


Innovations in the Design of the MacLeod High-Density Sludge (HDS) Treatment Plant

Envirobay

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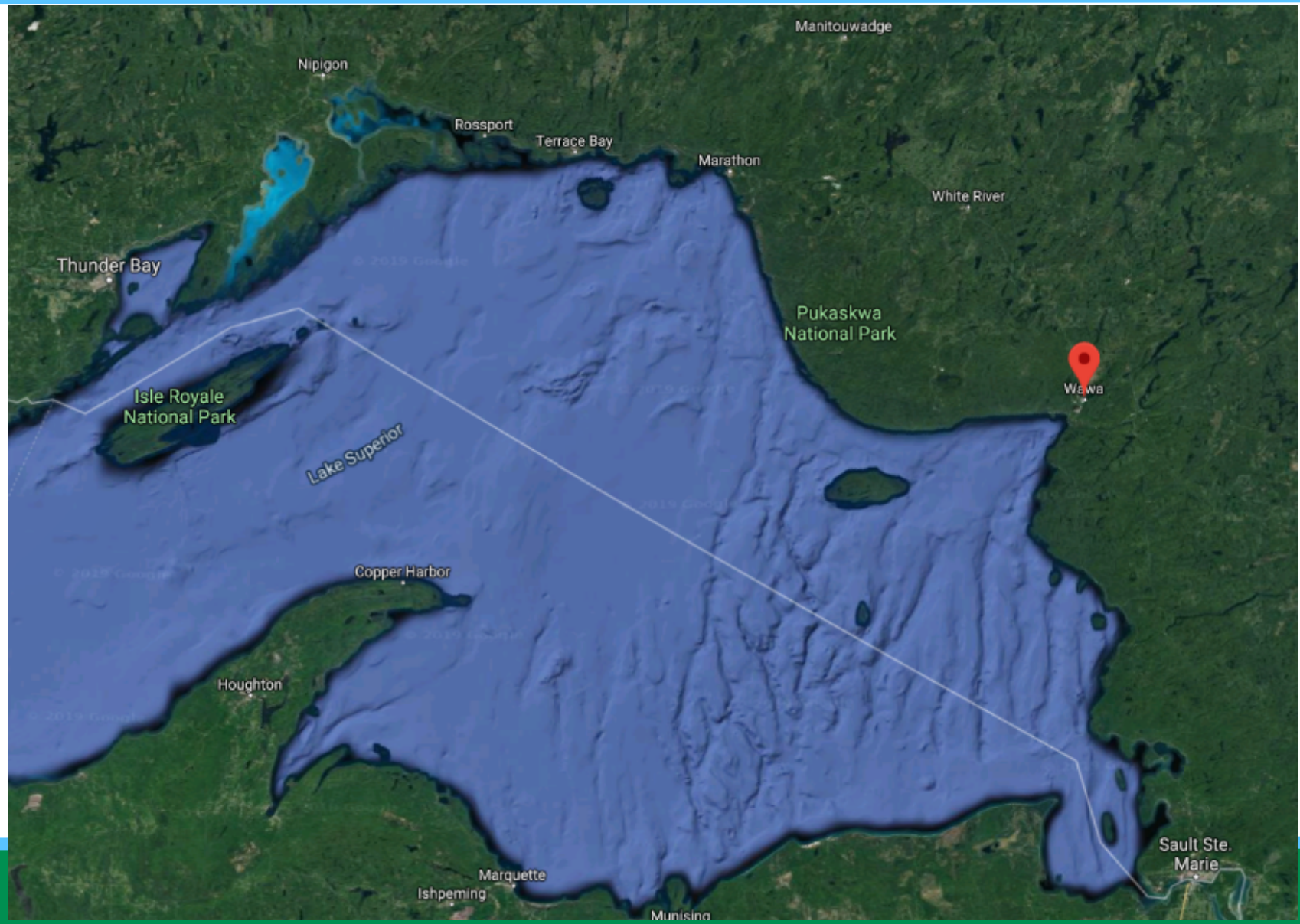
MacLeod Mine

- Near Wawa, Ontario, it is part of the Helen Iron Range which started operations in 1897
- Algoma Steel operated the MacLeod Mine until June 1998



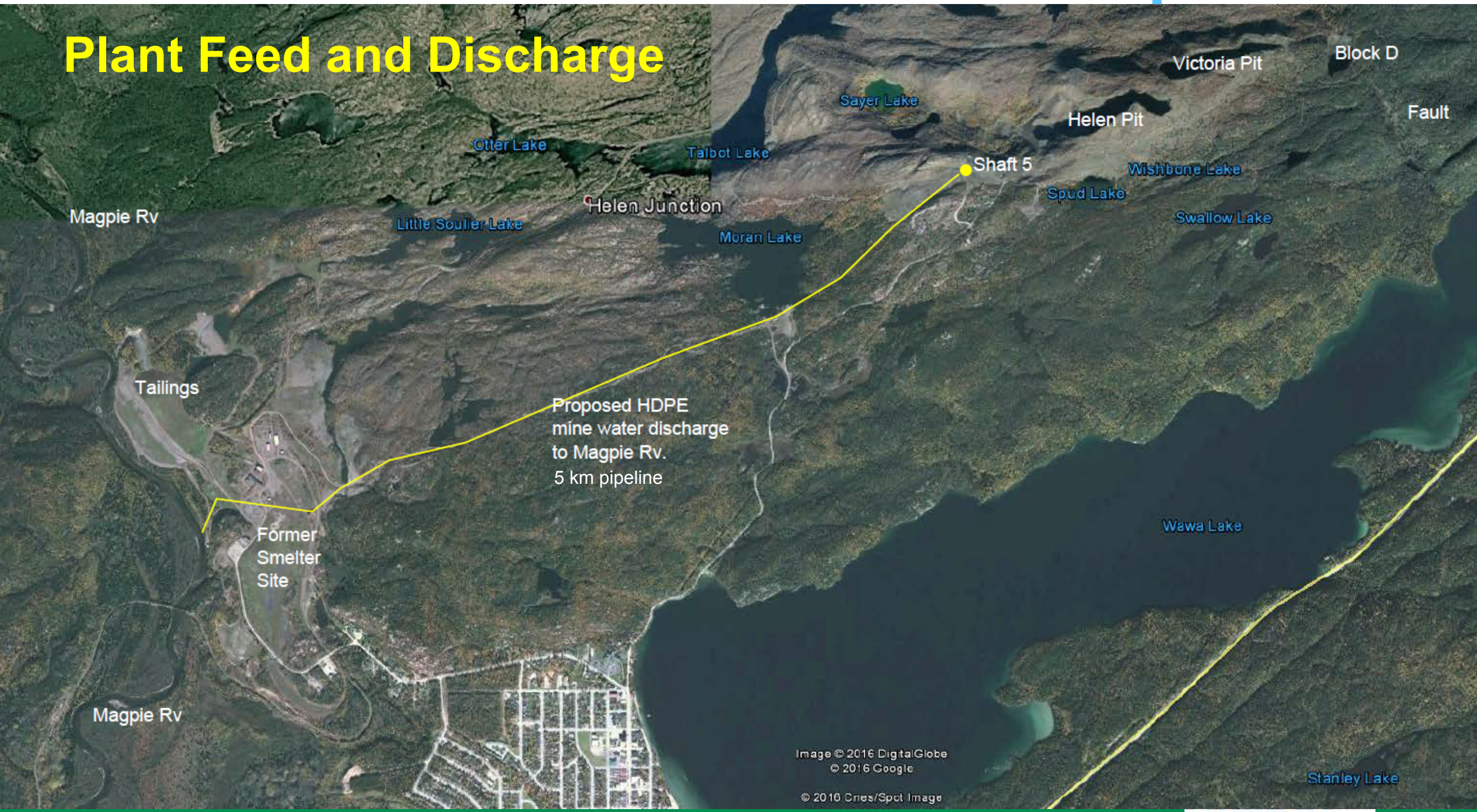
MacLeod Mine Water

- Since the site became inactive in 1998, the mine voids have been slowly filling up with water
- Mine water is acidic and contains high iron (Fe) concentrations due to the presence of pyrrhotite
- This water must be pumped out to keep the water level below natural levels and maintain the mine workings as a “sink”
  - Critical to maintain below the level of the nearby Wawa Lake
- Pumped water must be treated to strict discharge requirements prior to release into the Magpie River

MacLeod Mine Water

- Essar Steel Algoma Inc. (Now Algoma Steel Inc.) commissioned tests in 2016 that indicated that HDS would be the preferred treatment process
- Algoma sent out a request for proposals for a turnkey HDS plant of 1,300 usgpm (295 m^3/h)
- ANMAR won the bid with subcontractor Ecodyne and later Envirobay
- The Ontario Ministry of Northern Development and Mines (then MNDM, now ENDM) then took over management of the inactive site
- Management included construction supervision and now operations – which are contracted to OCWA (Ontario Clean Water Agency)

Plant Feed and Discharge



Feed Water Quality

- Shaft No. 5 water characterised by slightly acid pH, high sulphate associated to Fe, Mg, and Ca
- All regulated metals other than Fe are quite low
- Design lime consumption 2.4 g/L, Solids production ~4 g/L

MacLeod Water Characterisation		Raw Water
Averages in 2019		
pH		5.2
Sulphate	mg/L	4644
Fe	mg/L	724
Ca	mg/L	436
Mg	mg/L	532
As, Co, Cu, Ni, Pb, Zn	mg/L	<0.5

The Basic Chemistry of Lime Treatment

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- Lime dissolution and increase in pH

$$Ca(OH)_2 \Rightarrow Ca^{2+} + 2OH^-$$

- Precipitation of metals as hydroxides (fast reactions)

$$Fe^{3+} + 3OH^- \Rightarrow Fe(OH)_3$$

$$Me^{x+} + XOH^- \Rightarrow Me(OH)_x$$

- Gypsum Precipitation (slow reaction)

$$Ca^{2+} + SO_4^{2-} \Rightarrow CaSO_4 \cdot 2H_2O$$

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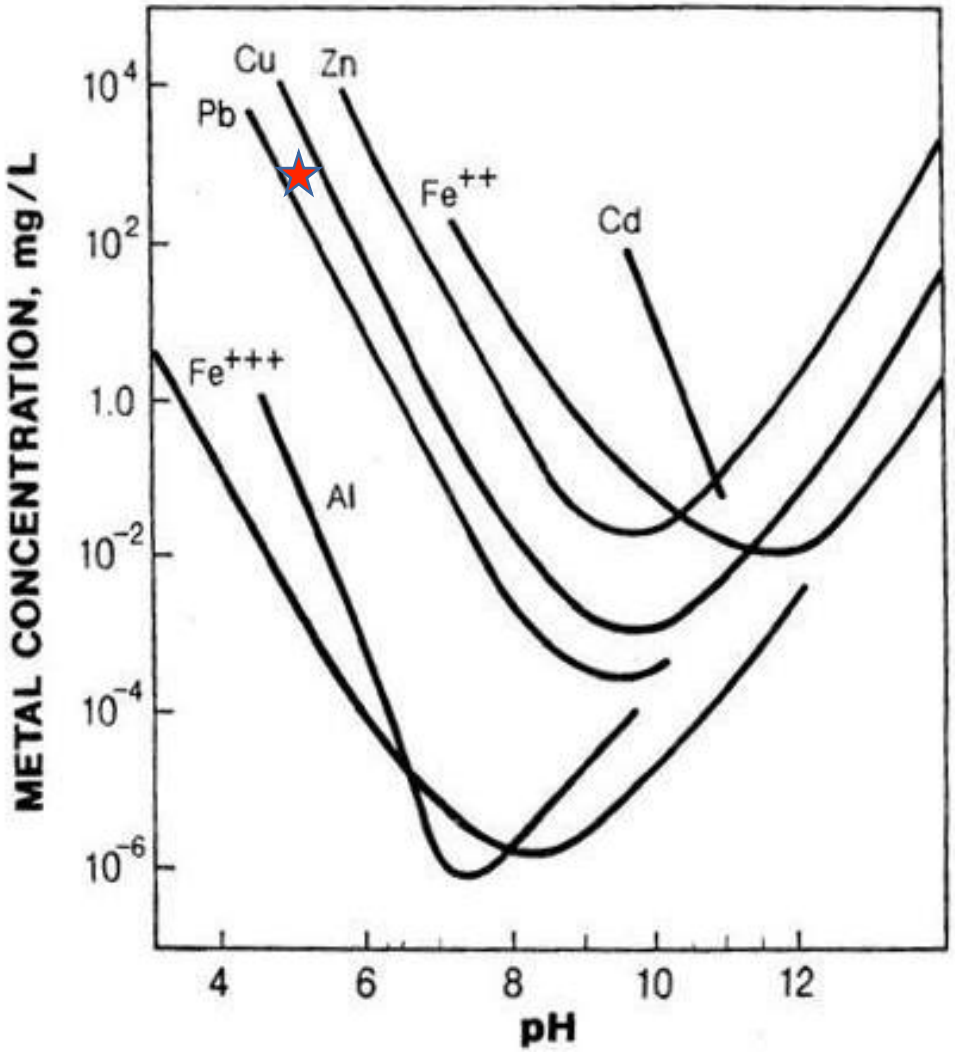
Basic Chemistry of Lime Treatment

- Insolubility of heavy metals in alkaline conditions is the basis of lime treatment

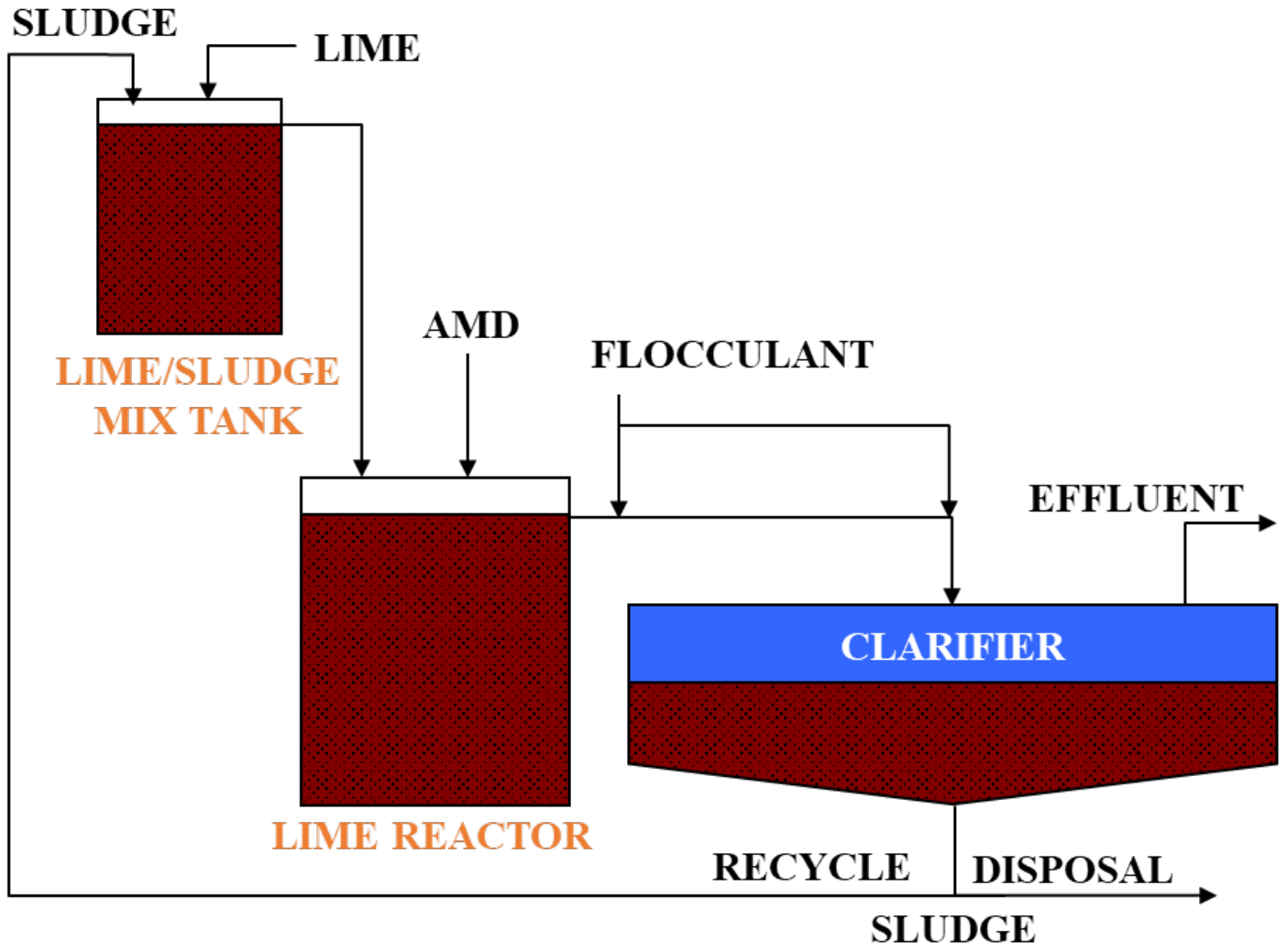
★ Feed Water Quality
  pH 5.2
  Fe 724 mg/L
  Clearly contains ferrous iron (Fe^{2+})



The HDS Process

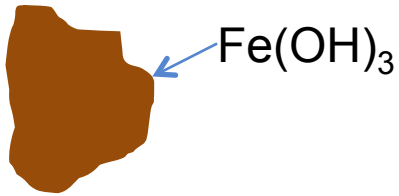
The HDS Process is the current standard in lime treatment:

- higher sludge density,
- better lime efficiency,
- improved metal removal,
- better solid/liquid separation, and
- improved removal of sulphate

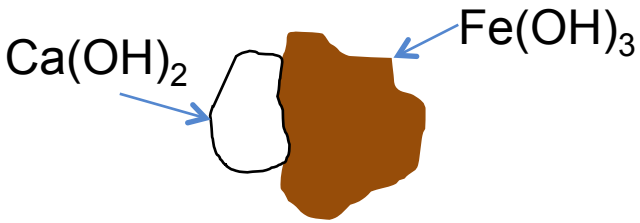


Micro-Physical Basis of the HDS process

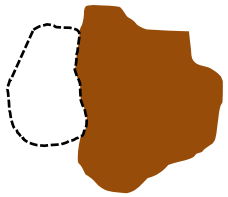
1. Solids in sludge:



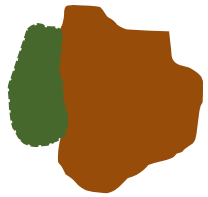
2. In Lime/Sludge Mix Tank (coagulation of lime with solids from sludge) :



3. In neutralisation reactor (dissolution of lime and precipitation of metals):

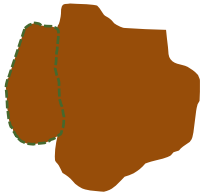


$Ca(OH)_2 \rightarrow Ca^{2+} + 2OH^-$



$Fe^{3+} + 3OH^- \rightarrow Fe(OH)_3$

4. New solids with particle growth:

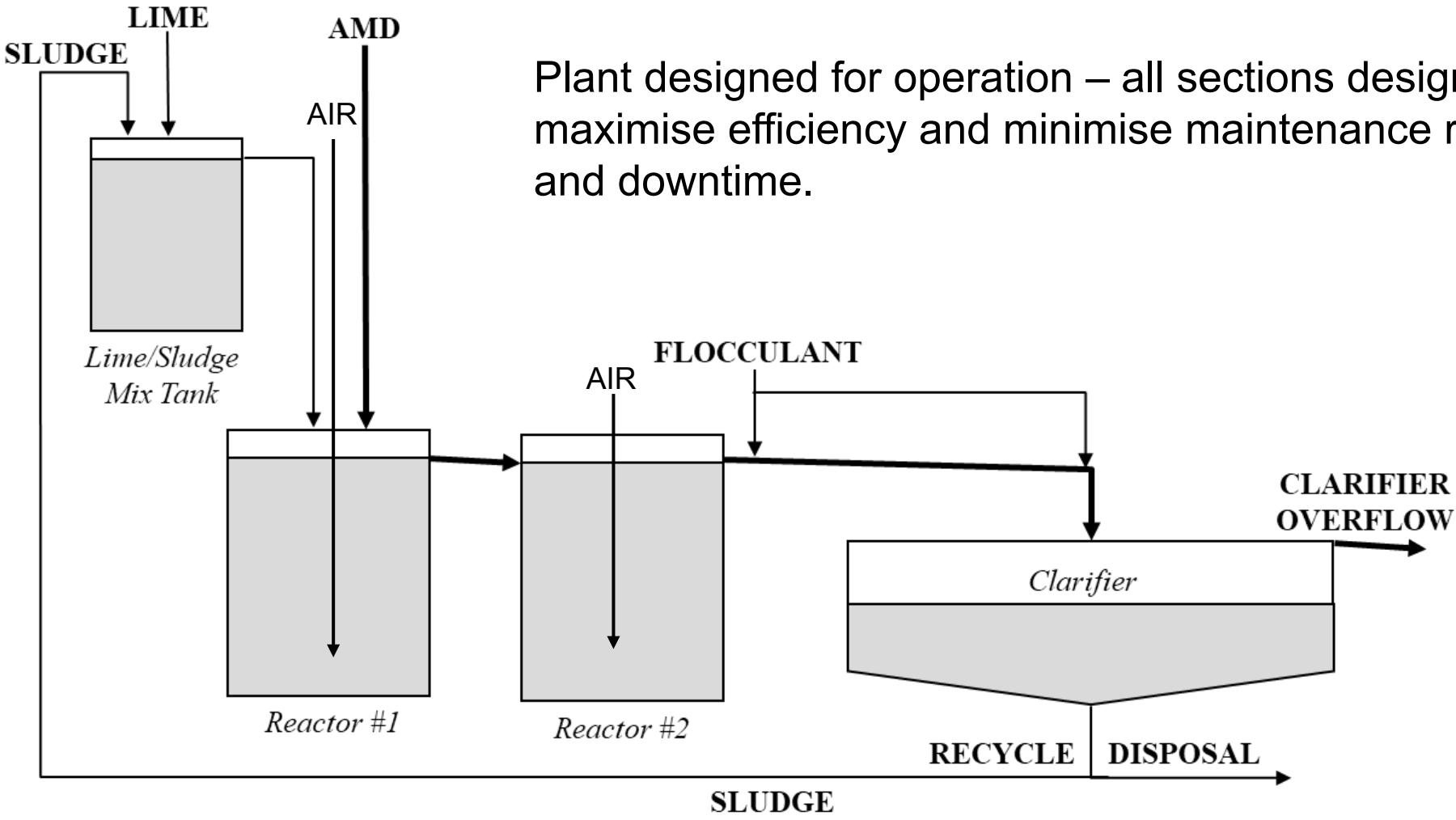


Note: Same principal for gypsum, but much slower reaction

Why Modify the HDS Process?

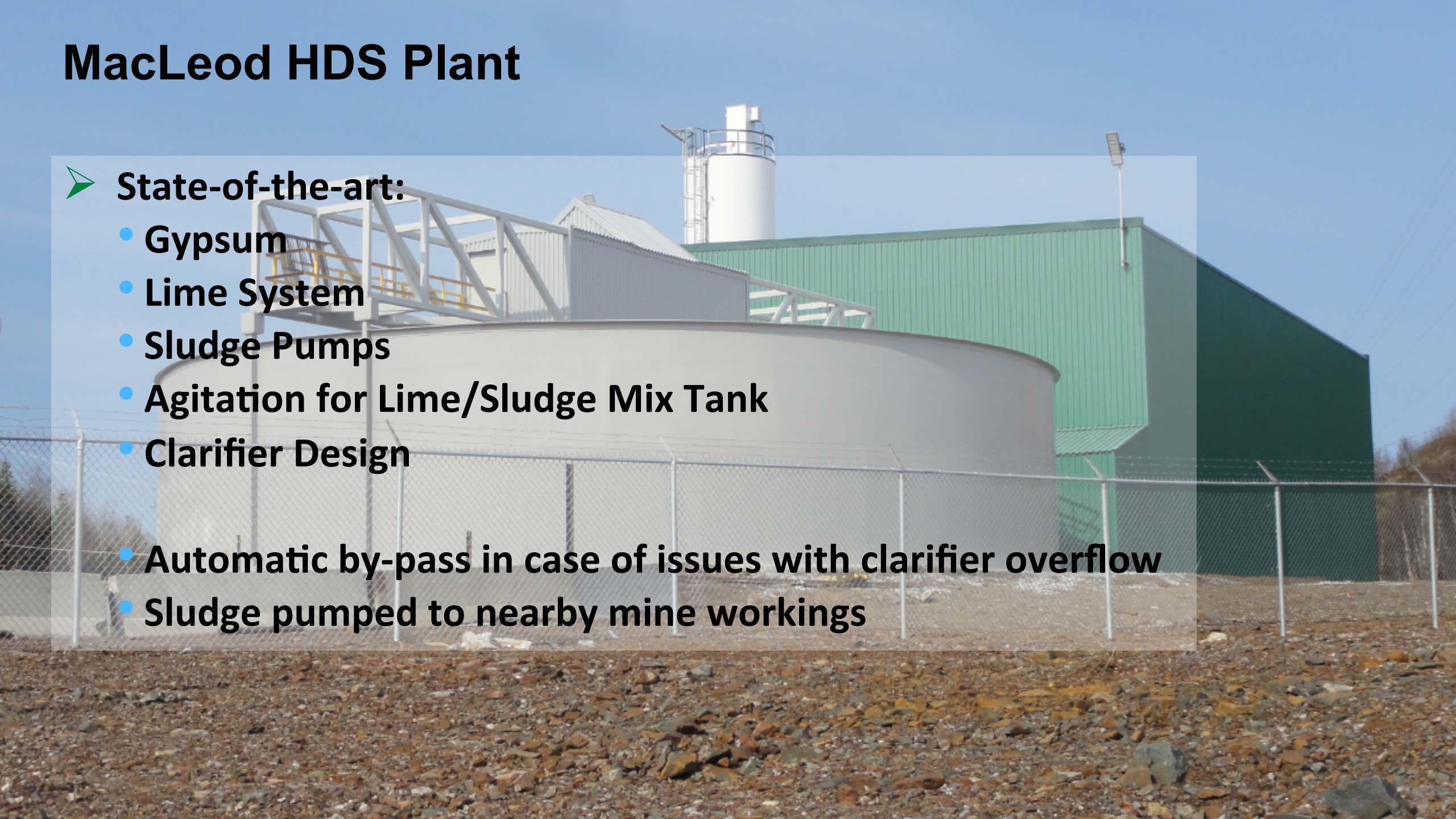
- HDS process has existed for almost 50 years and has shown reliability and applicability to many different acid water problems
- While the success rate is excellent, operations can sometimes require significant maintenance particularly for one single operator
- Key maintenance items include:
  - Lime slurry preparation system
  - Lime delivery and pH control
  - Sludge pumping
  - Lime/Sludge Mix Tank issues
  - Gypsum scaling
  - Clarifier “donuting”

MacLeod HDS Plant



Plant designed for operation – all sections designed to maximise efficiency and minimise maintenance requirements and downtime.

MacLeod HDS Plant



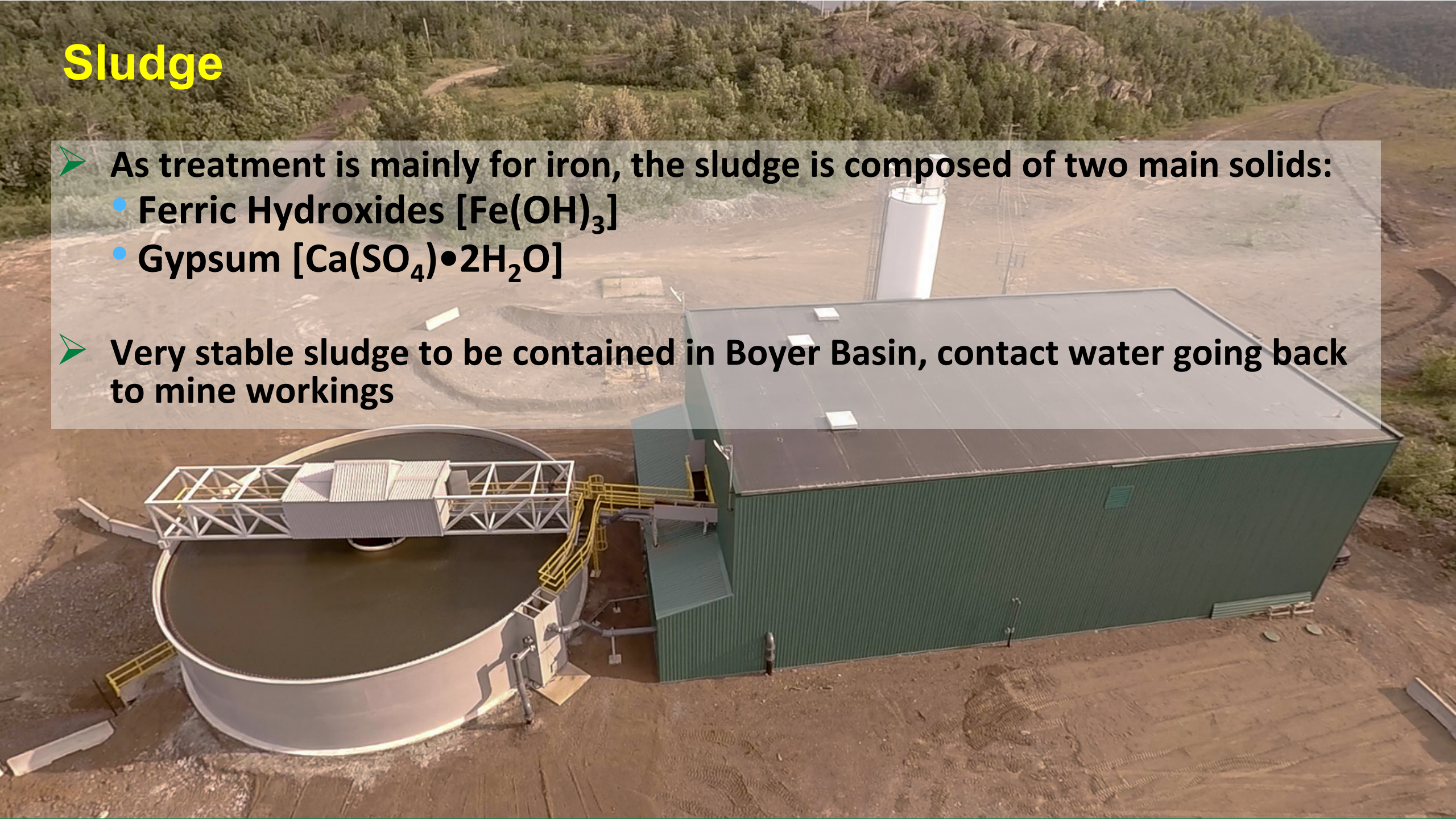
- State-of-the-art:
  - Gypsum
  - Lime System
  - Sludge Pumps
  - Agitation for Lime/Sludge Mix Tank
  - Clarifier Design

  - Automatic by-pass in case of issues with clarifier overflow
  - Sludge pumped to nearby mine workings

Sludge

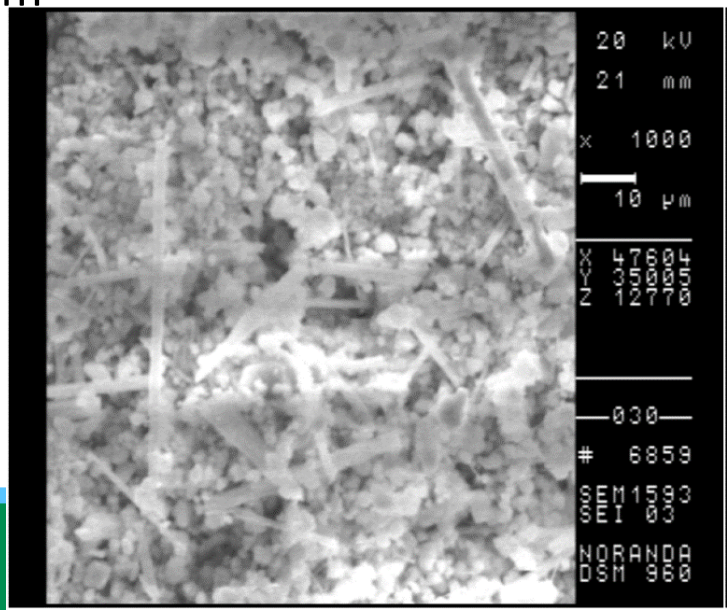
- As treatment is mainly for iron, the sludge is composed of two main solids:
  - Ferric Hydroxides [$Fe(OH)_3$]
  - Gypsum [$Ca(SO_4)•2H_2O$]

- Very stable sludge to be contained in Boyer Basin, contact water going back to mine workings



Gypsum Precipitation at MacLeod Mine

- With a 5 km effluent pipeline, need to minimise scaling
  - Gypsum tends to form on existing gypsum (does not nucleate)
- Minimise scaling by maximising gypsum precipitation in process:
  - Increased reactor retentions times: minimum retention of 2 hours at maximum treatment rate
  - Increase sludge recycle rate: a single sludge recycle pump can provide up to 23% of feed rate volumetrically (69 m^3/h) [typical 10 to 12%]
  - Designed to provide at least 35 g/L of solids in reactors to enhance gypsum precipitation – max to be determined
- The final sulphate concentration depends significantly concentrations of sodium, potassium, and magnesium



Lime Slurry System

- Silo and slaker elevated for easy and reliable operation
  - Fresh slurry feeds into lime slurry storage tank by gravity
  - No troublesome lime slurry transfer pump
- Grit drops down into concrete buggy
- Large lime slurry storage tank
  - Allows to operate continuously even when there are issues with slaker
  - Minimises variability in lime slurry solids content
  - Can help significantly to operate slaker continuously

MacLeod Slaker Platform

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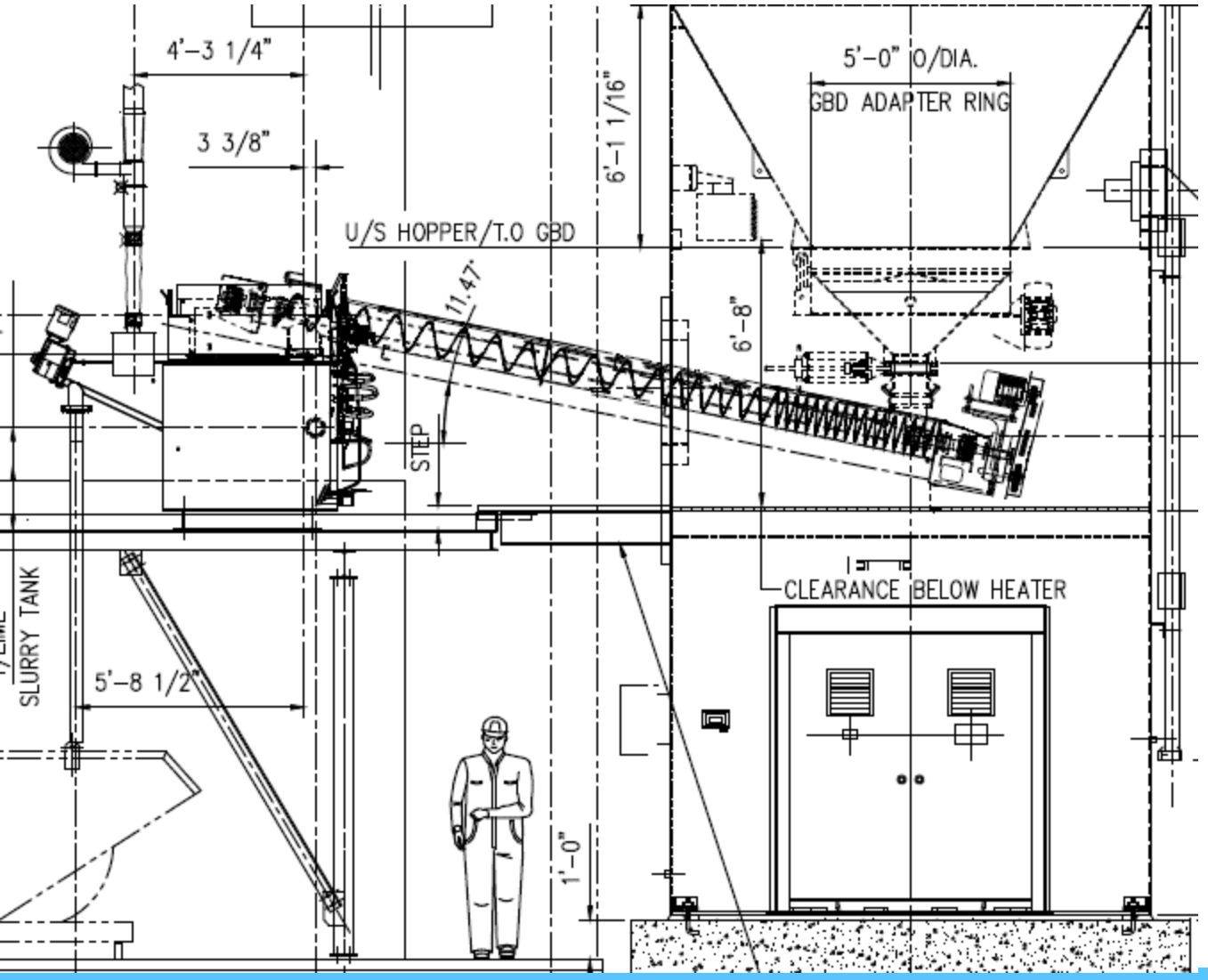
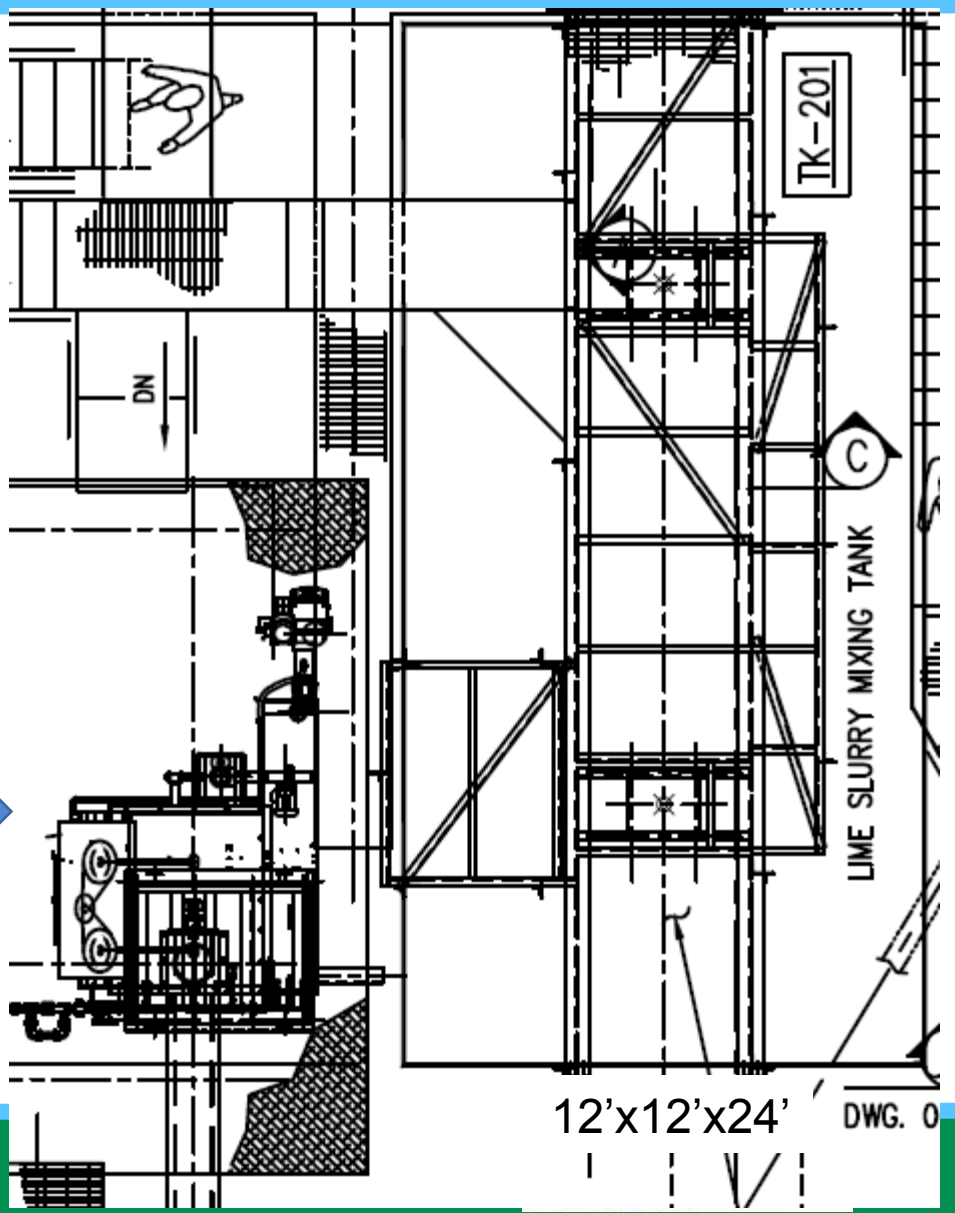


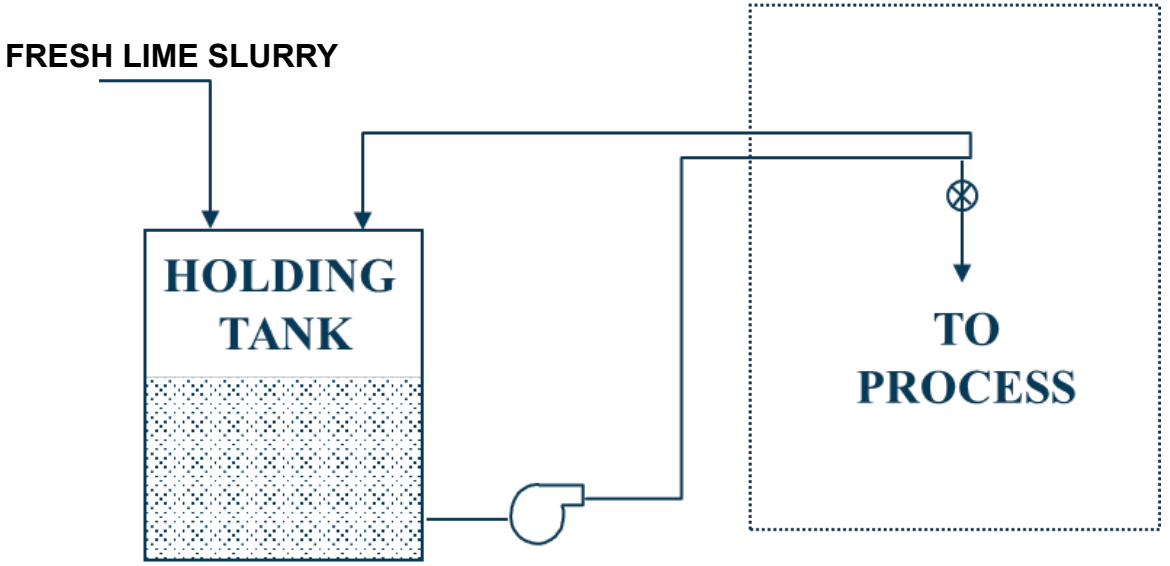
Side View

Plan View



Conventional Lime Dosing

- Conventional systems use slurry pump with loop and On/Off pinch valves on split-time proportional control
  - Good for multiple dosing points
  - Need high flow and back-pressure
  - High power consumption
  - Sanding up problems
  - Pipe and valve erosion
  - Plugging up at valves



Peristaltic Lime Pumps

- Dual automated pumps with flush and drain
- Can provide high suction and high discharge pressure
- Variable speed with huge range
- Excellent pH control
- Cost-effective pre-built skids
- Low maintenance – with two years completed, tubing has not been replaced

Traditional Sludge Pumps

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- Slurry (SRL) pumps traditionally used
  - Inexpensive
  - Have no suction
  - Don’t create much pressure
  - Designed for mill slurries, Not for viscous fluids
- Operations manuals and practice include diluting sludge for easier pumping
  - Why create dense sludge if you’re going to dilute it?

Sludge Viscosity

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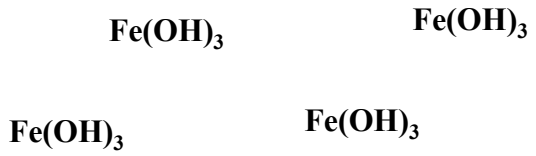
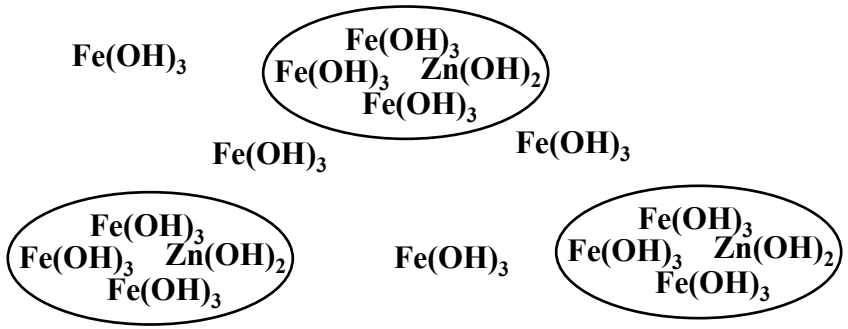
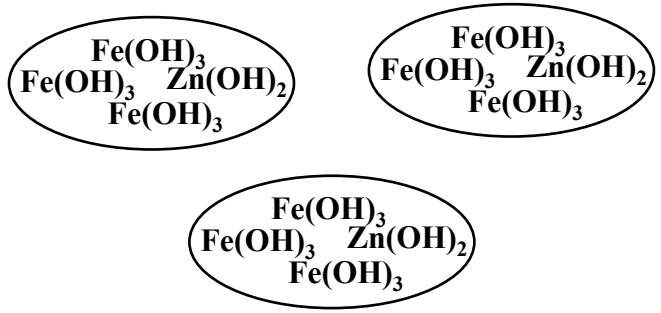
LOW density, not viscous



MID density, highly viscous



HIGH density, slightly viscous



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MacLeod Sludge Pumps

- Positive displacement pumps (progressive cavity) create suction and pressure to overcome high viscosity
- Do not require dilution to get through difficult sludge stages

Lime/Sludge Mix Tanks

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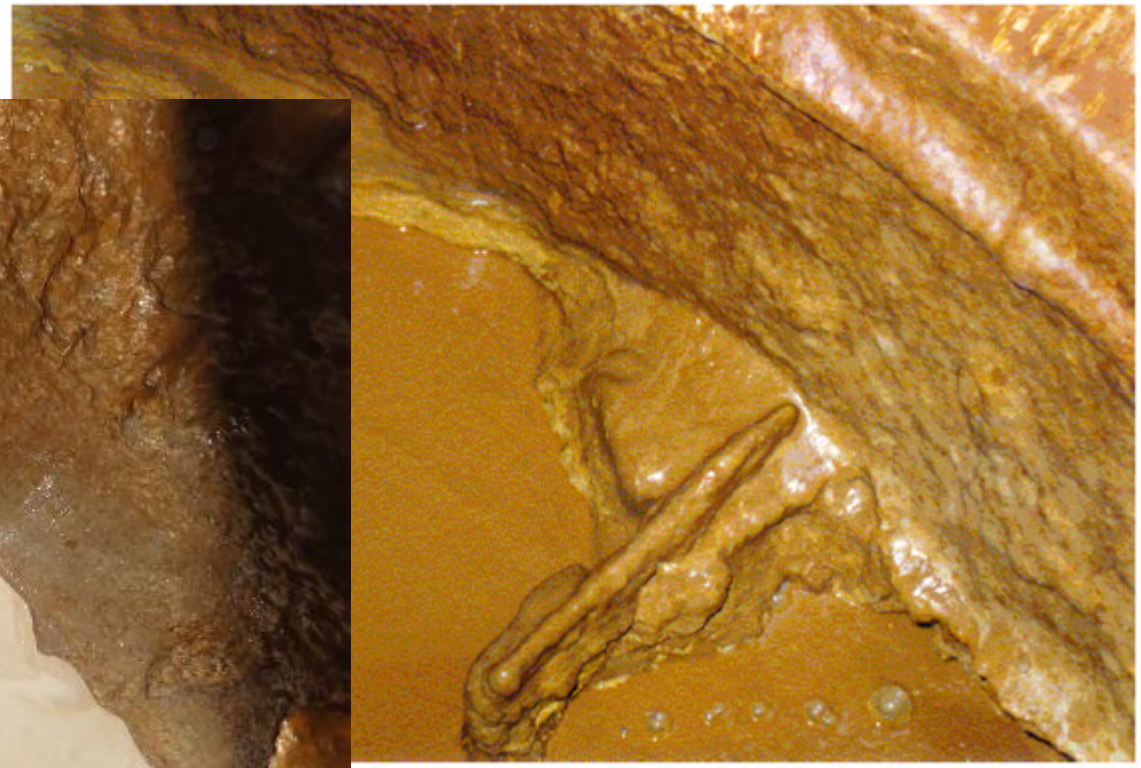
Lime is a pain, sludge is a pain, mix them together and you get problems

Photos from three different HDS plants, showing stagnant sections of Lime/Sludge Mix Tanks and low mixing



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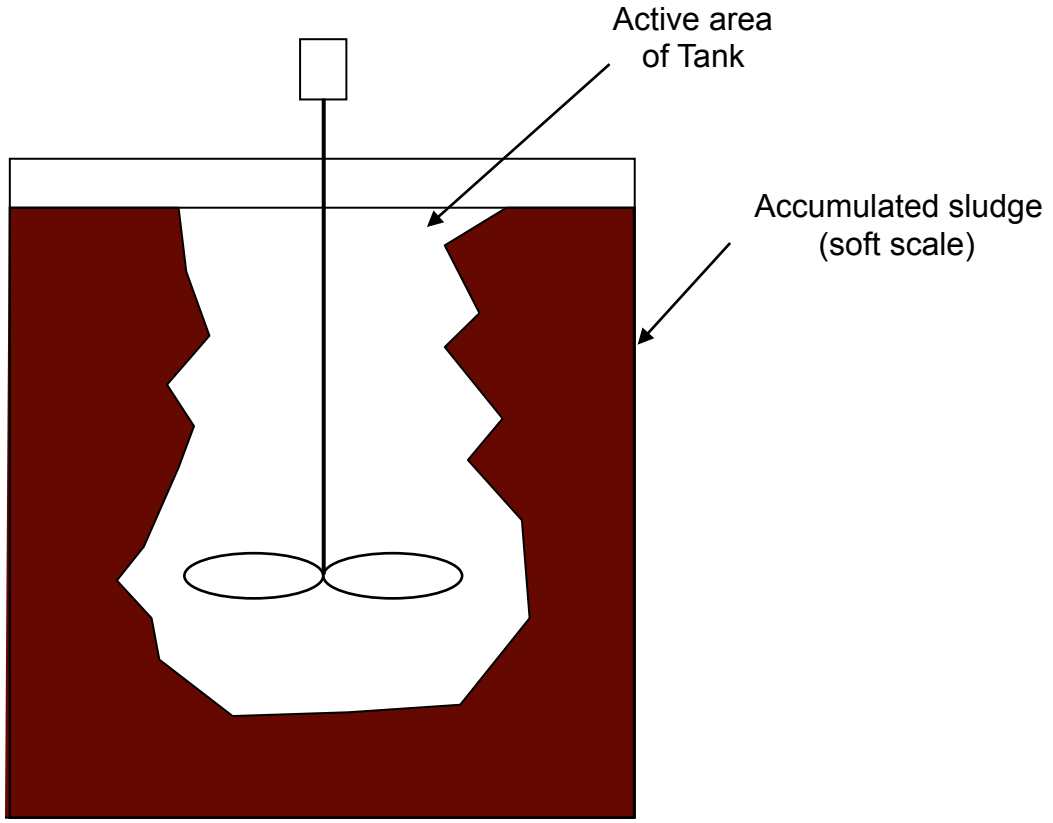
Lime/Sludge Mix

- Two viscous/problematic fluids makes a very thixotropic mixture
  - Keeps reasonably low viscosity in constant movement
  - Congeals where insufficient energy imparted



Proper contact and coagulation between lime and sludge particles important.

Lime/Sludge Mix Solution

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- Requirement:
  - Need agitation for highly viscous fluids
  - Need to reduce inactive sections of the tank
  - Need to impart more energy – better dispersed
- Solution:
  - High-viscosity impeller
  - Use smaller baffles
  - Use shorter risers (while still ensuring no short-circuiting)

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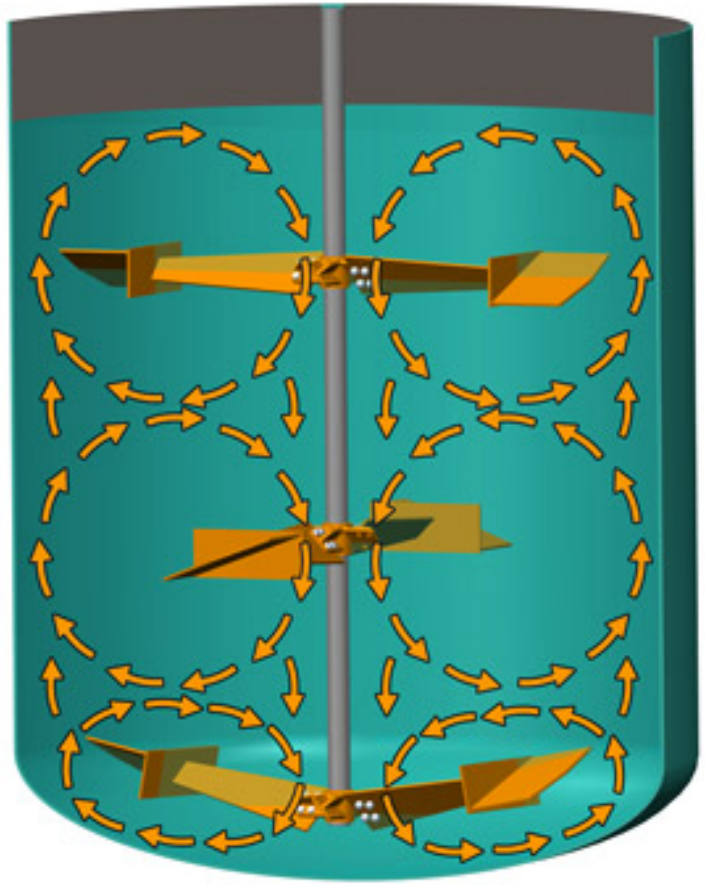
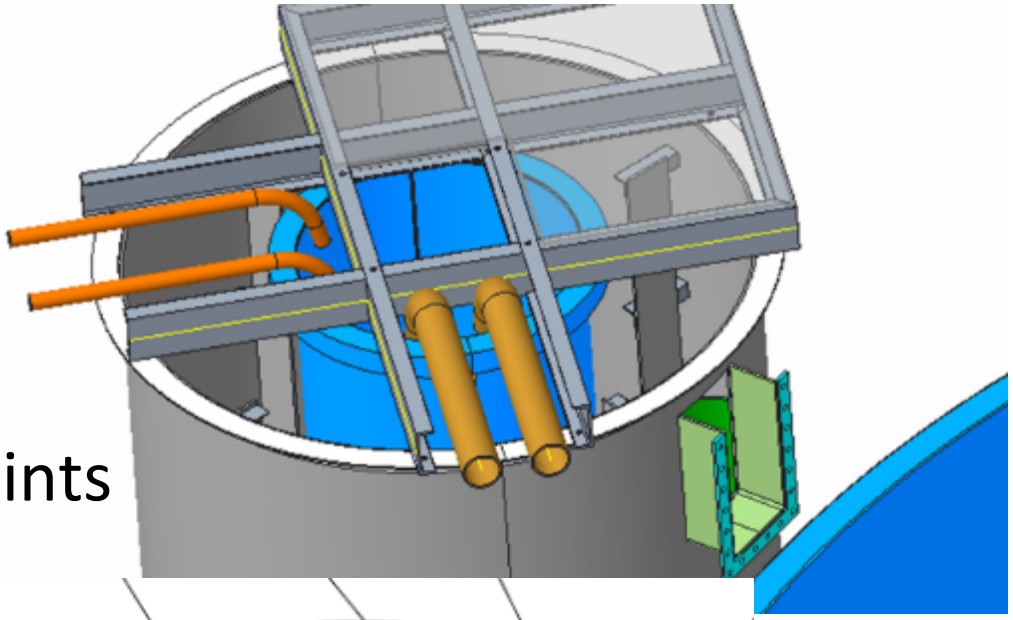
Lime/Sludge Mix Solution

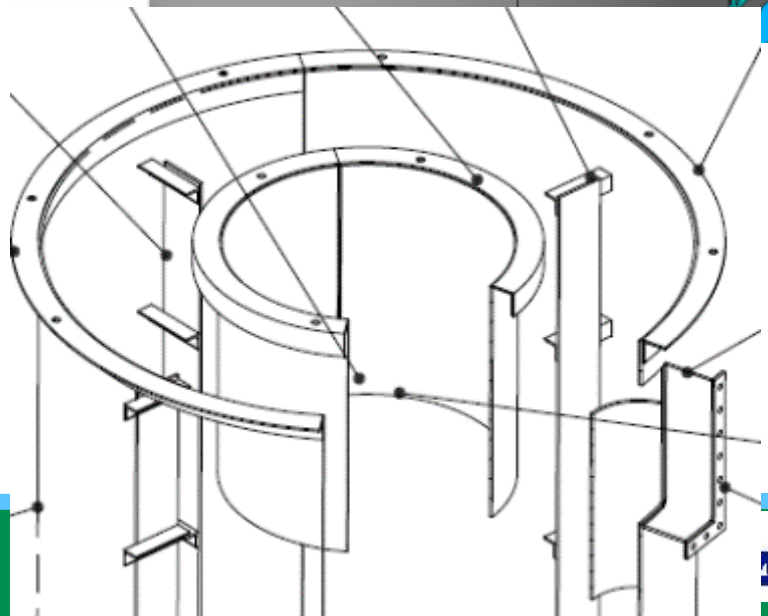
- Counterflow impeller
  - Larger diameter (2/3rd instead of 1/3rd)
  - Dual action: pushes down and pulls up
  - Minimises risk of creating “stagnant caverns”
  - Requires greater power



Lime/Sludge Mix Solution

- All inputs (lime and sludge) into feed well
  - Sized to coincide with transition on impeller
- Feed well goes down 15 cm into slurry
- Riser only goes down 30 cm
- Reduced bridge allows access to all key points
  - Install hose nearby
  - Access to feed well, end of pipes, riser, launder





Note: Envirobay design

Lime/Sludge Mix

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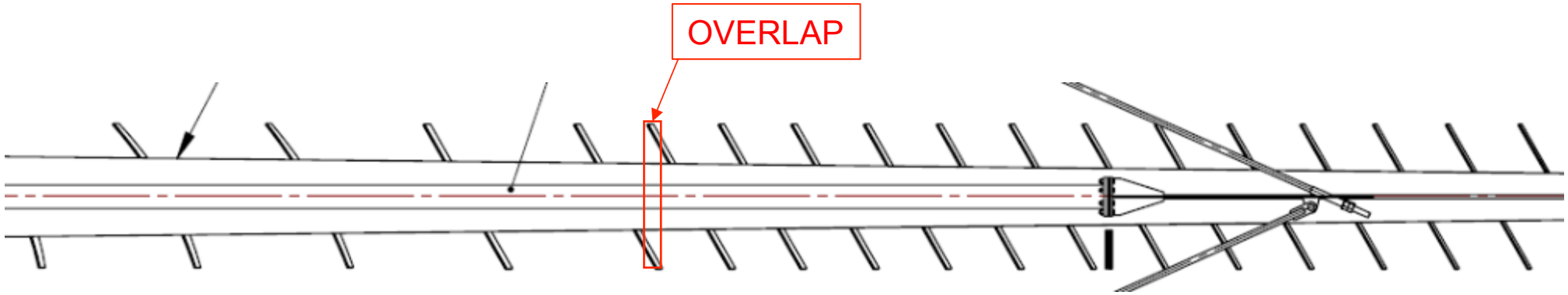
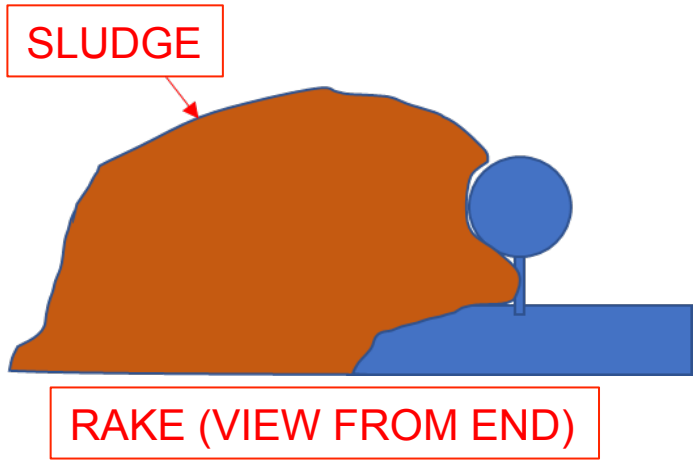
- Required no maintenance in the two years to date

Clarifier Rakes





Due to sludge viscosity, too much profile ends up with rake pushing sludge around instead of rake it toward the center

- Low-density sludge ends up drawn from center (seen by variations in density)
- Lose some constancy in process – can affect pH control, subsequent sludge, turbidity

Clarifier Rake Solution

- Remove overlap on single rake arm
- Ensure sufficient slope (1:6)

Treated Effluent Quality

- Discharged 644,000 m^3 in 2018 and 710,000 m^3 in 2019
- Excellent treated water quality consistently produced (Fe limit 3 mg/L)
- Passed all trout and *Daphnia Magna* bioassays, most by 100% survival

MacLeod Water Characterisation		Raw Water	Treated Effluent
Averages in 2019			
pH		5.2	8.8
Sulphate	mg/L	4644	4392
Fe	mg/L	724	0.6
Ca	mg/L	436	936
Mg	mg/L	532	484
As, Co, Cu, Ni, Pb, Zn	mg/L	<0.5	Non-detect

MacLeod HDS Plant

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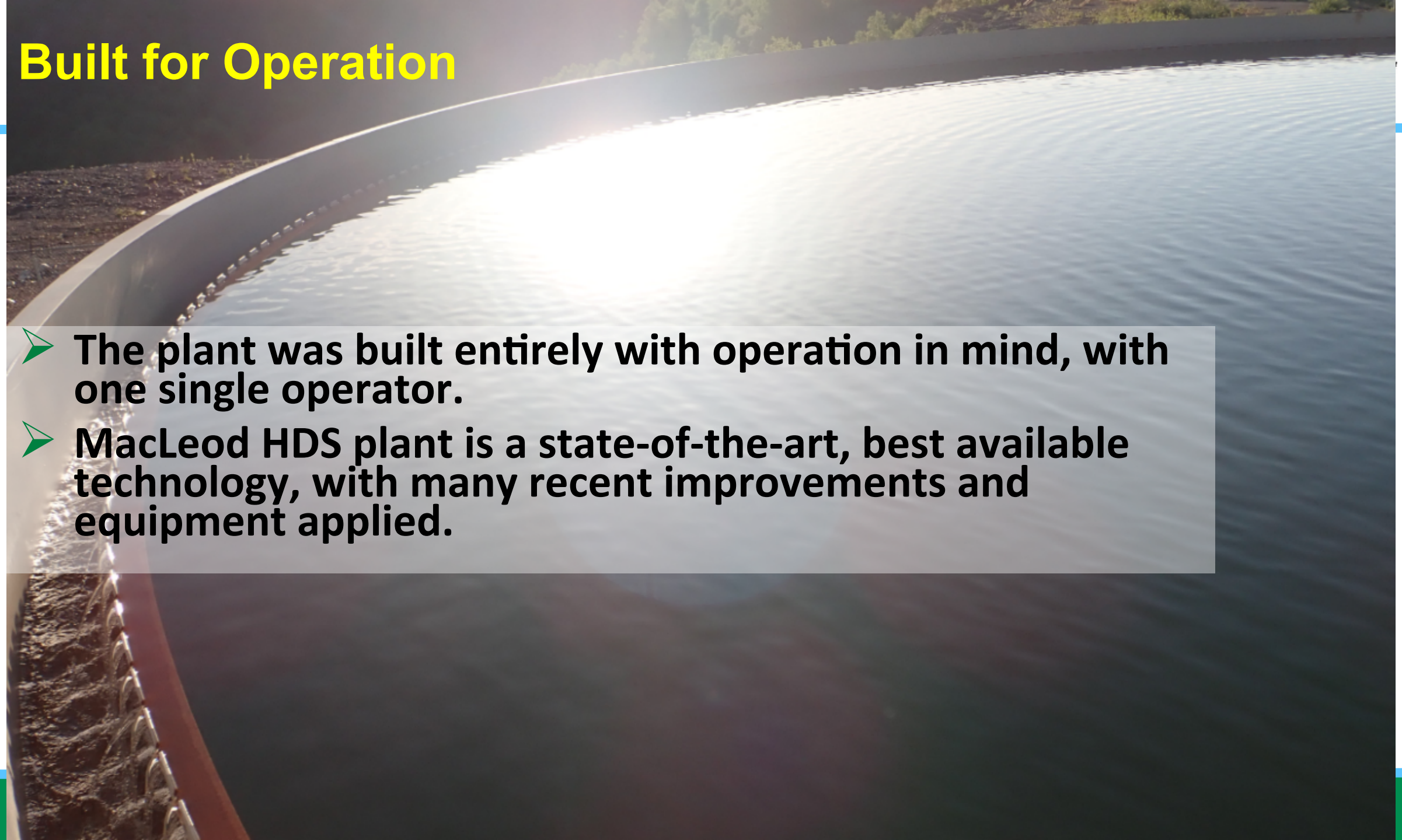
Built for Operation



- The plant was built entirely with operation in mind, with one single operator.
- MacLeod HDS plant is a state-of-the-art, best available technology, with many recent improvements and equipment applied.


THANK
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