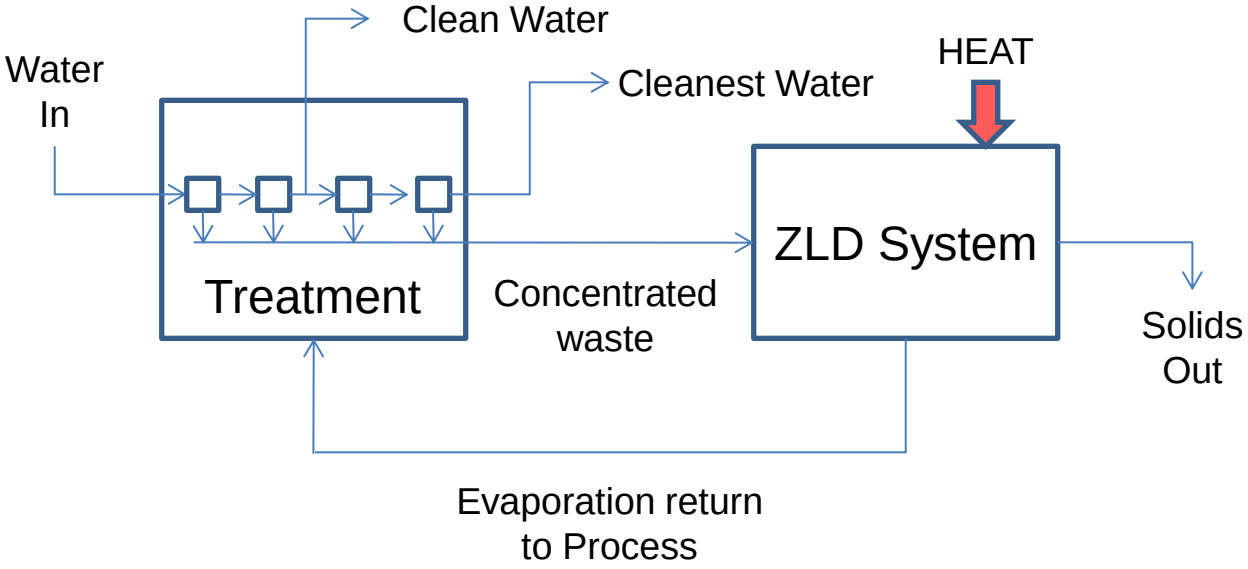
No other options work

Concentrate the TDS to TSS by adding heat

Brine Concentrator / Crystallizer

Solids sent to landfill

Evaporated water reused in process (BC/C)



ZLD Contingencies

- ZLD systems are challenging
- Nearly all are struggling with capacity and operations to some degree
- The following measures can help:
  - Redundancy
    - 4 x 50% recommended on thermal systems
  - Excess Capacity
  - Tankage
  - Trucking / Mobile Equipment Plan
  - Call facilities
    - Lessons learned
    - Materials
    - Things done differently
    - Vendor Support

Conclusions

- Power plants will have concentrated waste streams from demineralized water production and cooling
- These concentrated waste streams can undergo additional treatment to further concentrate and remove problem constituents
- The ultimate in wastewater treatment is zero liquid discharge
  - Complex and Costly
  - It helps to pre-concentrate as much as possible to reduce size of the “final” ZLD

Questions / Open discussion