Dominion Diamond Corporation

Jay Project – Pit Lake Hydrodynamic Models

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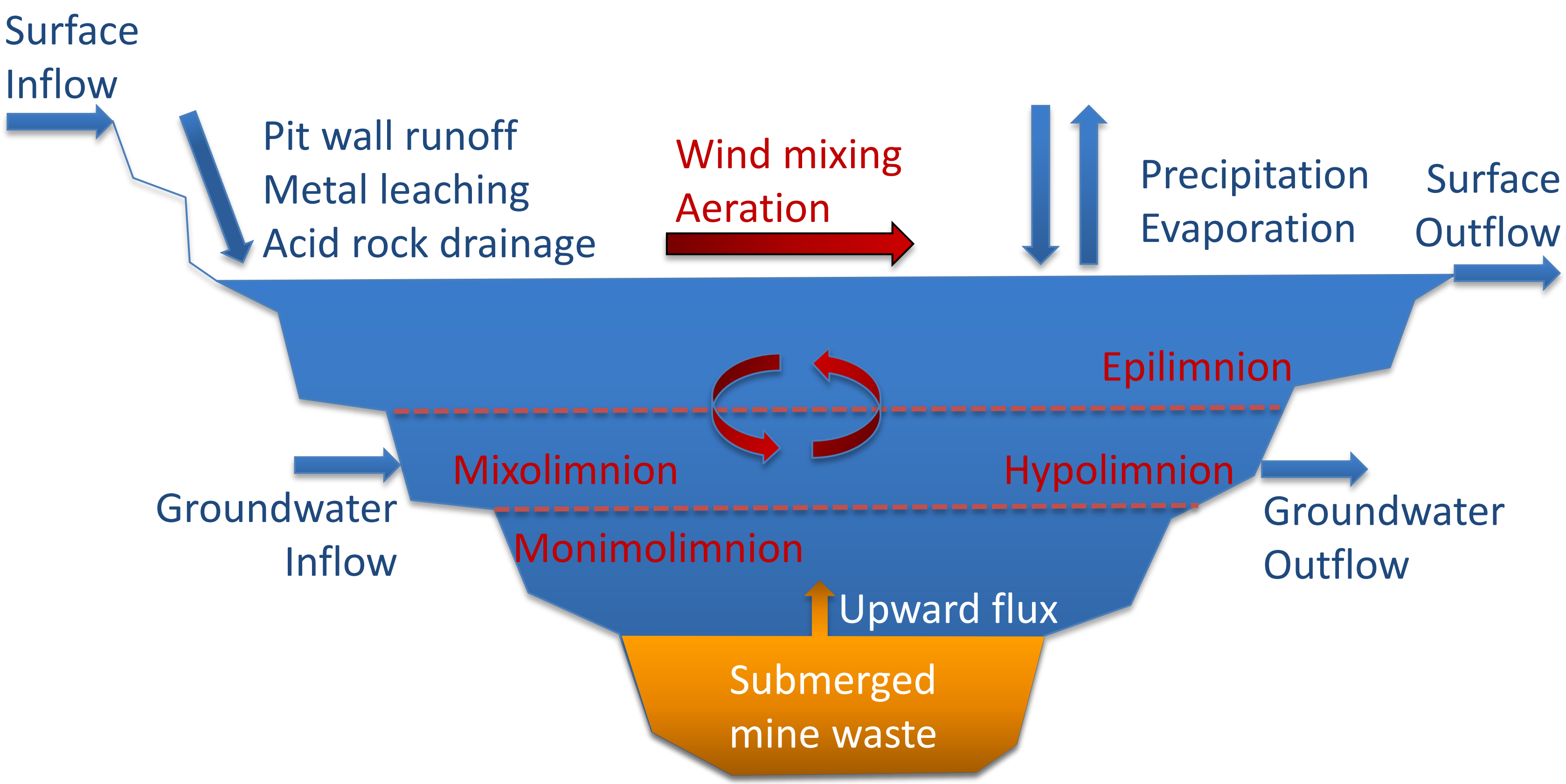
Outline

- Lines of Evidence for Meromixis
  - Conceptual Model
  - Analogous Lakes
  - Analytical Equations
  - Numerical Model
- Pit Lake Hydrodynamic Models
  - Overview of CE-QUAL-W2
  - Setup
  - Inputs
  - Demonstration

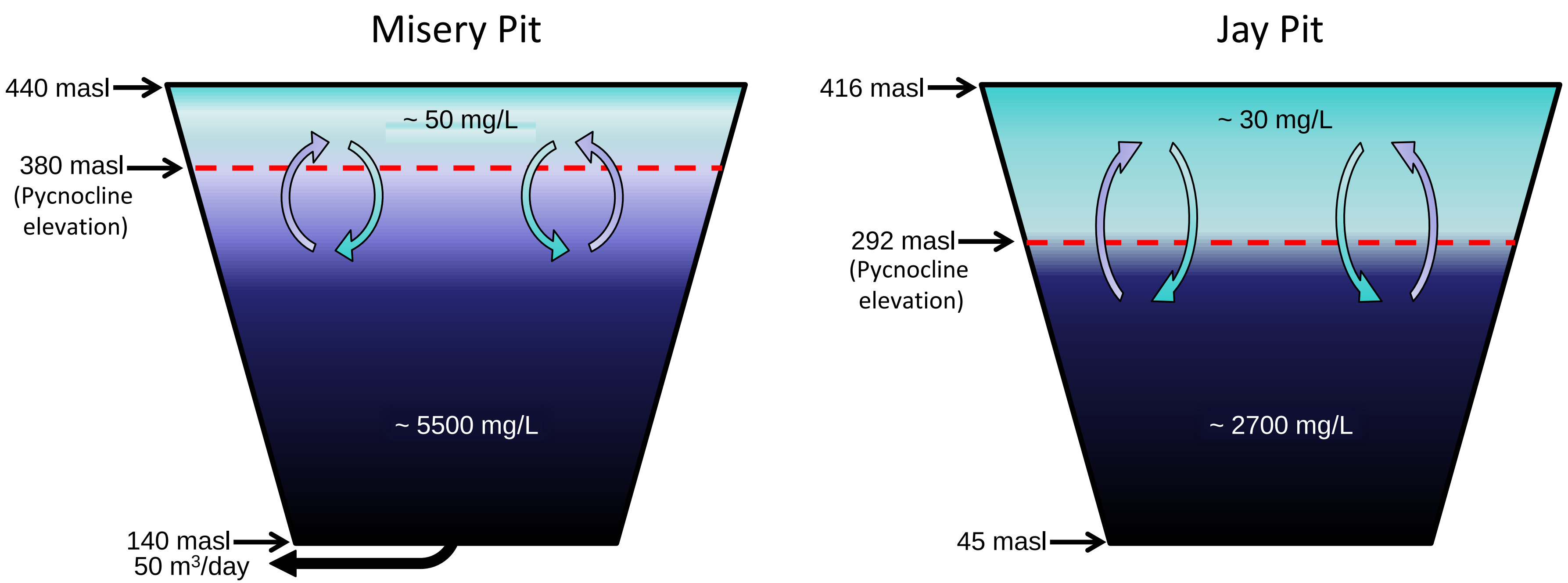
LINES OF EVIDENCE FOR MEROMIXIS

Conceptual Model (Generic Pit Lake)



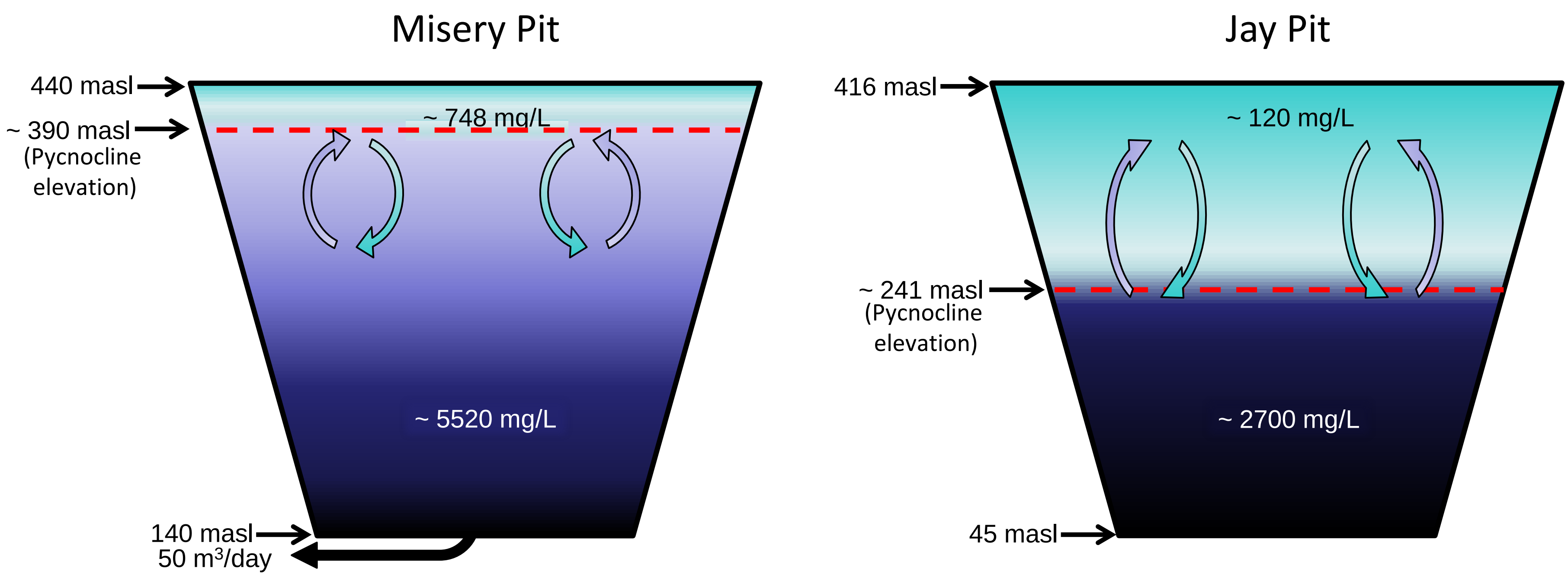
Reference: Vandenberg, McCullough & Castendyk 2015 ICARD

Pit Lake Conceptual Model - Post-Closure Updated Assessment Case



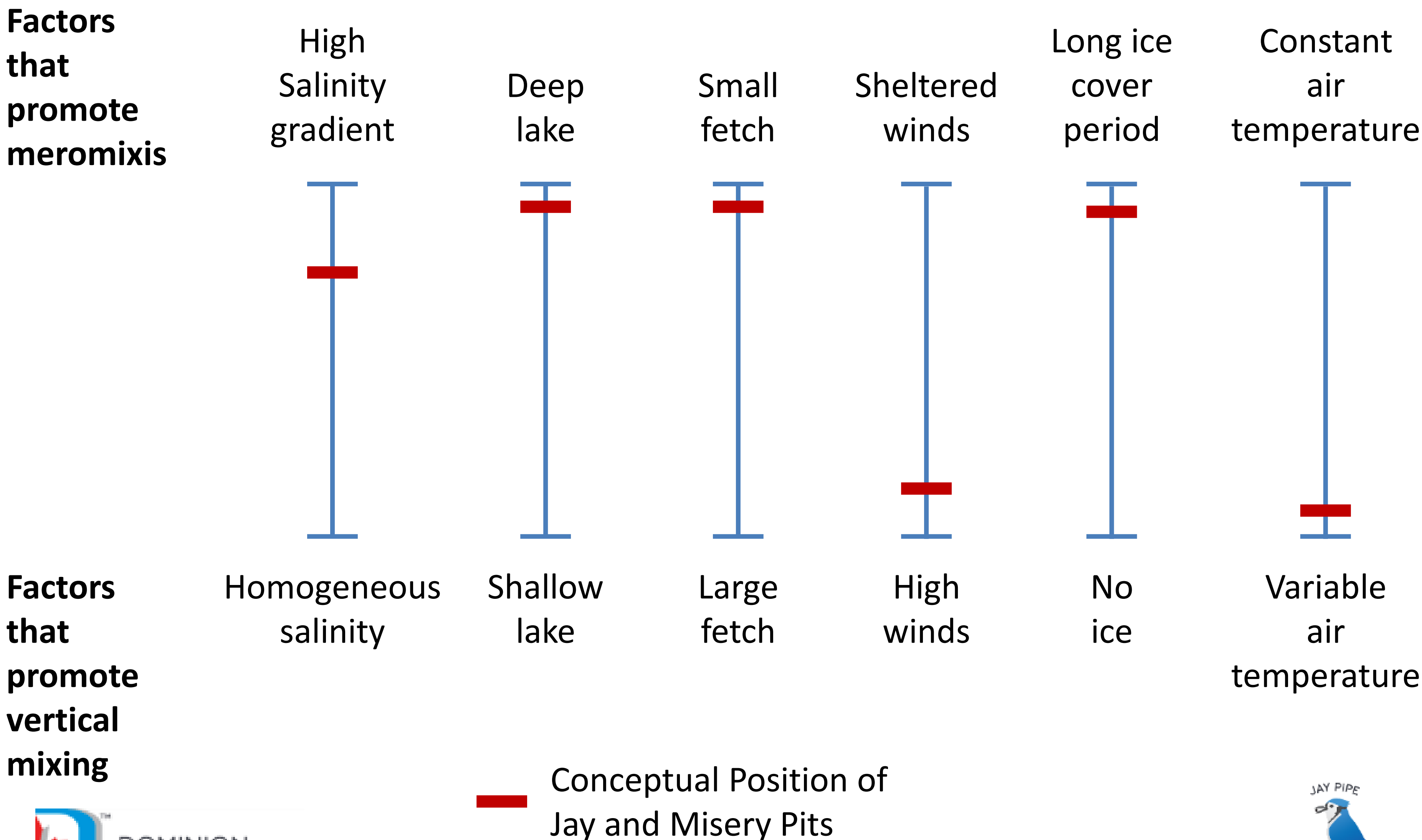
Not to Scale

Pit Lake Conceptual Model - Post-Closure
Updated Assessment Case



Not to Scale

Conceptual Model



Conceptual Model

Both
Jay Project
Pit Lakes

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Analogous Lakes

- DAR-GNWT-IR-62 compared Jay Pit Lakes to other pit lakes
  - Based on work of Boehrer & Schultze; Castendyk; Pieters & Lawrence
  - Focused on subarctic lakes
  - All pit lakes became meromictic
    - Except those presently being influenced by operations
    - Even lakes that did not have an initial density gradient
  - Most notably, Gunnar Pit Lake
    - On north shore of Lake Athabasca
    - Flooded entirely with lake water
    - Similar depth/area ratio as Jay pit lakes
    - Established meromixis over time

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Analytical Equations

- Analytical equations
  - Presented in DAR-GNWT-IR2-08
  - Provide an *indication of mixing potential or tendency*
  - All of these equations are suggestive of meromixis
  - Caution: none of these equations account for all variables

$$Salt\ deficit\ ratio = \frac{\int_0^h \big(S(h) - S(z)\big)A(z)dz}{h_i^* S(0)A(0)}$$

$$z_{\text{relative}} = \frac{50 \times z_{\max} \times \sqrt{\pi}}{\sqrt{A_{\text{surface}}}}$$

$$Salinity\ stability = \frac{g\beta}{A_0}\int_0^H \left(S(z) - \bar{S}\right) zA(z)dz$$

$$Meromictic\ ratio = \frac{St_S^*}{\Delta St_S}$$

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Numerical Models

- Explicitly account for
  - Fetch
  - Pit geometry
  - Water density (salinity, temperature, TSS) at each depth
  - Time-varying air temperature, wind speed and direction
  - Time-varying inflows at depth
  - Salt rejection (most models require modifications)
- Calculate state variables and momentum at small time steps (~5 minutes)

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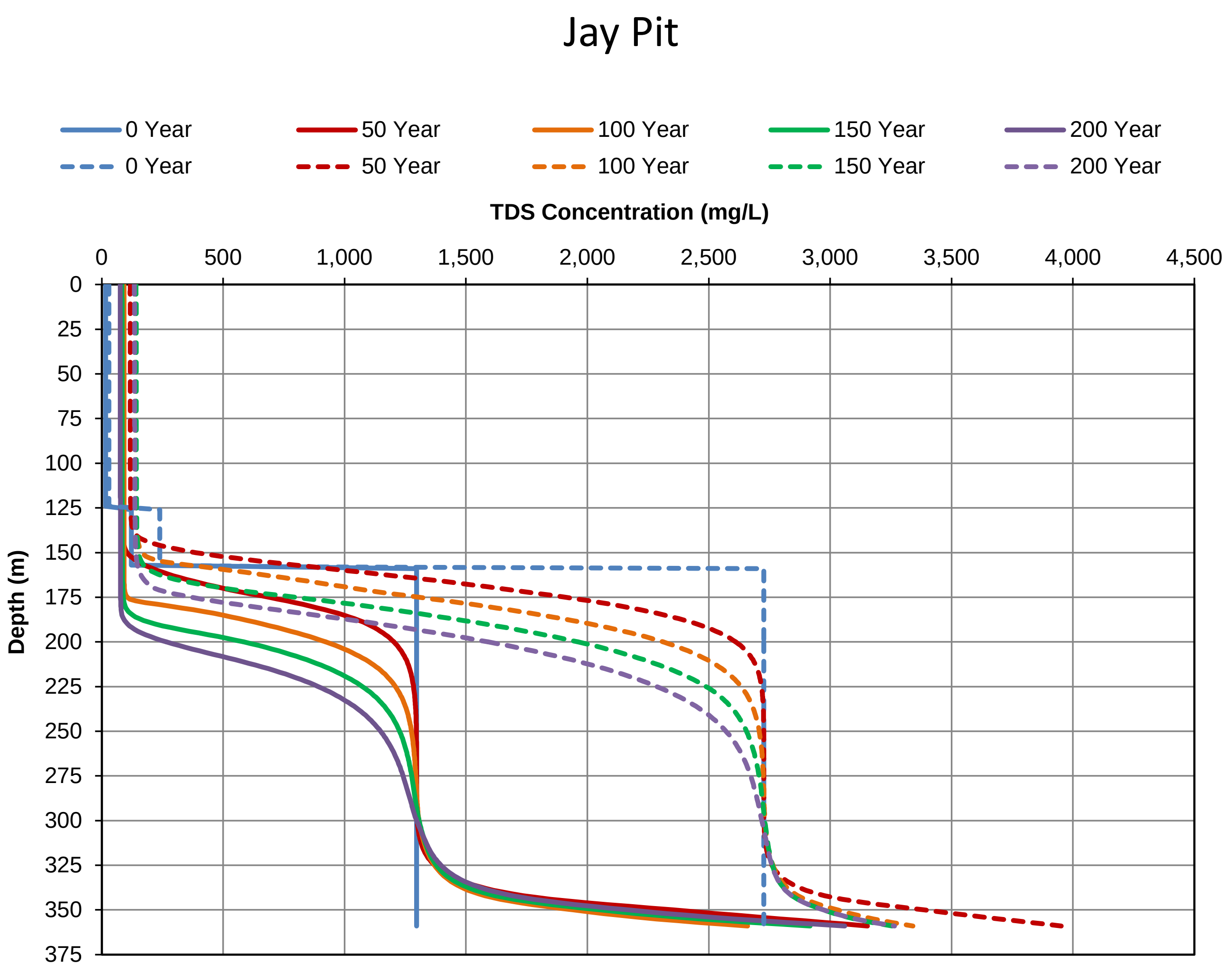
Hydrodynamic Modeling Results – Reasonable Estimate Case



Summary of Lines of Evidence

- All lines of evidence suggest Jay Pits will be meromictic
  - Conceptual Model
  - Analogous Lakes
  - Analytical Equations
  - Numerical Model
- Different scenarios indicate variable strength of meromixis
  - Higher salinity/density at depth ⇨ stronger meromixis
  - Lower salinity at depth ⇨ weaker meromixis
    - Also ⇨ less mass of constituents available to release to surface waters (i.e., lower consequence if meromixis does not establish)

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PIT LAKE HYDRODYNAMIC MODELS

Overview of CE-QUAL-W2

- Two-dimensional (longitudinal/vertical; laterally-averaged) hydrodynamic and water quality model
- Developers:
  - Originally Buchak and Edinger in 1975 for US Army Corps of Engineers
  - Presently Wells, Cole and Berger at Portland State University
- Applications:
  - Reservoirs
  - Rivers
  - Lakes
  - Pit lakes
  - Estuaries

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Overview of CE-QUAL-W2

- Mechanistic model based on first principles

x-Momentum Equation

$$\underbrace{\frac{\partial \bar{u}}{\partial t}}_{\substack{\text{unsteady}\\ \text{acceleration}}} + \underbrace{\bar{u}\frac{\partial \bar{u}}{\partial x} + \bar{v}\frac{\partial \bar{u}}{\partial y} + \bar{w}\frac{\partial \bar{u}}{\partial z}}_{\text{convective acceleration}} = \underbrace{g \sin \alpha}_{\text{gravity}} - \underbrace{\frac{1}{\rho}\frac{\partial \bar{p}}{\partial x}}_{\substack{\text{pressure}\\ \text{gradient}}} + \underbrace{\frac{1}{\rho}\left(\frac{\partial \tau_{xx}}{\partial x} + \frac{\partial \tau_{xy}}{\partial y} + \frac{\partial \tau_{xz}}{\partial z}\right)}_{\text{turbulent shear stresses}}$$

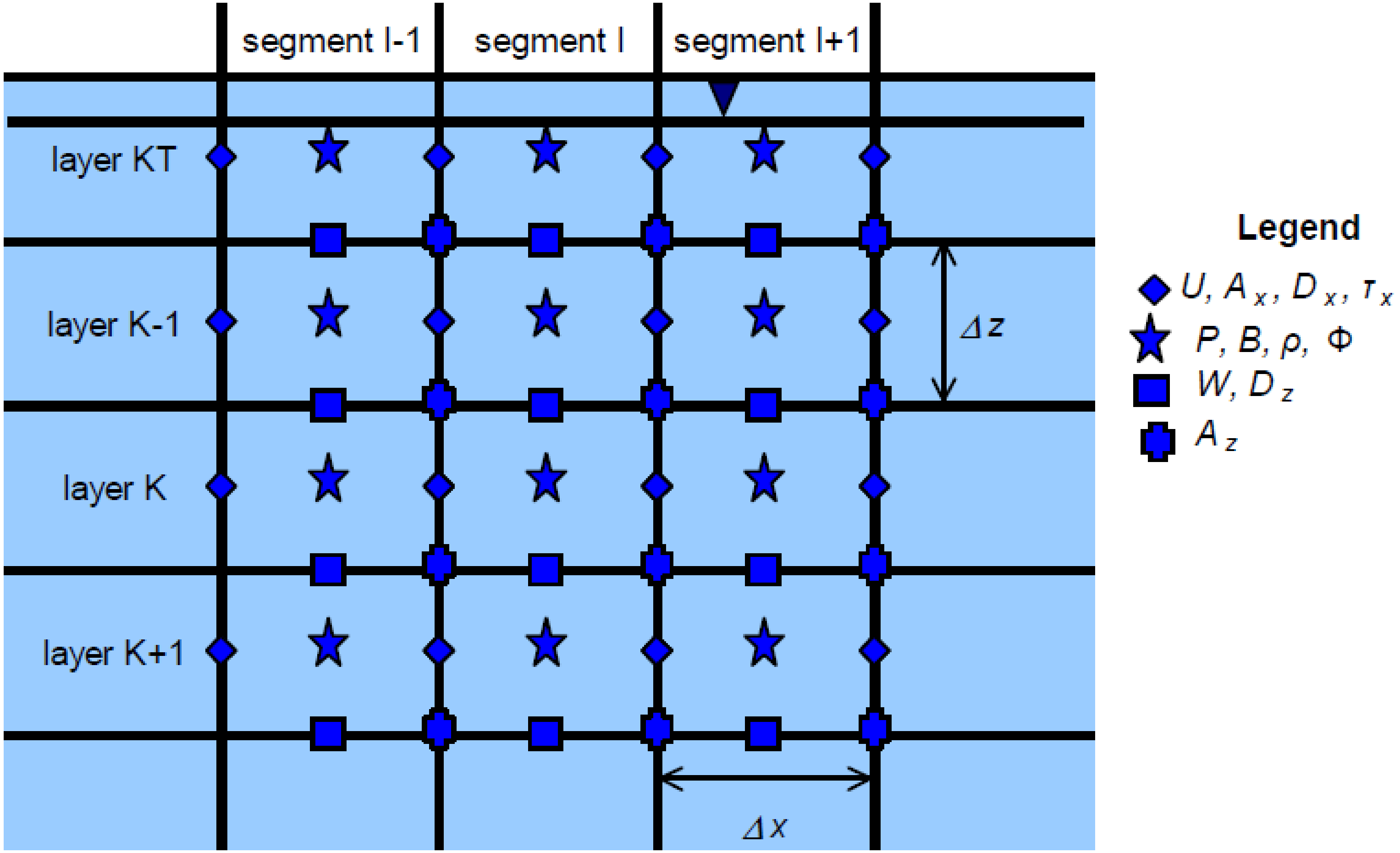
y-Momentum Equation

$$\underbrace{\frac{\partial \bar{v}}{\partial t}}_{\substack{\text{unsteady}\\ \text{acceleration}}} + \underbrace{\bar{u}\frac{\partial \bar{v}}{\partial x} + \bar{v}\frac{\partial \bar{v}}{\partial y} + \bar{w}\frac{\partial \bar{v}}{\partial z}}_{\text{convective acceleration}} = -\underbrace{\frac{1}{\rho}\frac{\partial \bar{p}}{\partial y}}_{\substack{\text{pressure}\\ \text{gradient}}} + \underbrace{\frac{1}{\rho}\left(\frac{\partial \tau_{yx}}{\partial x} + \frac{\partial \tau_{yy}}{\partial y} + \frac{\partial \tau_{yz}}{\partial z}\right)}_{\text{turbulent shear stresses}}$$

z-Momentum Equation

$$\underbrace{\frac{\partial \bar{w}}{\partial t}}_{\substack{\text{unsteady}\\ \text{acceleration}}} + \underbrace{\bar{u}\frac{\partial \bar{w}}{\partial x} + \bar{v}\frac{\partial \bar{w}}{\partial y} + \bar{w}\frac{\partial \bar{w}}{\partial z}}_{\text{convective acceleration}} = \underbrace{g \cos \alpha}_{\text{gravity}} - \underbrace{\frac{1}{\rho}\frac{\partial \bar{p}}{\partial z}}_{\substack{\text{pressure}\\ \text{gradient}}} + \underbrace{\frac{1}{\rho}\left(\frac{\partial \tau_{zx}}{\partial x} + \frac{\partial \tau_{zy}}{\partial y} + \frac{\partial \tau_{zz}}{\partial z}\right)}_{\text{turbulent shear stresses}}$$

Overview of CE-QUAL-W2



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Inputs to CE-QUAL-W2

- Initial conditions
- Inflow volumes
- Inflow chemistry
- Inflow temperature
- Wind sheltering
- Dynamic shading
- Meteorology
- Bathymetry
- Rates and coefficients

Questions?