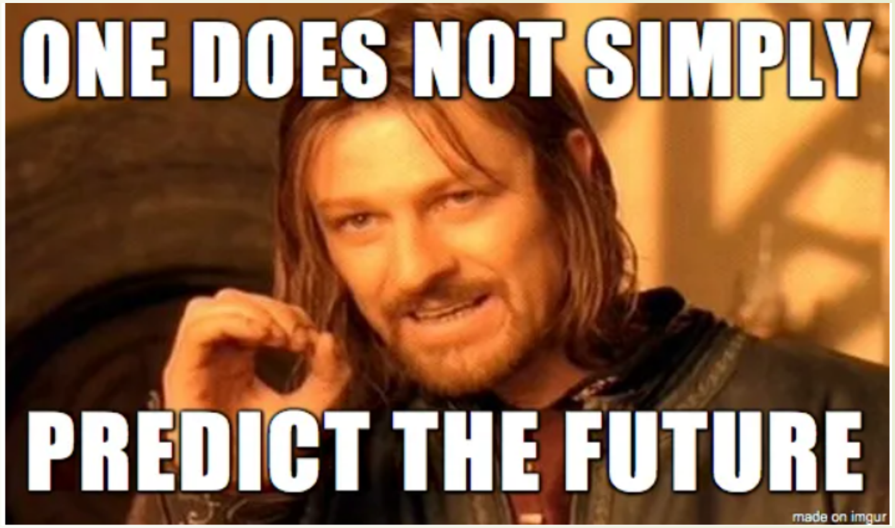
Approaches Needed to Address the Challenges Associated with Water Balance and Water Quality Modelling

Katie Jones

Water Balance Water Quality Model

- Water Balance / Water Quality Model (WBWQM)
  - Understand drainage quantity and quality
  - Predict future drainage quantity and quality

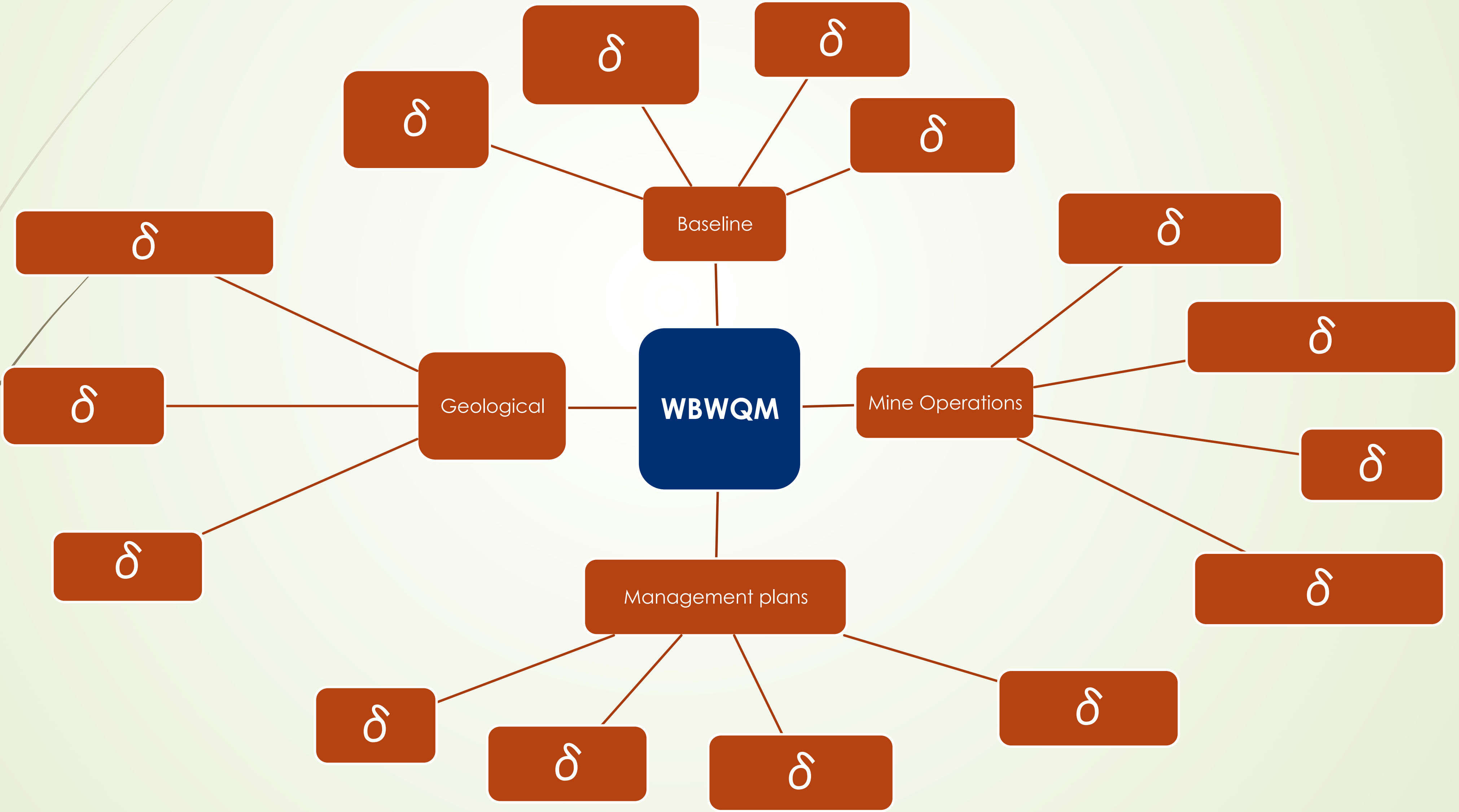
- Modelling
  - Based on the simplification of processes using mathematical expressions
  - Inputs / source terms
  - Conceptual model
  - First develop your water balance and use that understanding to develop you mass balance
  - Sources of uncertainty and error
    - Uncertainty in data sources
    - Complexity of the model
    - Uncertainty in assumptions
    - Uncertainty in benchmarking
    - What can we do about it?



https://christianjhoward.me/blog/index.php/2016/08/15/predicting-the-future-an-intro-to-models-described-by-time-dependent-differential-equations/

WBWQM Inputs

All Inputs Have Error and/or Uncertainty (δ)

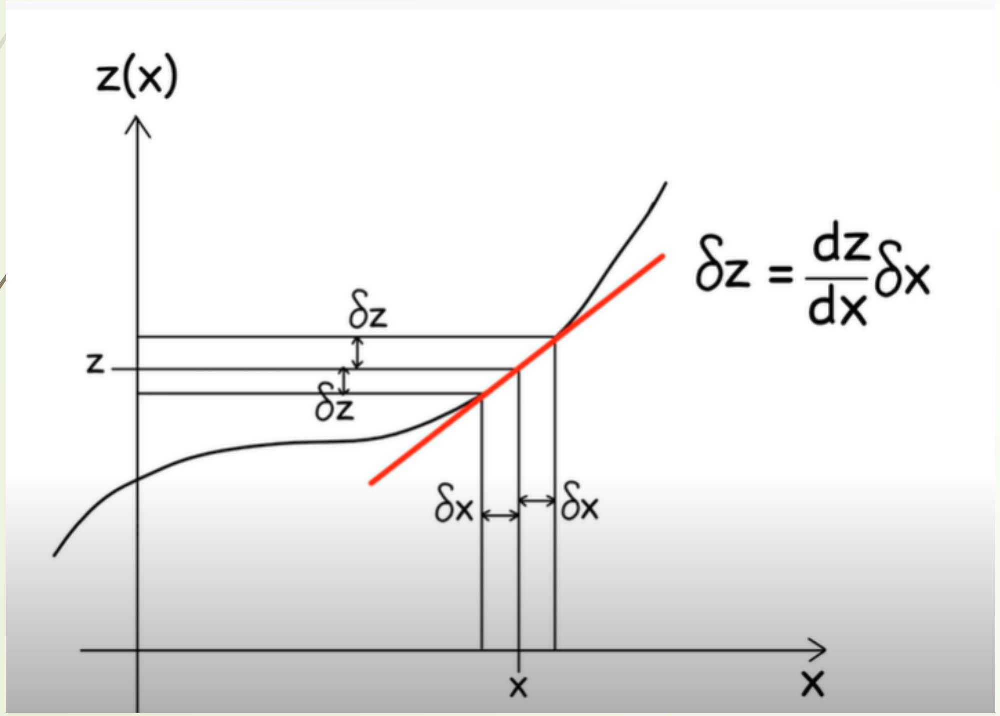


Error or Uncertainty in the Measurements

- Error in inputs - Everything is based on this data
  - Water Quality
    - Variability over a certain period of time or location
    - Website "The Canadian Association for Laboratory Accreditation Inc. (CALA) [formerly CAEAL] was formed in 1989 on the initiative of a number of public and private sector laboratories and is incorporated as a not for profit association"
      - Depends on parameter
      - CALA: Most labs can make 15% (I am sure much better) but to be accredited labs require 30%.
  - Flow
    - My first mine site – hydrologists provided a mean annual precipitation (MAP) estimate of ~1240 mm (PE = 21%) and through the course of the EA it was changed to ~865 mm (PE = 16%), value used ~1025 mm
    - Site last year – The hydrologist estimated MAP at 1242 mm (PE 20%) and a different hydrologist estimated MAP at 1032 mm
    - Site last week - Climate BC Estimate of MAP was 564 mm, regression estimate of MAP was 738 mm (percent difference is 27%)

Uncertainty / Error

- *Concentration = 1000 mg/L +/- 15%*
- *Flow = 0.25 L/s +/- 20%*



https://www.youtube.com/watch?v=V0ZRvvHfF0E

- $L_{load} = C_{concentration} \, x F_{flow}$
- $L_{load} = 250 mg/s$
- $\delta L = \sqrt{\left(\frac{\partial L}{\partial C} \delta C\right)^2 + \left(\frac{\partial L}{\partial F} \delta F\right)^2}$

- $\delta L/L = \sqrt{(\delta C/C)^2 + (\delta F/F)^2}$
- $\delta L/L = \sqrt{(0.15)^2 + (0.2)^2}$
- $\delta L/L = 0.25 = 25\%$

- $L_{load} = 250 mg/s \ (188 mg/s \ \ to \ 312 \ mg/s)$

What is a water quality modeller to do?

- First principles
  - Understand your task – it's big!
- Logic
  - Where first principles fall short – rely on logic
  - "Logic is the hygiene the mathematician practices to keep his ideas healthy and strong" – Hermann Weyl
- Transparency
  - "Honesty and transparency make you vulnerable. Be honest and transparent anyway" – Mother Theresa
- Update based on evidence
  - He who asks a question is fool for five minutes; he who does not ask a question remains a fool forever – Chinese Proverb

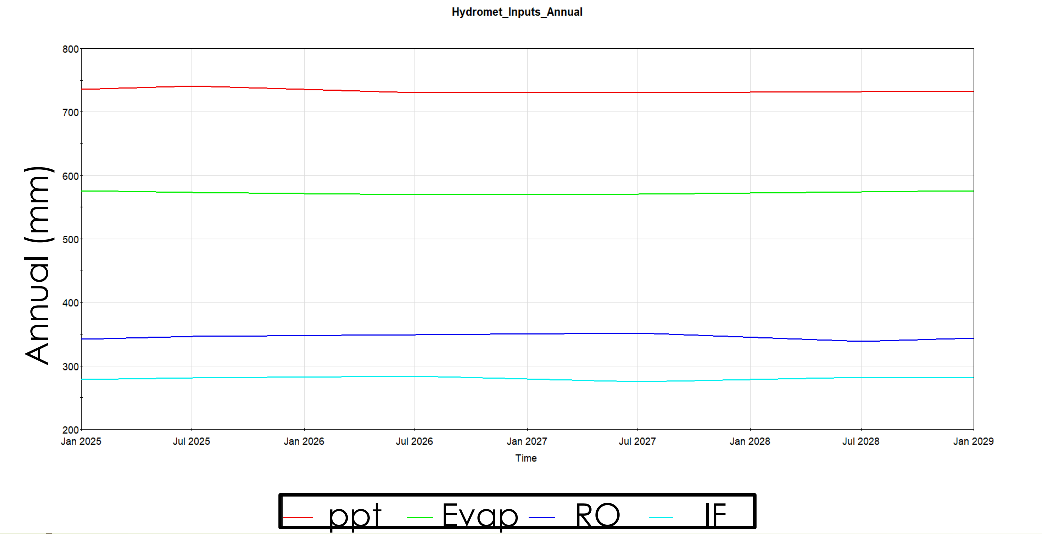
Understanding Water Quality Models

- Complex WBWQM can have 100s of inputs and user defined equations to model what is happening at a mine site

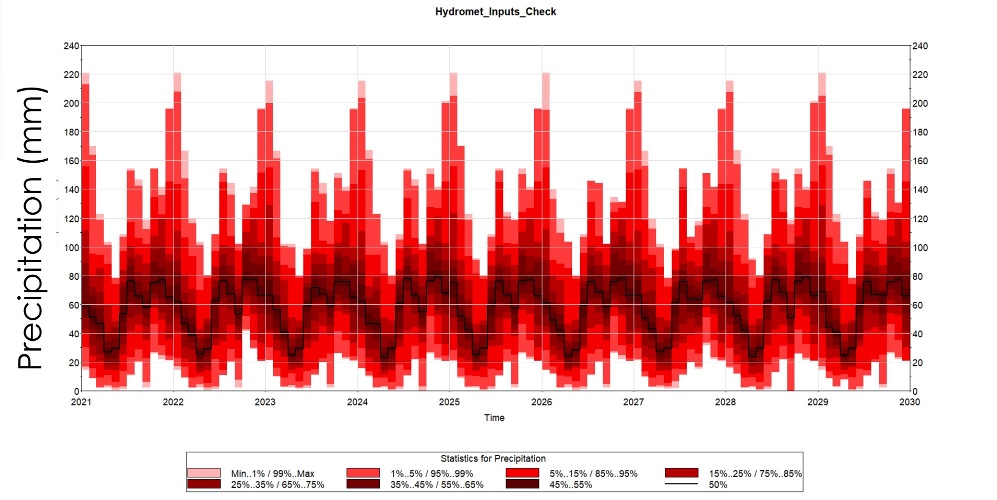
- Really Simple Little Flow Model (i.e. a water balance)
  - Used GoldSim™
    - Very common software program used for WBWQMs in Canada
    - Monthly reporting period /time step – interval over which model computes the calculations
  - One surface tailings pond – closed site – no pumping – catchment and TSF runoff
    - Objective: predict flow through the spillway
    - Reservoirs (1)
    - Input Data: 9 (all with uncertainty – error)
    - Functions (equations): 20 + 11 (verification formulas)
    - Result Outputs: (10)

Present the Data - Transparency

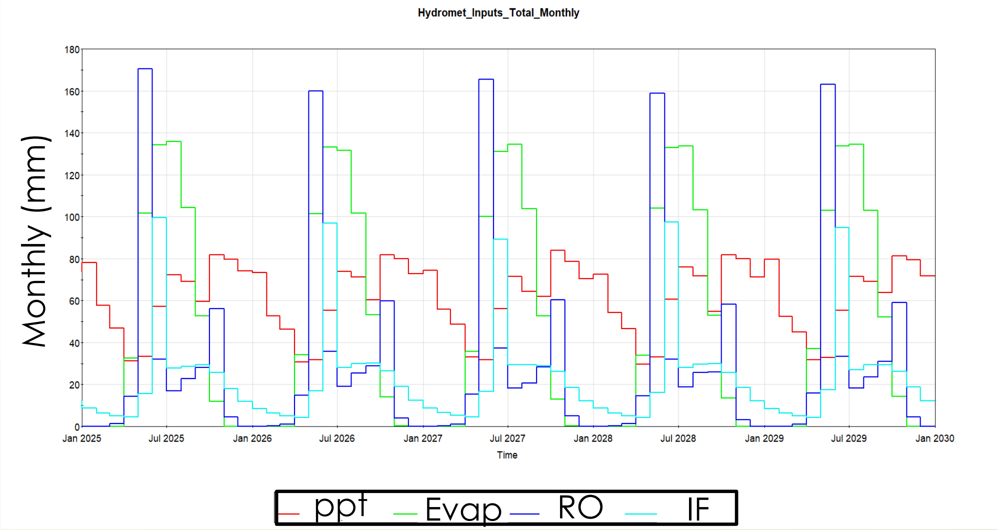
Hydrological Inputs



Variability in Inputs



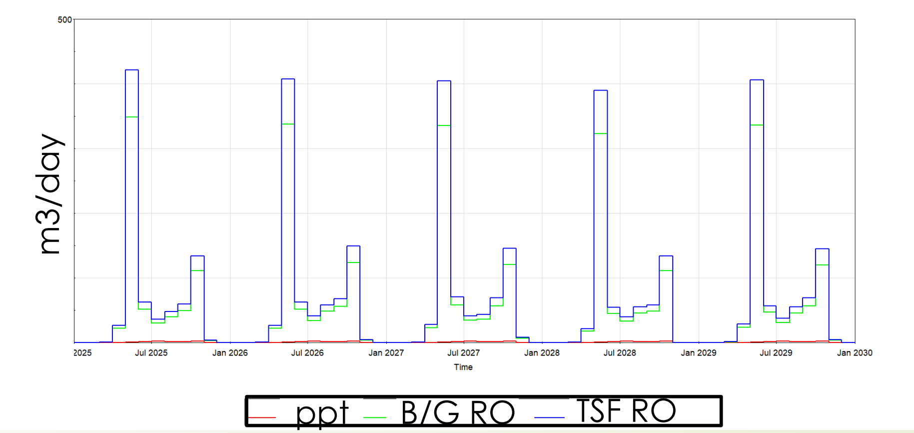
Annual Monthly Distribution of Inputs



How logical is our really simple little model?

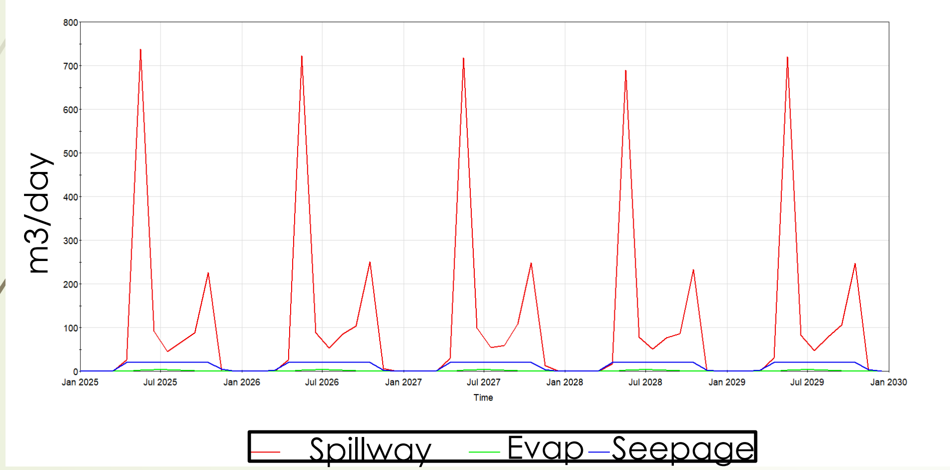
Cumulative Flows			
Inflow	**Total Inflows (m3)**	**Outflows**	**Total Outflows (m3)**
Runoff	258548	Final Volume	0
Catchment Runoff	214028	Spillway	430498
Precipitation	2592	Seepage	41118
		Evaporation	3554
Total Inflows	**475169**	**Total Outflows**	**475169**

Inflows

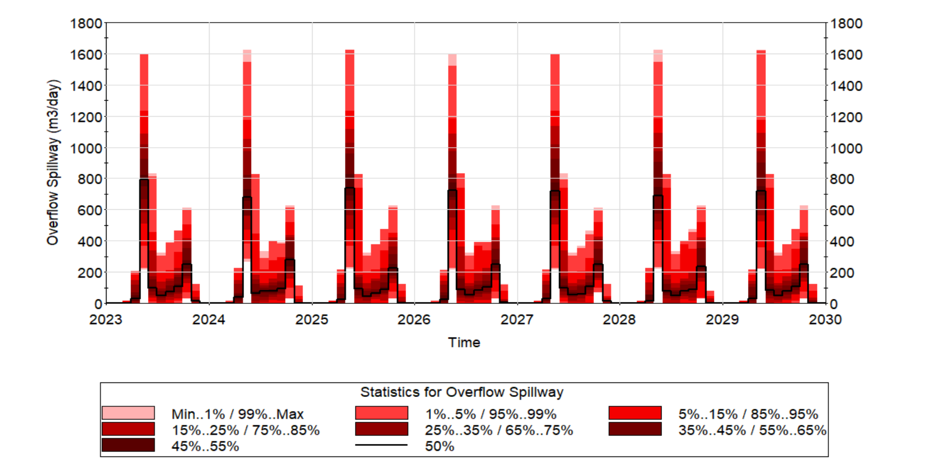


Results for our really simple model

Outflows

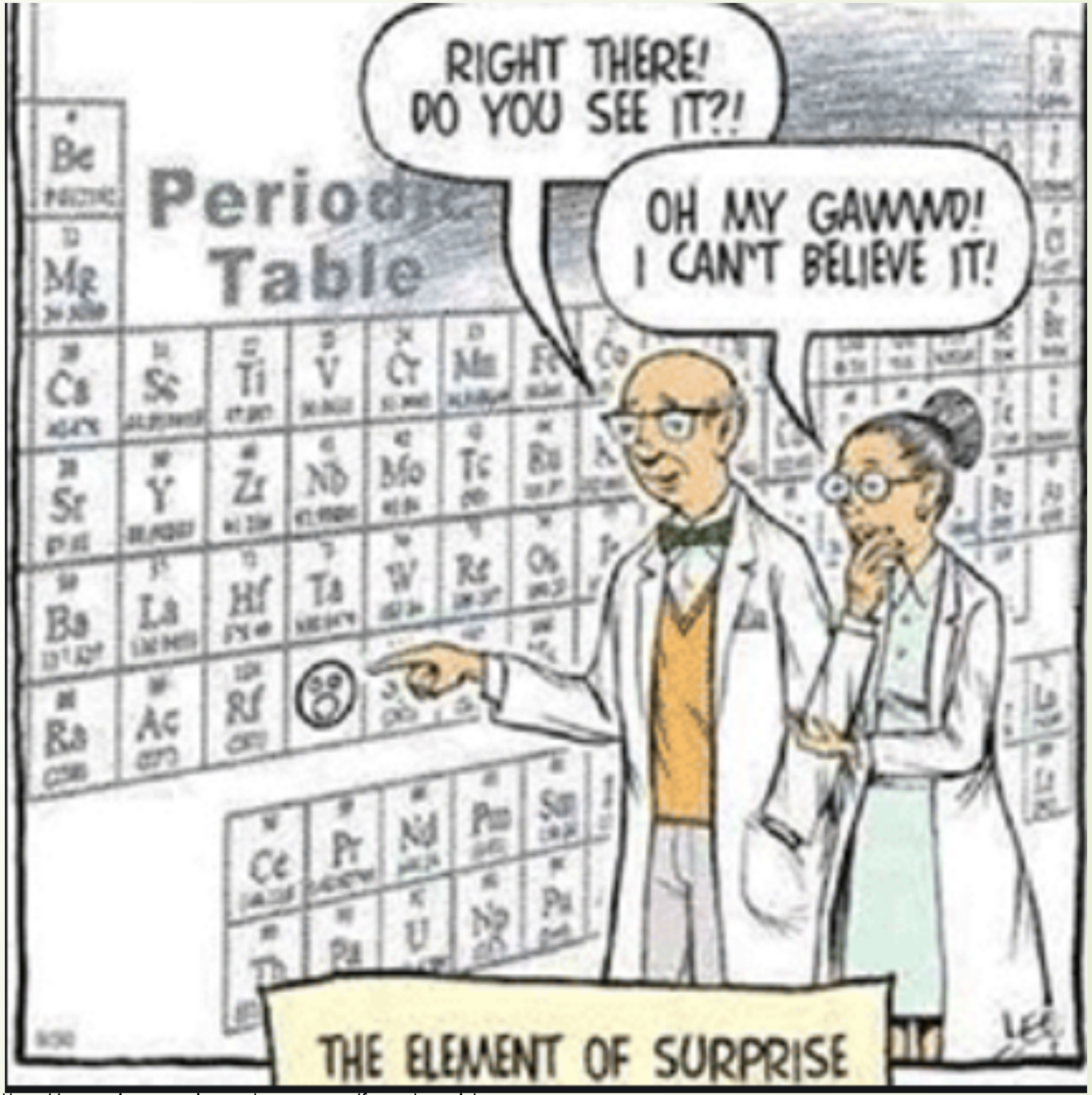


Result



Now let's talk chemistry

https://www.pinterest.ca/sciencex3/chemistry-fun/



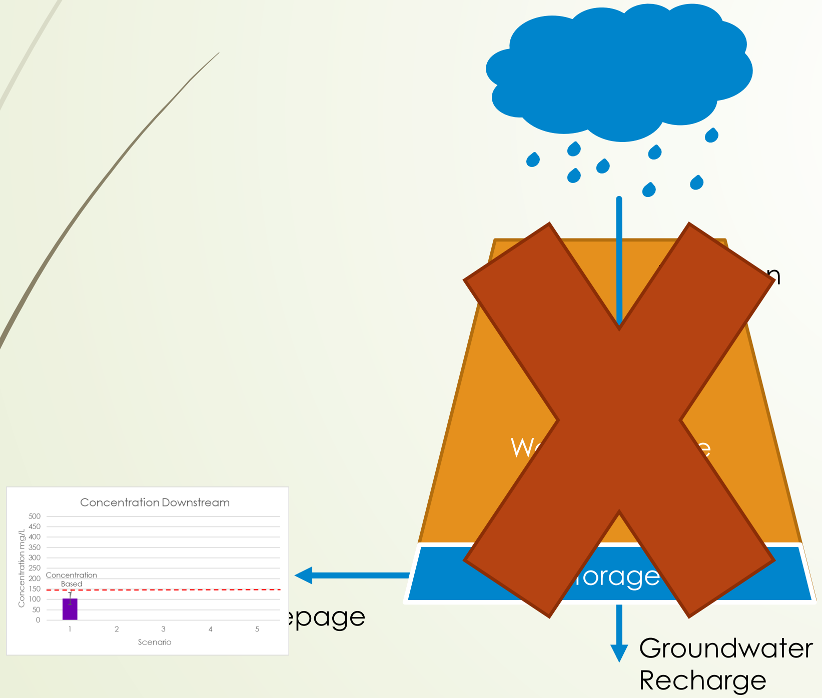
https://www.inorganicventures.com/fun-chemists

Load Calculation for Fictitious Problem

(Load(mg/time) = Concentration(mass/volume) X Flow(volume/time)

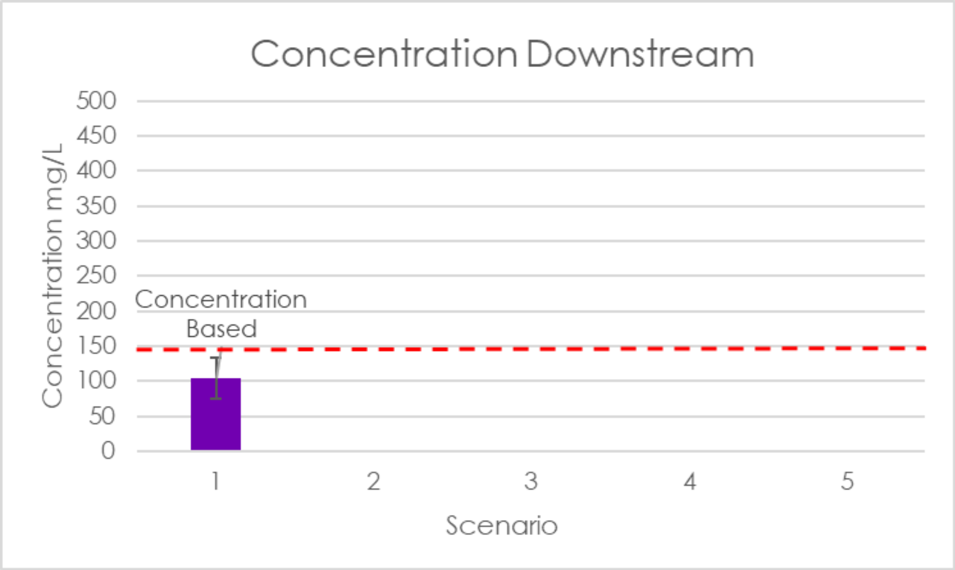
(~~Load (mg/kg/unit time)~~ (Don't need this for concentration based source term)

Fictitious Guideline of 150 mg/L



Assumptions:

- Seepage = 40% of MAP
- Observed concentration of seepage 875 mg/L
- Downstream 104 mg/L

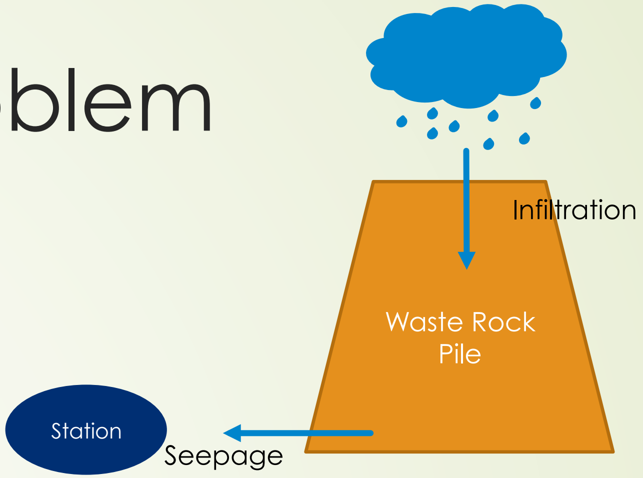


Load Calculation for Fictitious Problem

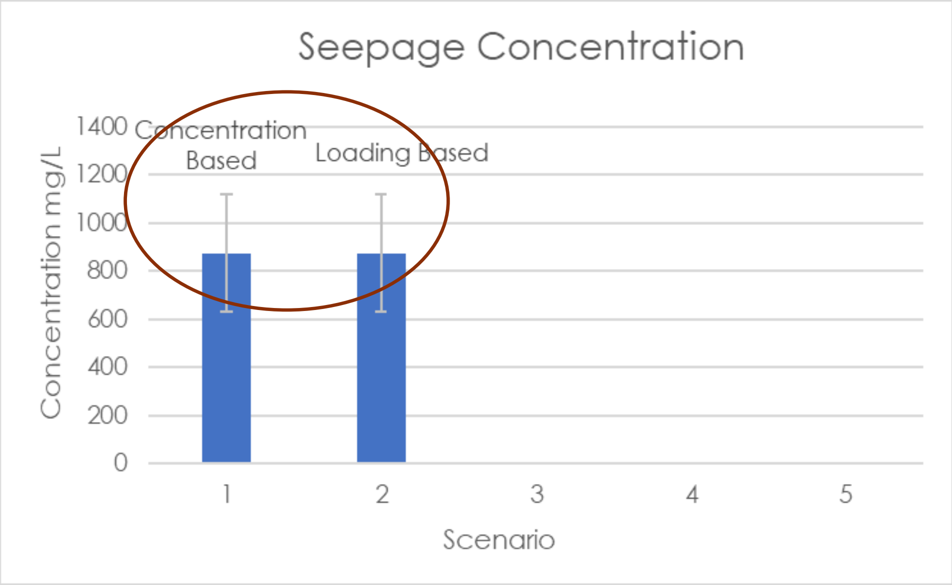
~~(Load(mg/time) = Concentration(mass/volume) X Flow(volume/time)~~

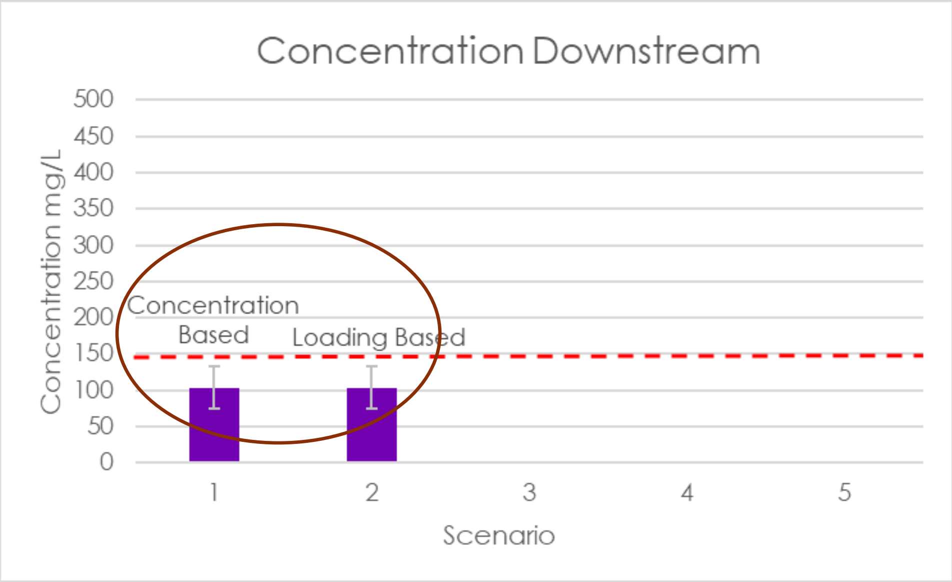
Load (mg/kg/time) – Loading based = 32 mg/kg/unit time

Fictitious Guideline = 150 mg/l



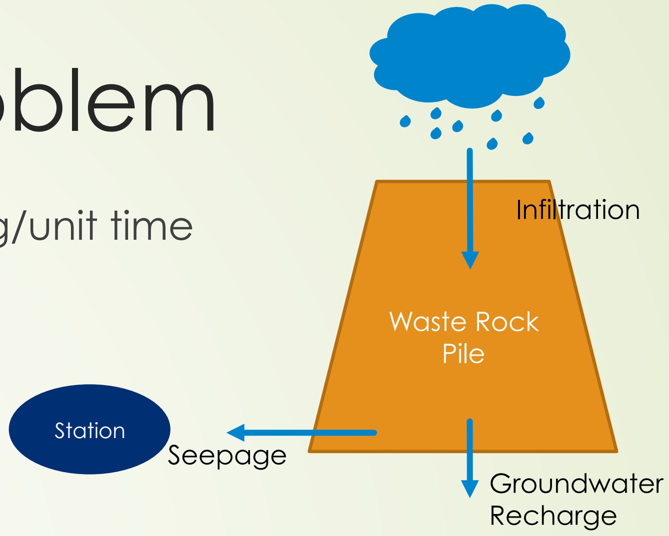
- Change in source term approach:
  - 875 mg/L is used to help scale and calculate field loading rate assuming 40% MAP seepage



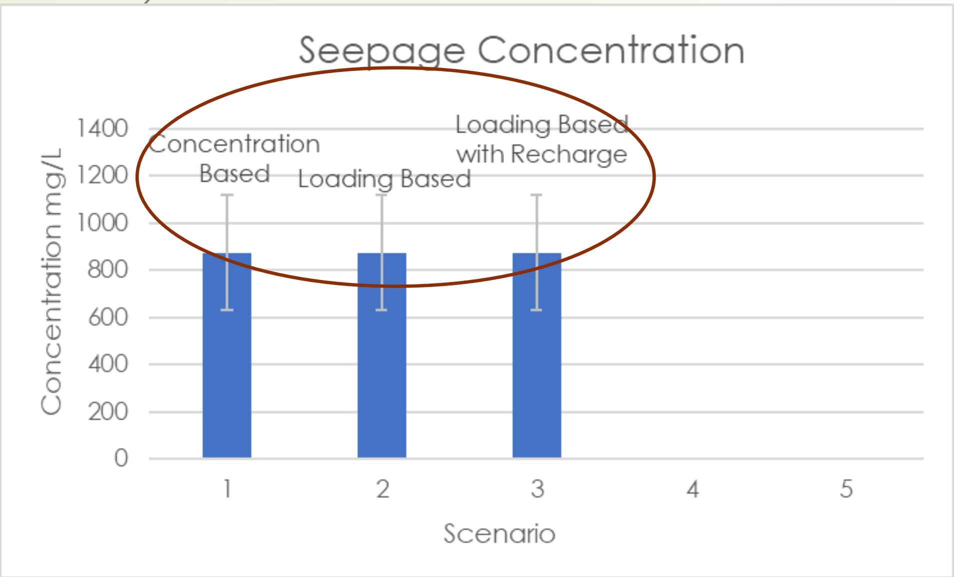


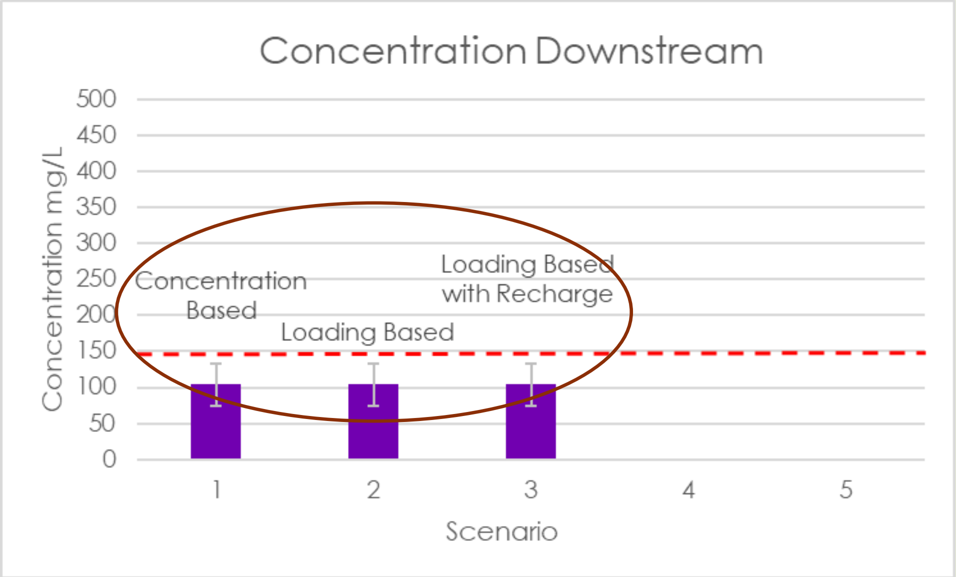
Load Calculation for Fictitious Problem

~~(Load(mg/time) = Concentration(mass/volume) X Flow(volume/time)~~
Load (mg/kg/time) – Loading based = ~~32 mg/kg/unit time~~ = 56 mg/kg/unit time
Fictitious Guideline = 150 mg/l



- Assumptions changed:
  - 875 mg/L is used to help scale and calculate field loading rate assuming seepage is 40% of MAP and recharge is 24% of MAP.



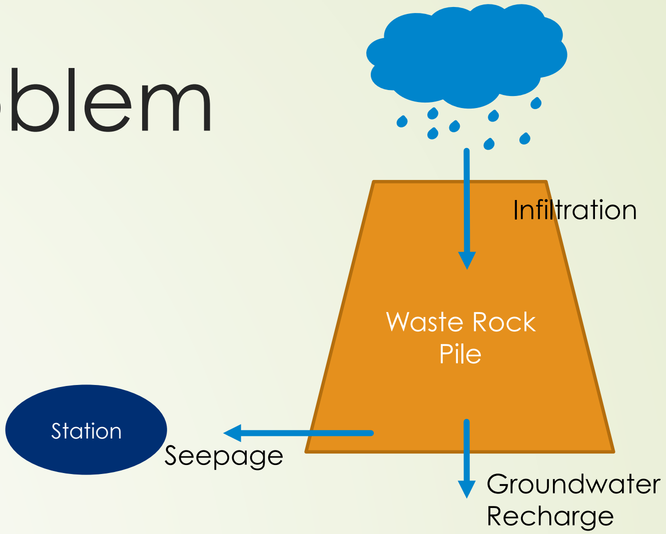


Load Calculation for Fictitious Problem

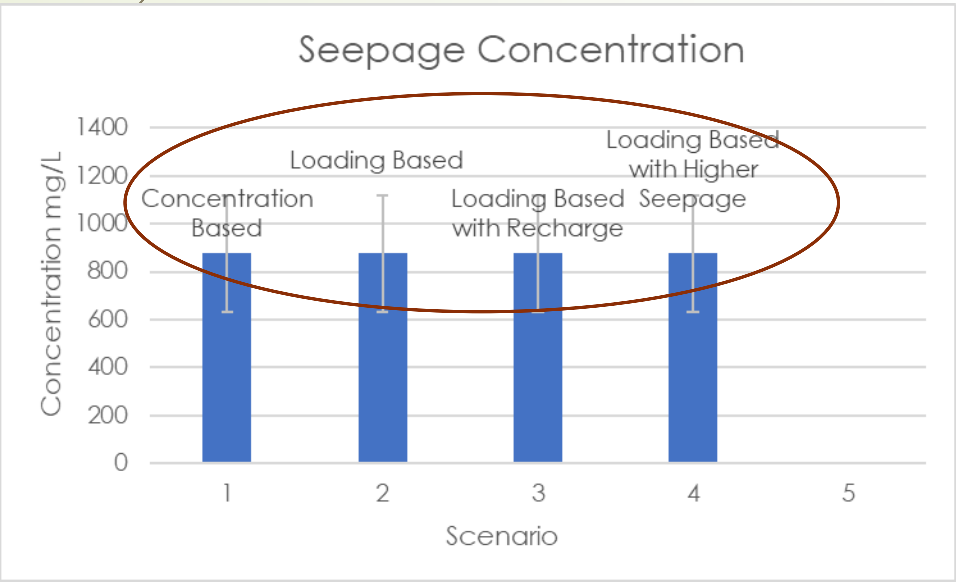
~~(Load(mg/time) = Concentration(mass/volume) X Flow(volume/time)~~

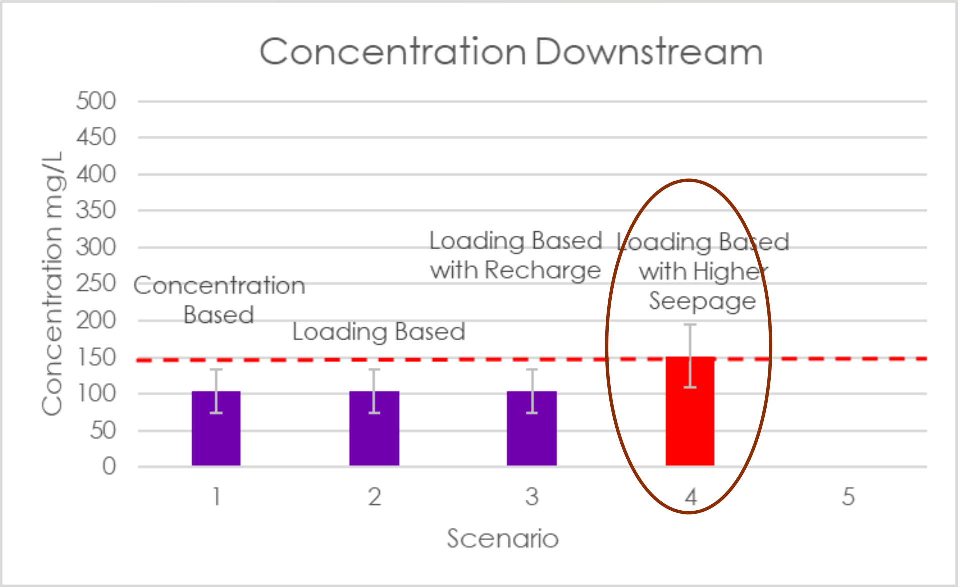
Load (mg/kg/time) – Loading based = 56 mg/kg/wk

Fictitious Guideline = 150 mg/l



- Assumptions changed:
  - Applied same loading rate as previous estimate but assumed 62% of MAP seeps out the toe and 2% groundwater recharge





Load Calculation for Fictitious Problem

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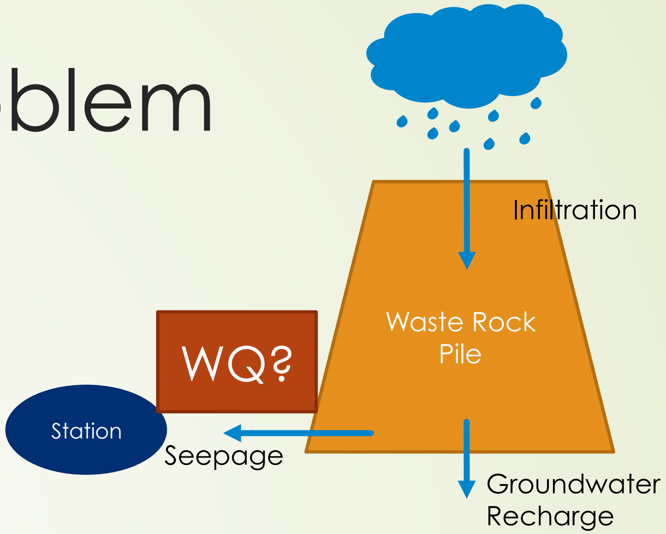
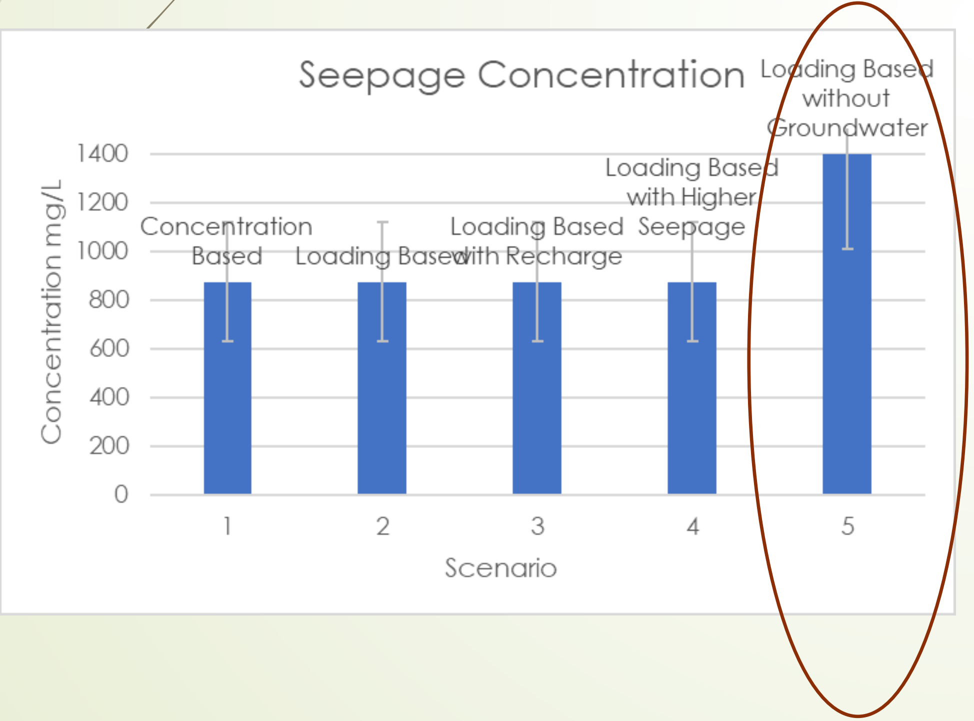
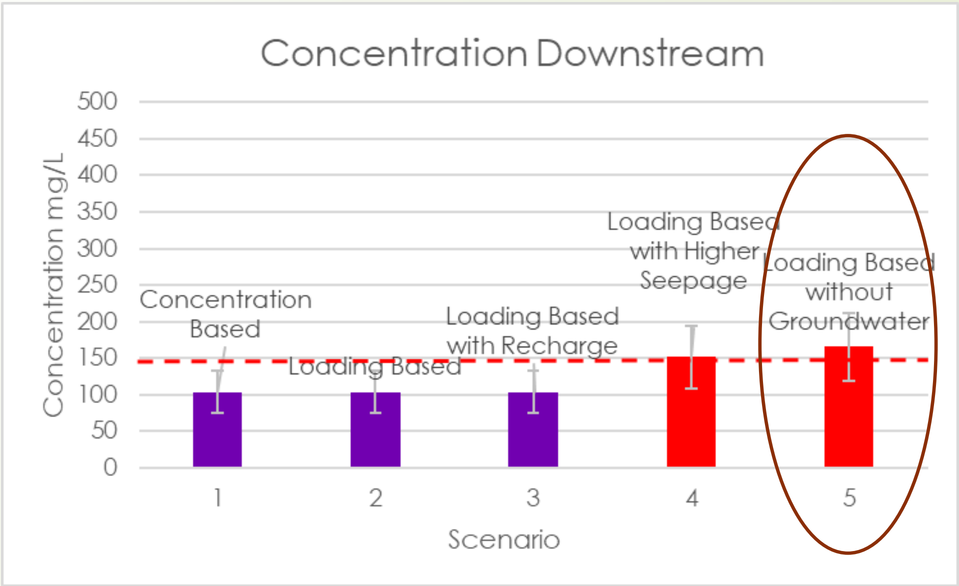


- Assumptions changed:
  - Assumed seepage is 40% MAP but with the higher loading rate





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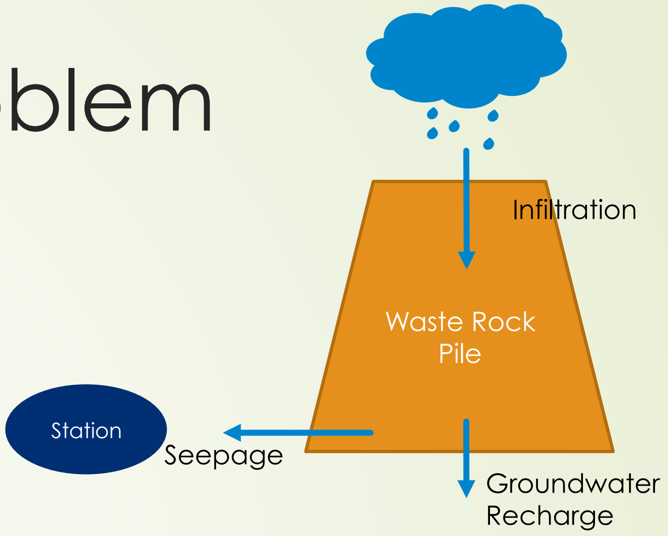
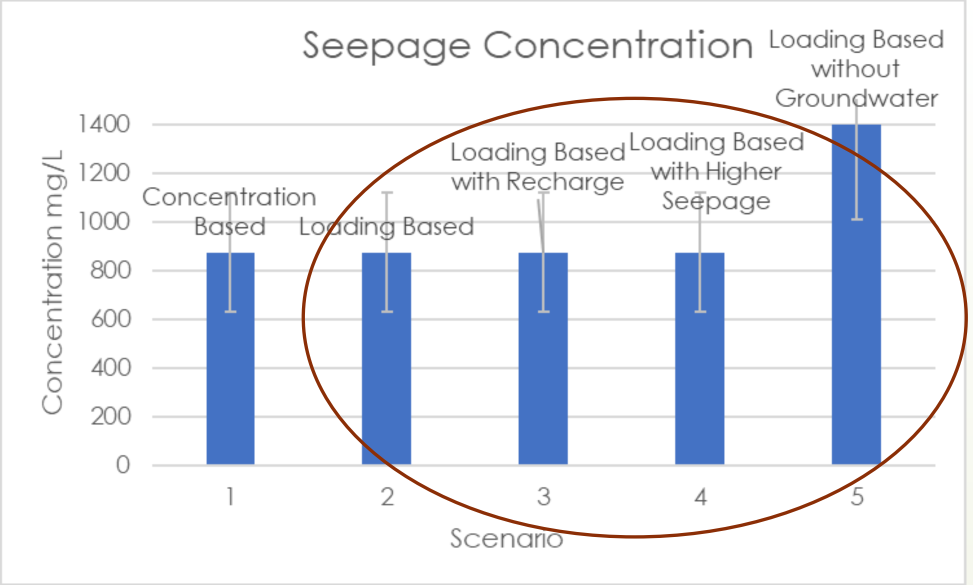
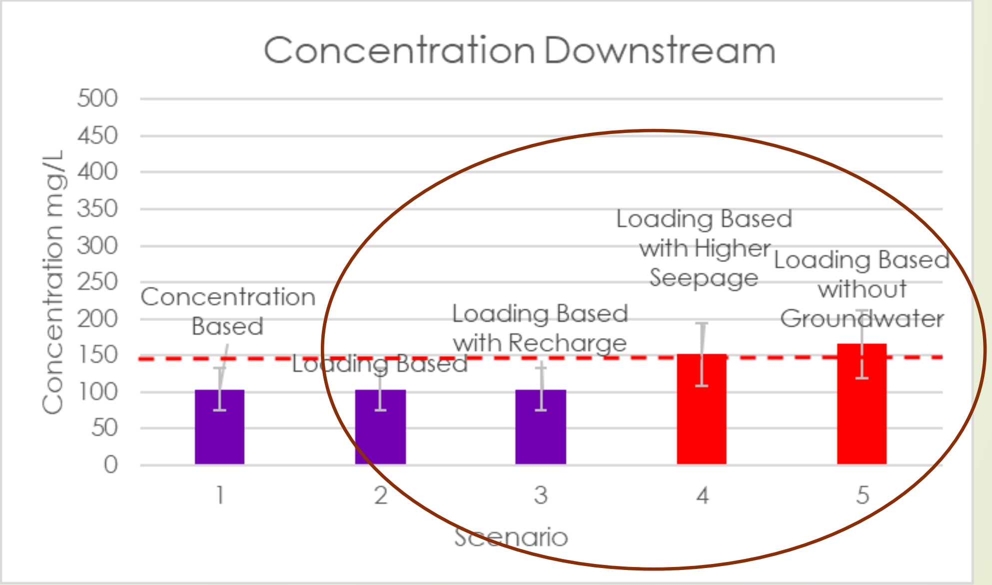
Load (mg/kg/time)
Fictitious Guideline = 150 mg/l



- Assumptions:
  - Reduce precipitation by 50% to model extreme dry years





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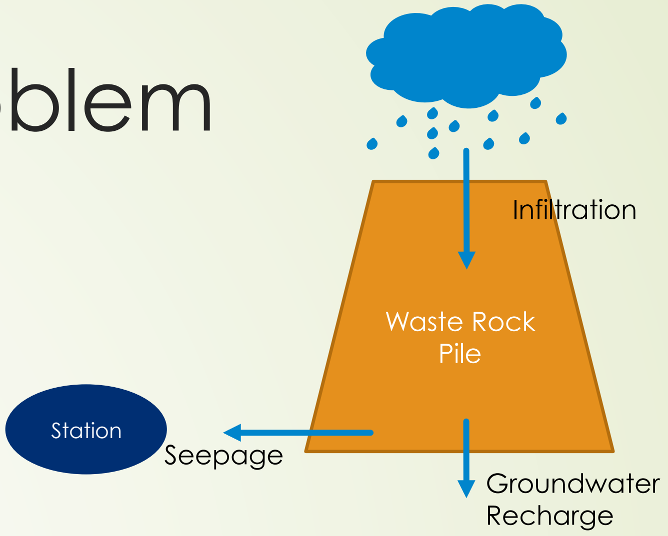
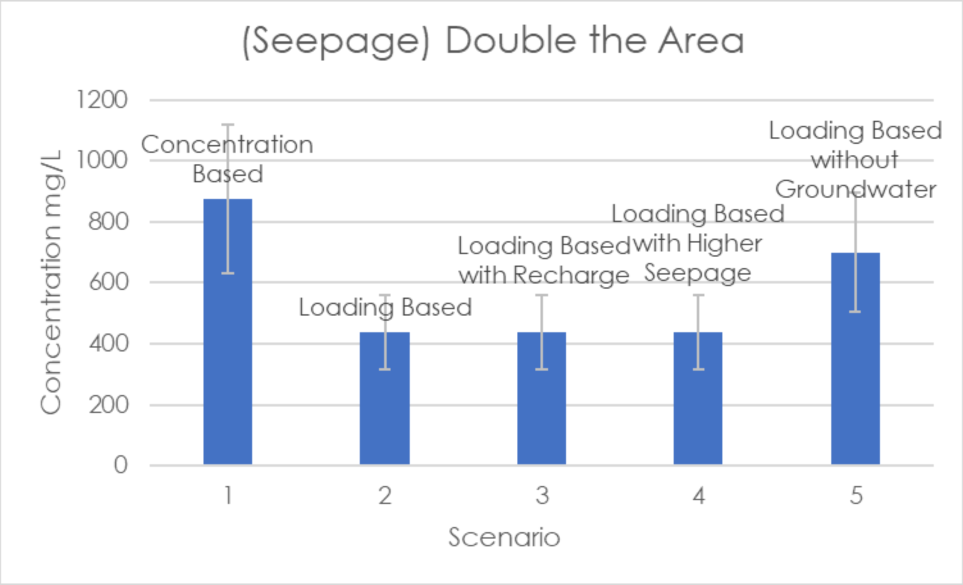
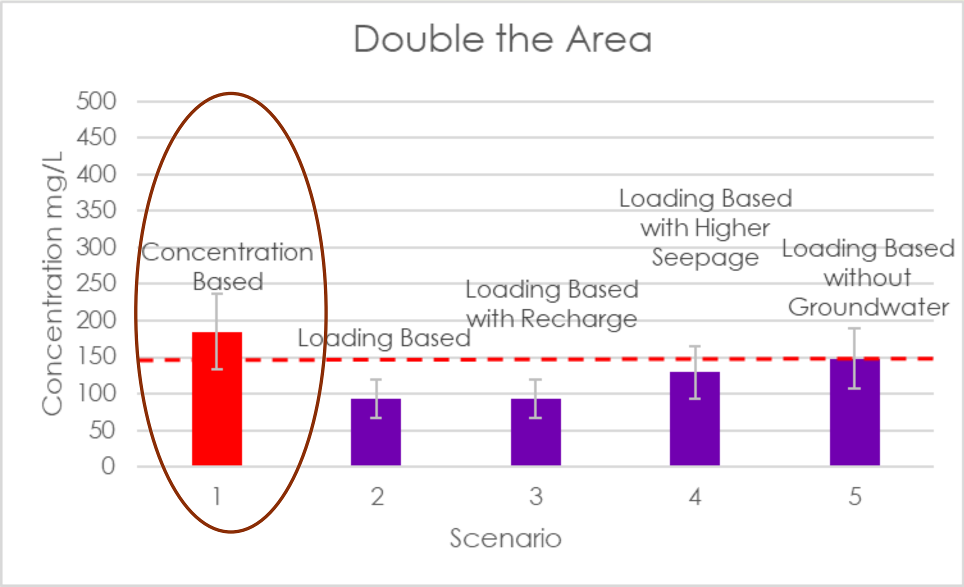


- Assumptions:
  - Area of waste rock pile doubles (configuration)
    - Tonnage stays the same
    - MAP stays the same





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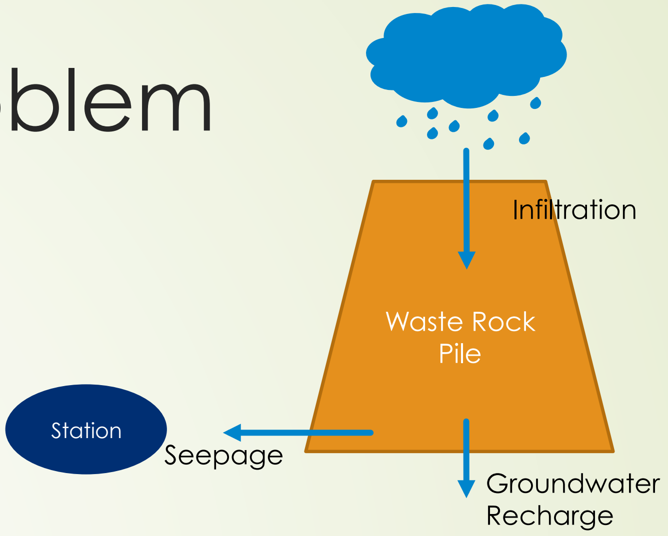
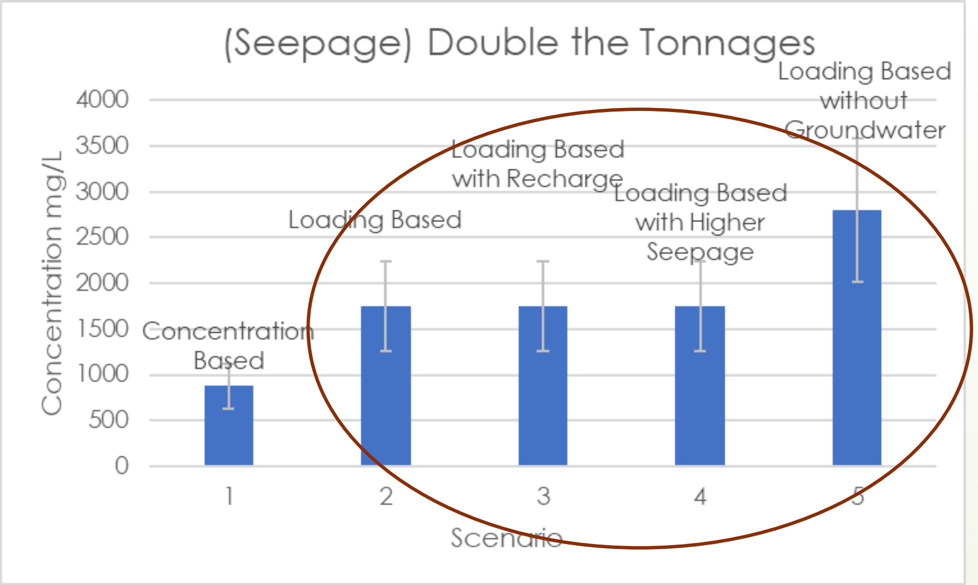
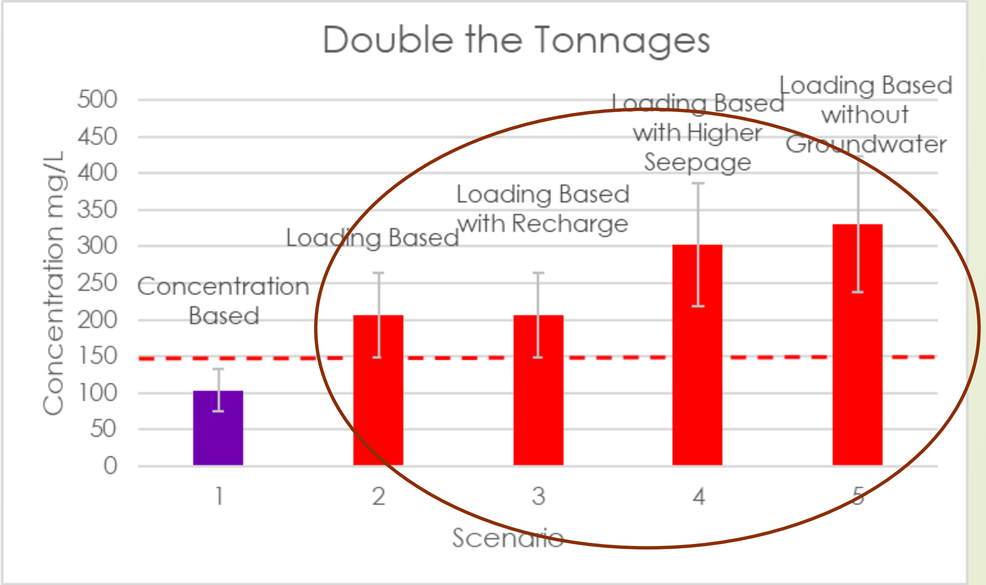


- Assumptions:
  - Mass of waste rock pile doubles through operations / mine expansion





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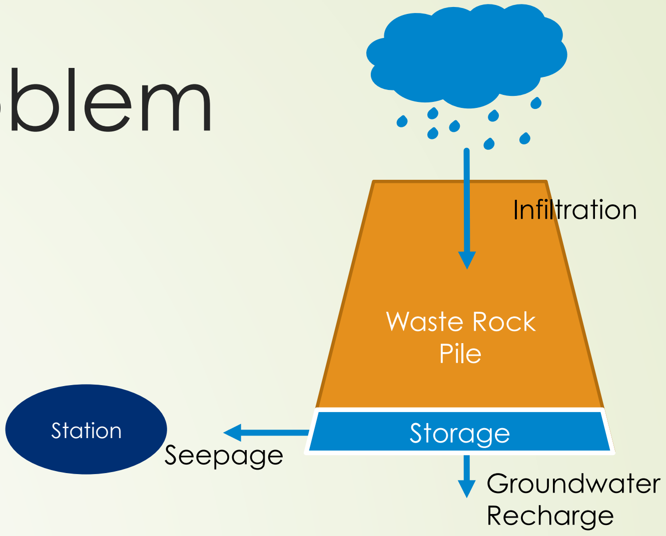
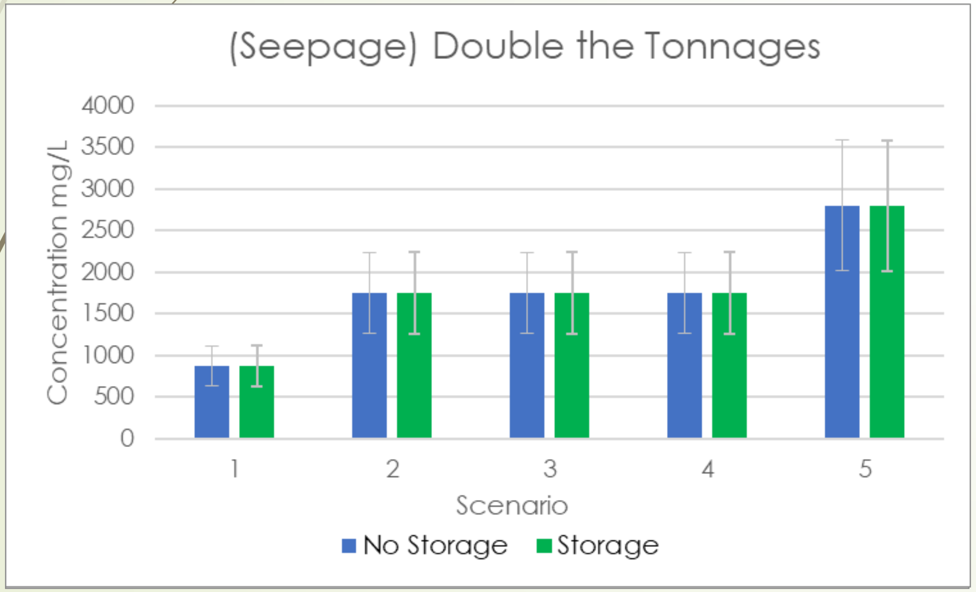
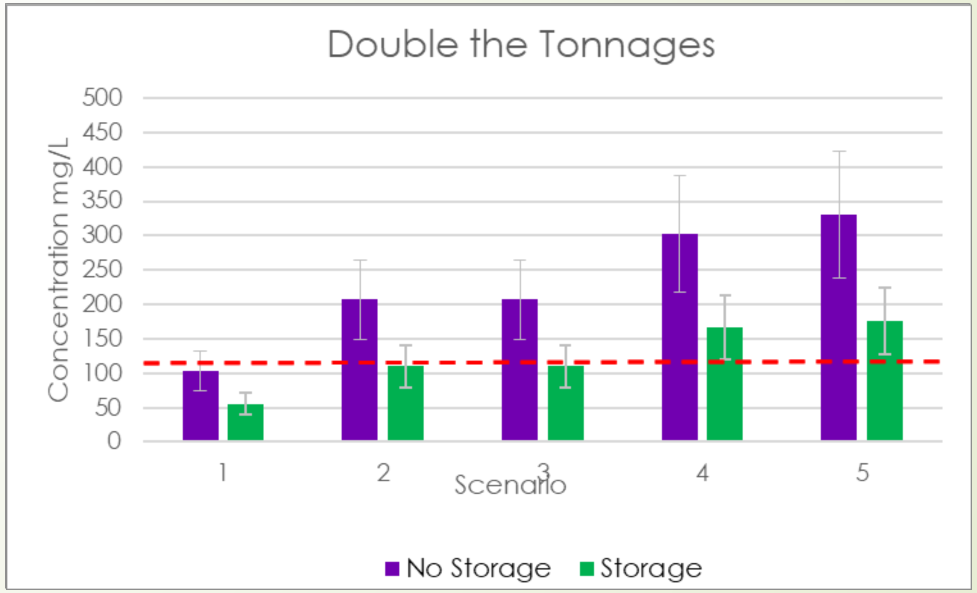
Load (mg/kg/time)
Fictitious Guideline = 150 mg/l

- Assumptions:
  - Double the tonnages
  - Half of the seepage water is lost to storage

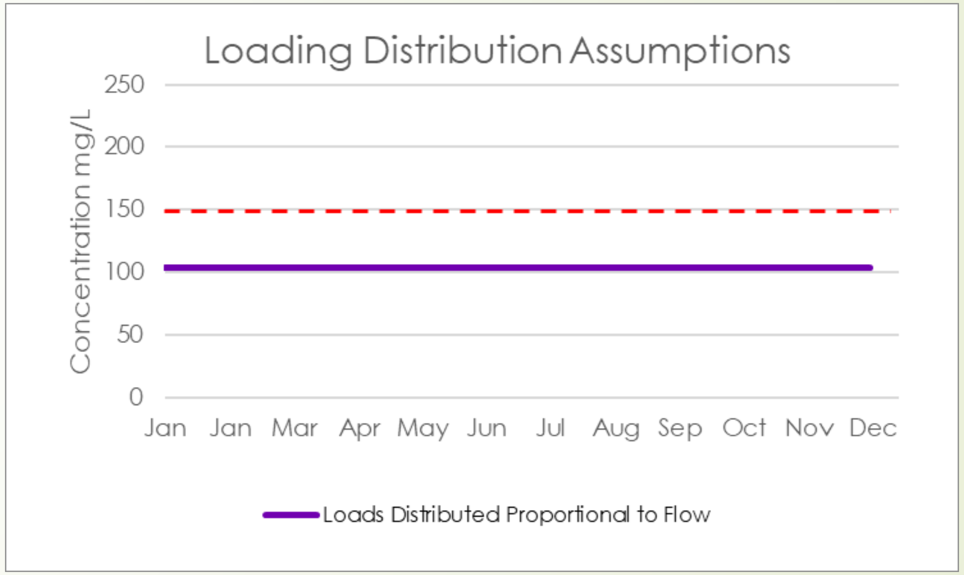






Seasonal Distribution of Load

- Scenario 3 (24% GW recharge, 40% seepage, minimal storage-simplification)
- Flow
  - Infiltration assumes runoff monthly distribution
  - Seepage assumes runoff monthly distribution
  - Groundwater recharge is constant
- Load
  - Distributed proportional to flow



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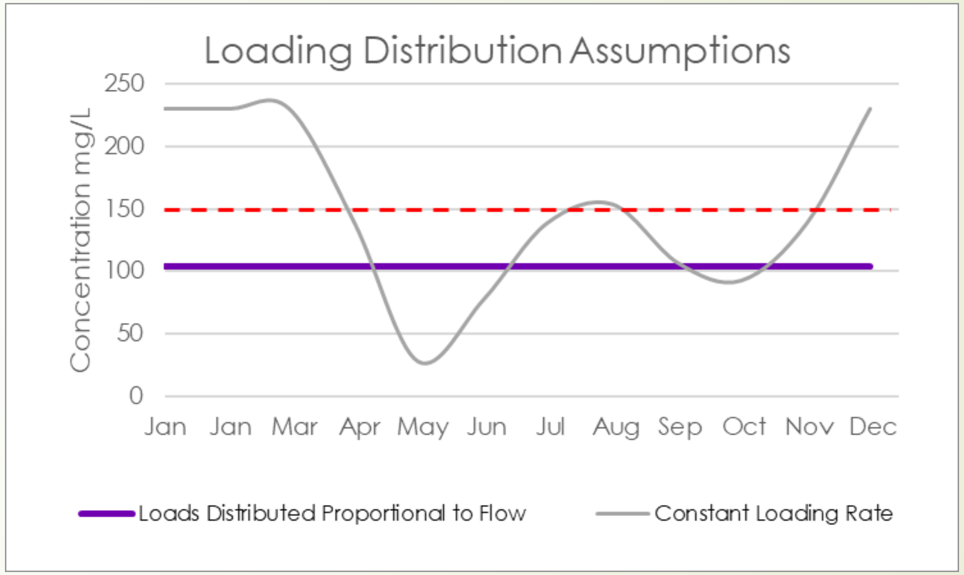
- Load
  - Distributed proportional to flow
  - Constant loading rate
    - Large preferential flow paths



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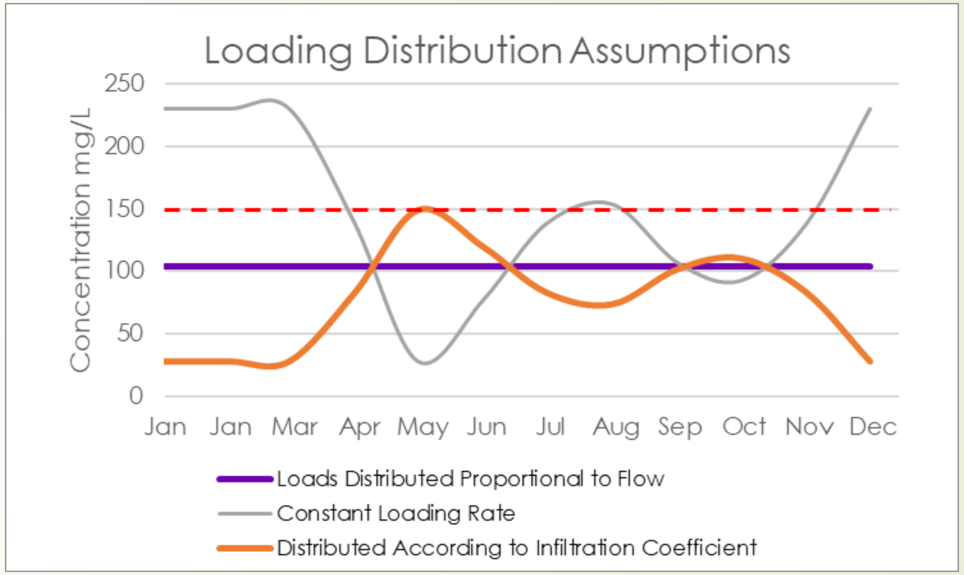
- Load
  - Distributed proportional to flow
  - Constant loading rate
  - Associated with runoff monthly distribution
    - Trying to simulate an observed flush



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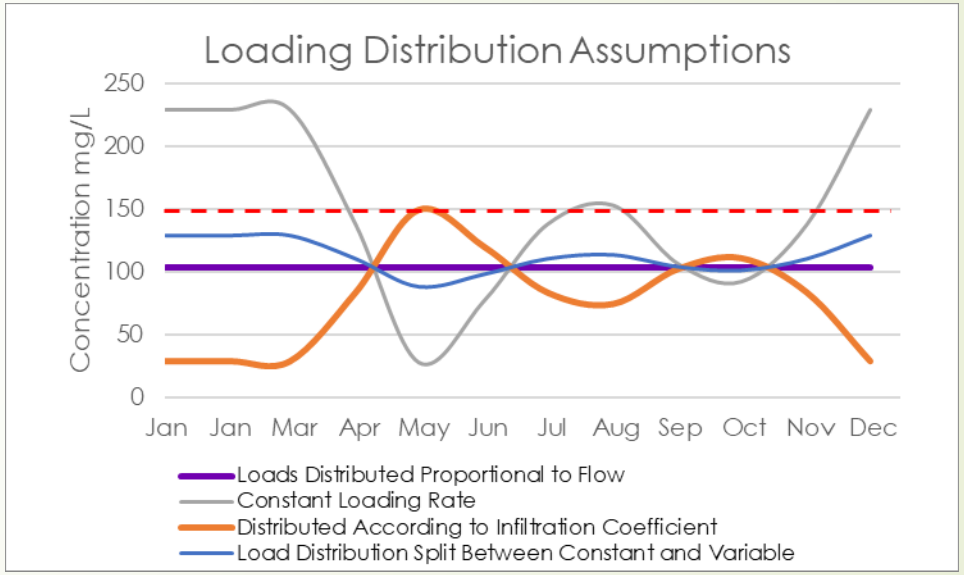
  - Split between constant loading rate and runoff monthly distribution



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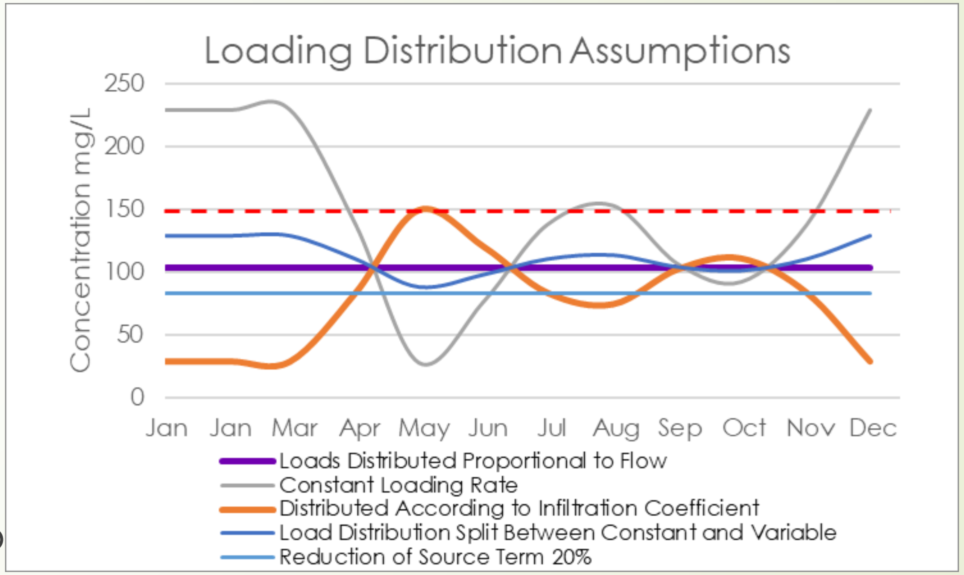
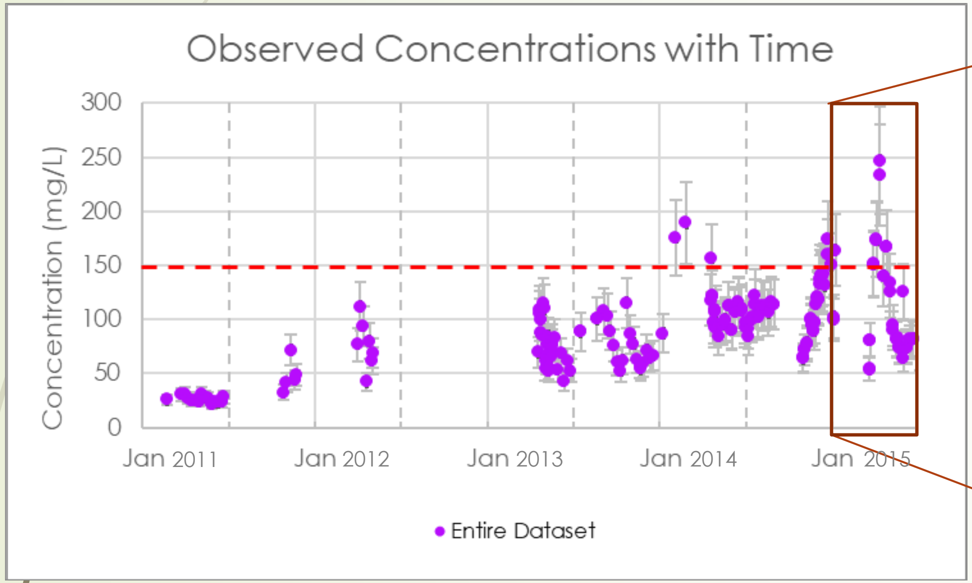


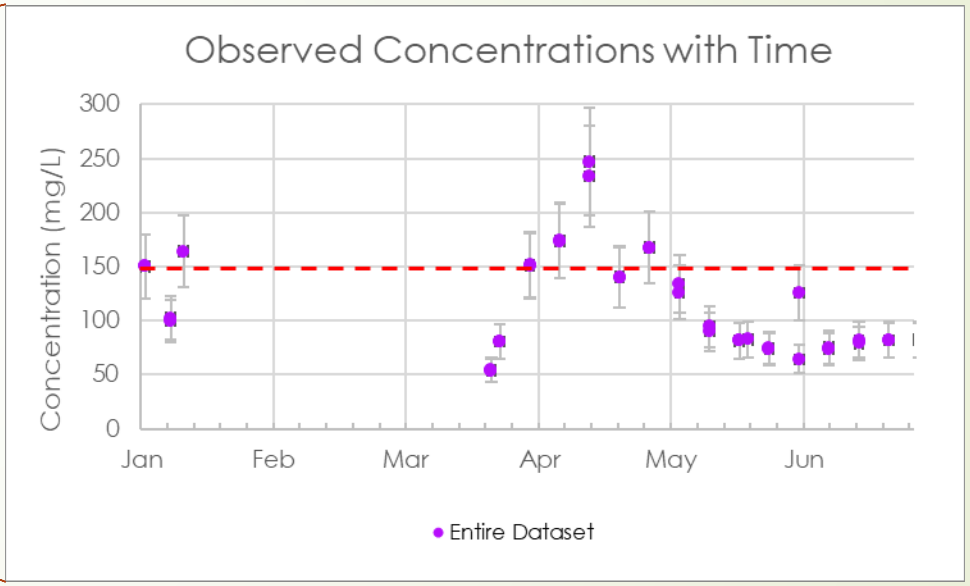
  - Loading rate changed by 20%

Honey I Shrunk the Source Terms

Water Quality Benchmarking
Comparing Predictions to Observed
What do we compare to?



Question: Does the model predict the increasing trend?



Many models predict monthly average concentrations but our water quality dataset is instantaneous – what do we compare to?

Water Quality Benchmarking
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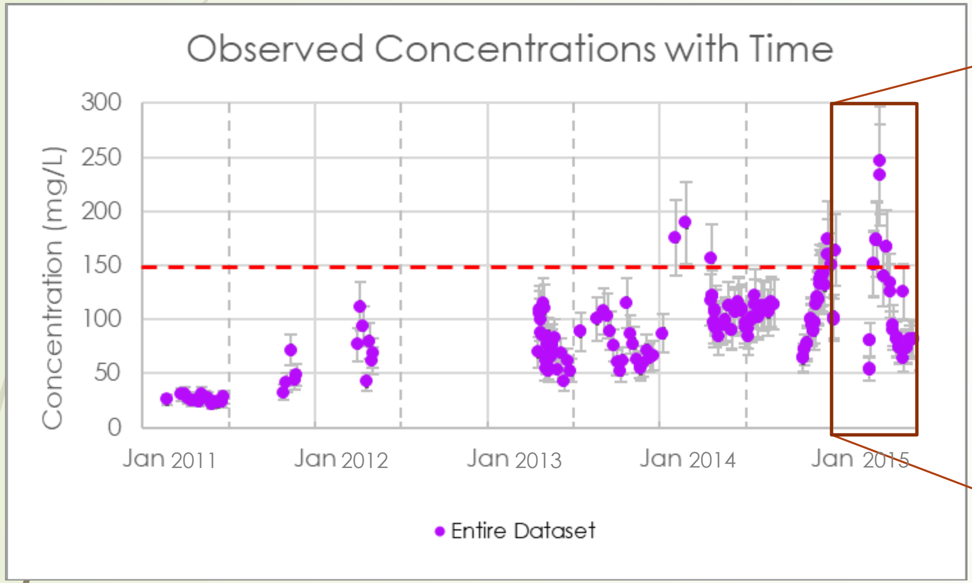

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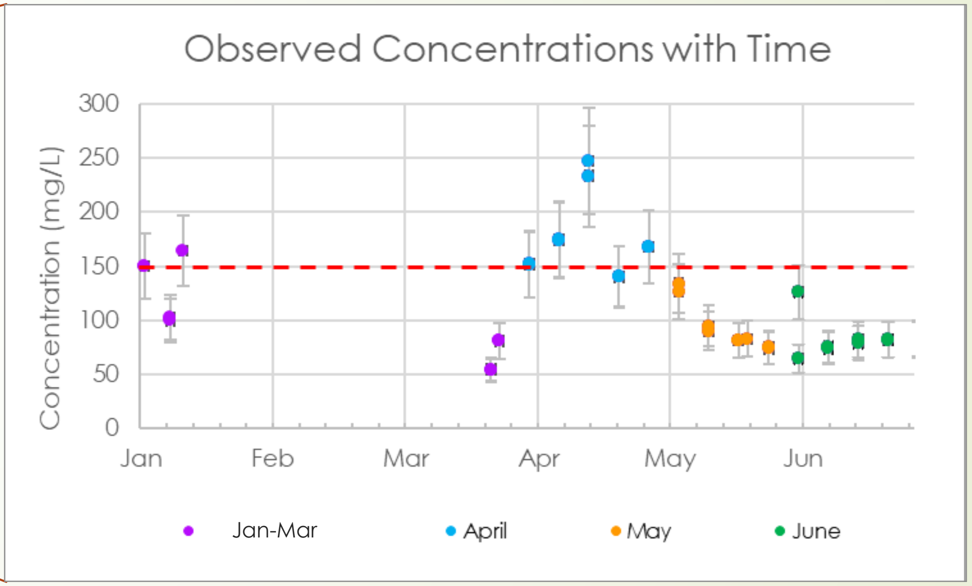

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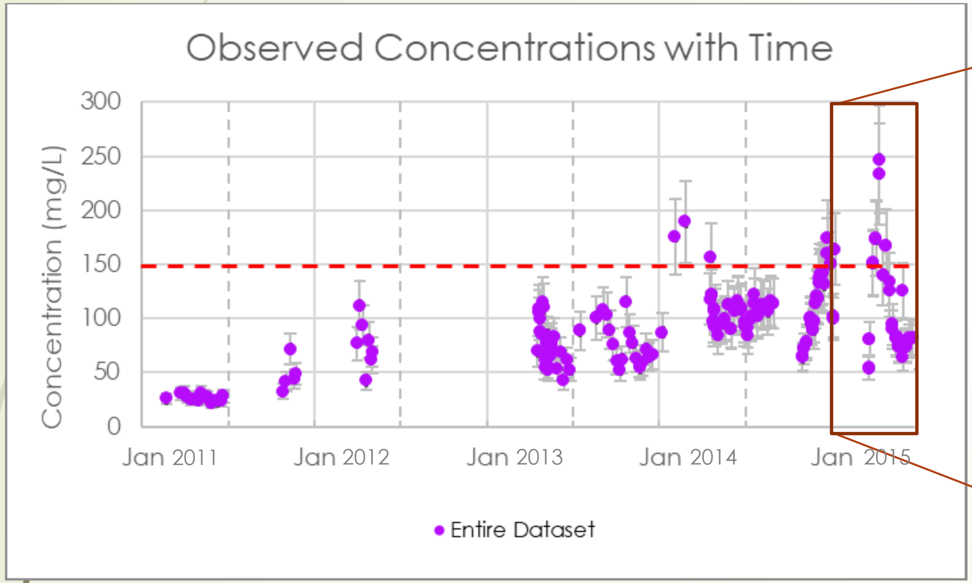
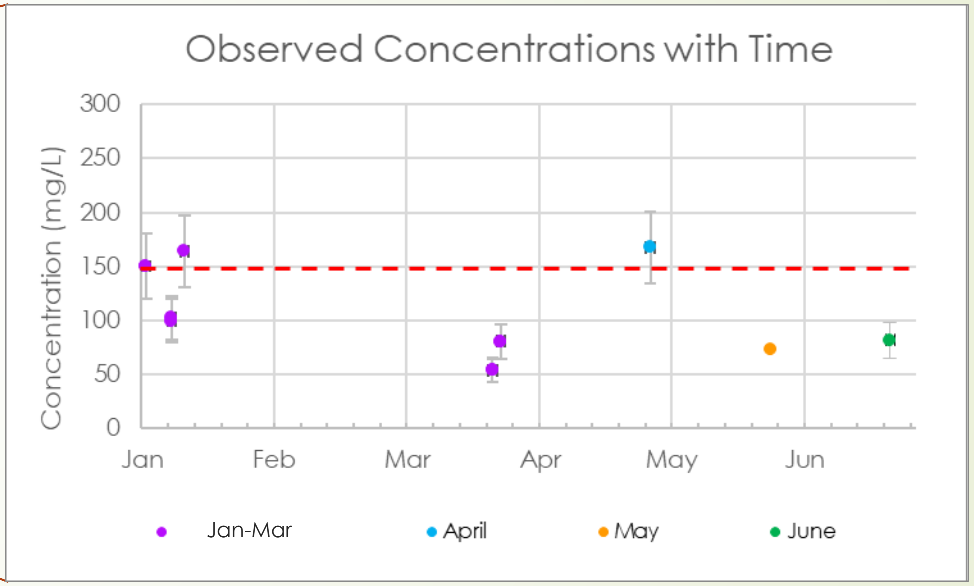
Comparing Predictions to Observed

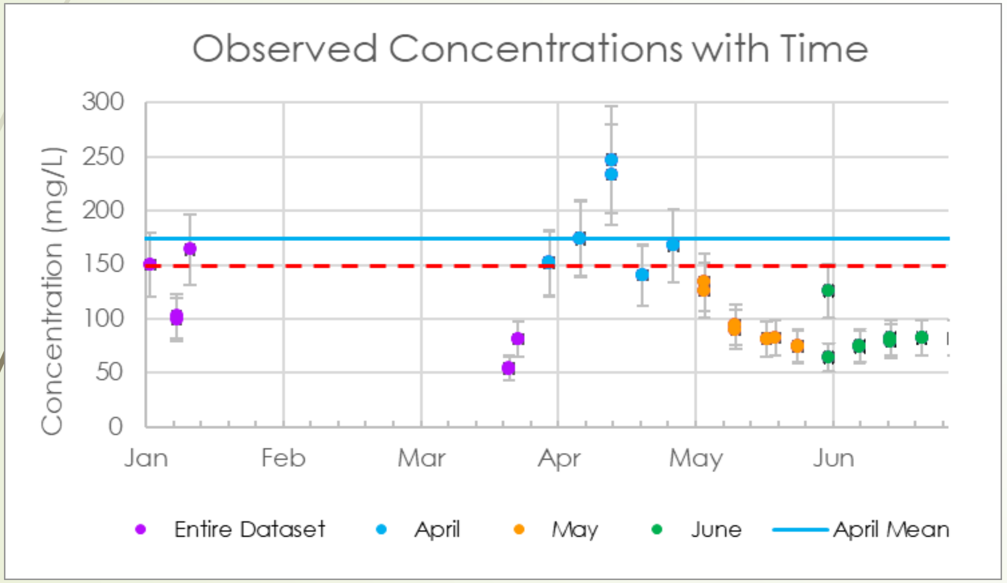




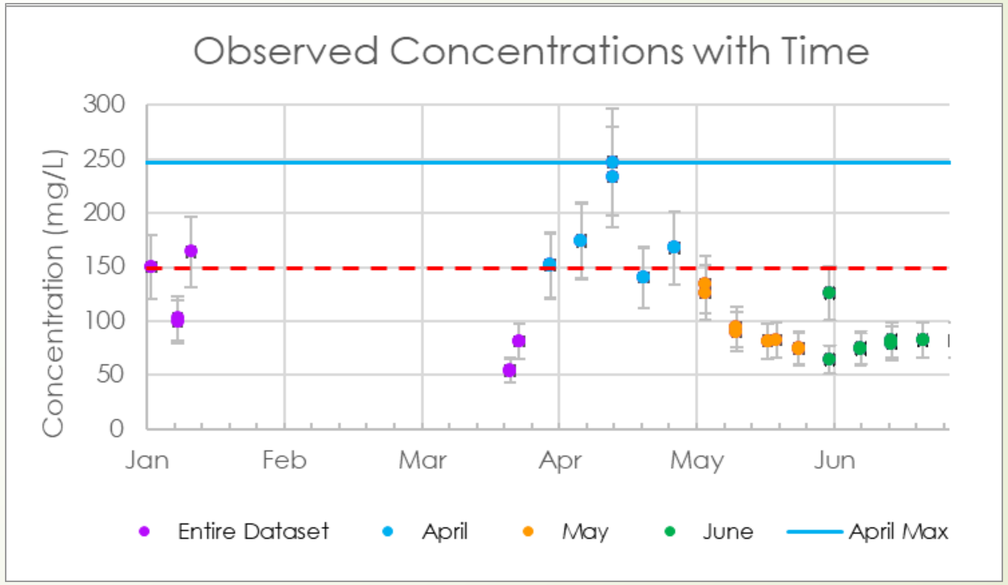
Is our dataset representative?
How do we know?

What do we compare our monthly predictions to in April to see if they are reasonable?

Do we want predictions to match, the mean observed concentration of April – management may be required?

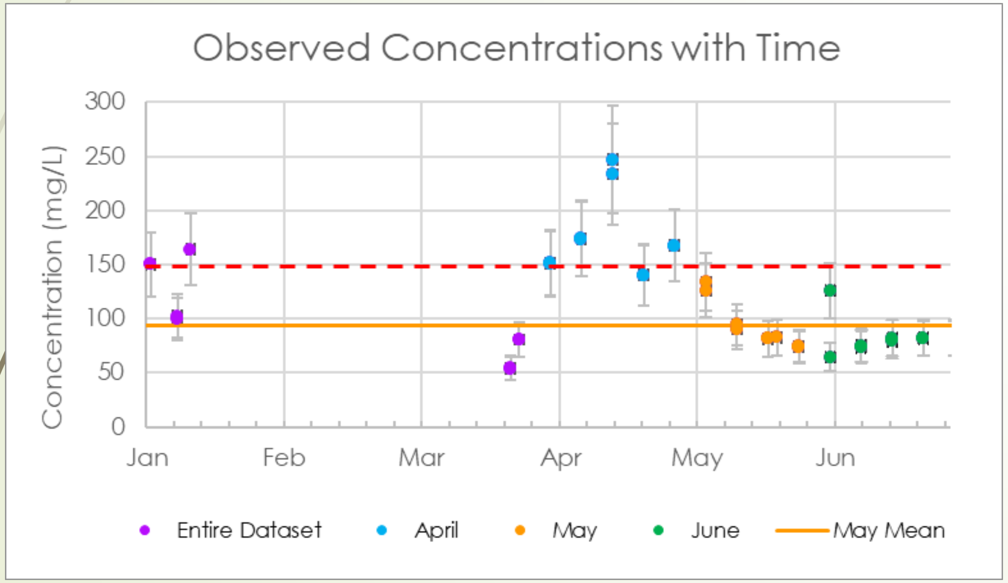


Or the maximum of April – management will likely be required?

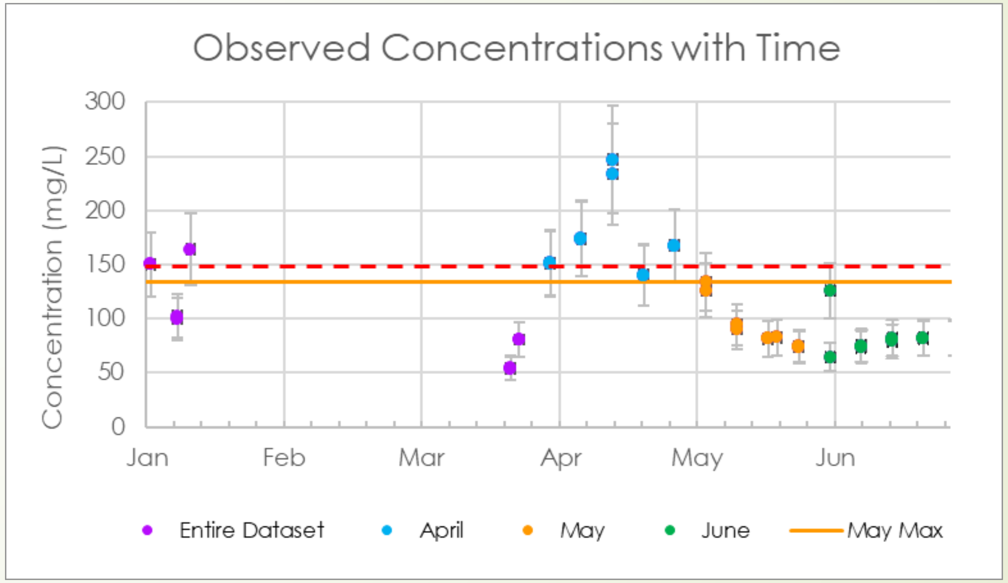


What do we compare our monthly predictions to in May to see if they are reasonable?

Do we want predictions to match the mean observed concentration of May?



Or the maximum of May as we would be predicting a potential exceedance?



With all this uncertainty – at least be transparent!

Example of a Predicted Cumulative Flow Balance

Inflow	Cumulative Mass (m3)	Outflow	Cumulative Mass (m3)
Total Inflows	**20.9**	**Total Outflows**	**20.9**
Initial volume of pond	0.00	Volume of reservoir	0.00
Waste Rock Facility	2.65	Effluent from pond	20.89
Temp Waste Rock	0.17		
Pipe #1	0.62		
Pipe A	0.01		
Stockpile #2	0.03		
Pipe #3	0.09		
Pipe #2	0.07		
Pipe B	0.01		
Diversion	7.89		
Site Runoff	0.91		
Site Runoff	7.71		
Pond Interflow	0.20		
Pond Runoff	0.46		
Stockpile #2	0.07		

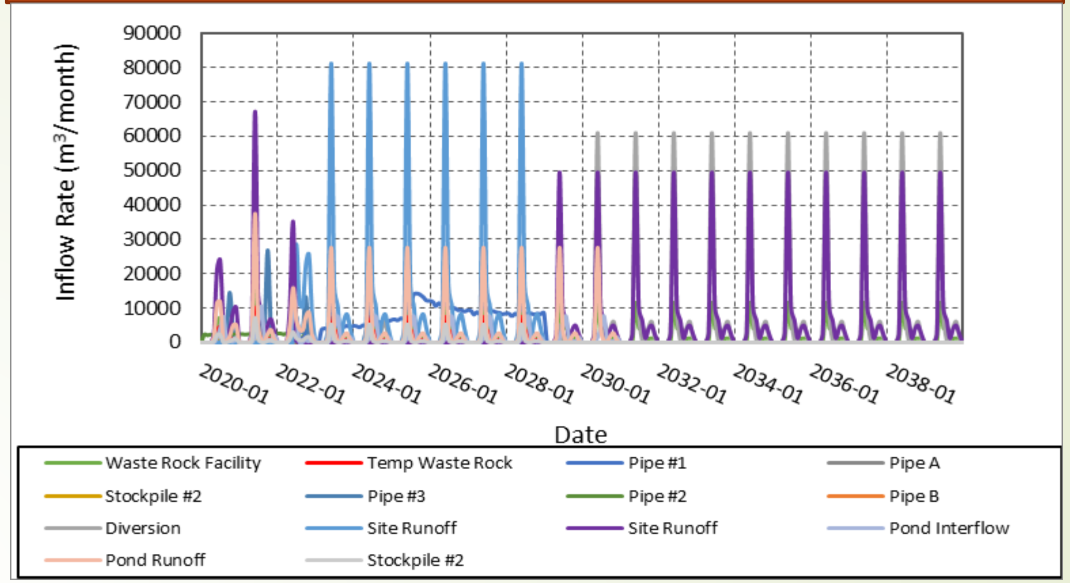
Example of a Predicted Cumulative Mass Balance

Inflow	Cumulative Mass (tonne)	Outflow	Cumulative Mass (tonne)
Total Parameter Inflow	**2780**	**Total Parameter Outflow**	**2780**
Initial Mass in Pond	0.20	Final Mass in Pond	0.00
Waste Rock Pile	2058	Outflow from Pond	2778
LG stock pile	4	Pipe #2 recirculation	0.00
HG stockpile	38		
Pipe #1	369		
Pipe #3	14		
LG stockpile 3	9		
Site Runoff	83		
Stockpile #1	54		
Diversion Ditch	41		
Site Runoff	68		
Pond Interflow	1		
Pond Runoff	2		
Stockpile #2	8		
Pipe #2	26		

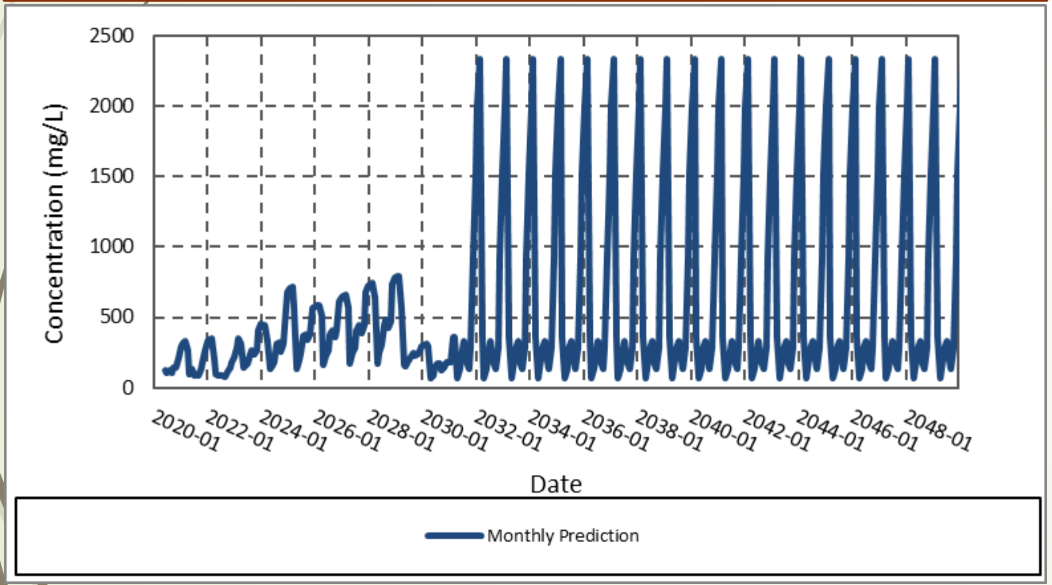
Transparency

- Complexity – too much makes transparency impossible
- Back of envelop calculations
  - Flow into the pond = 195000 m3/year
  - Annual Load = 26195 kg/yr

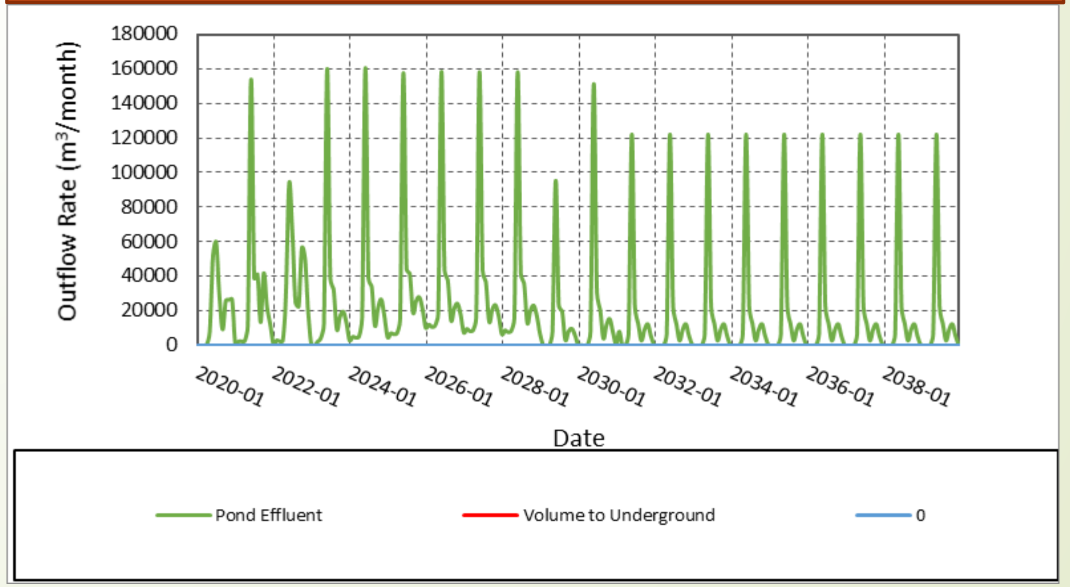
Predicted Monthly Inflows



Predicted Monthly Average Conc.



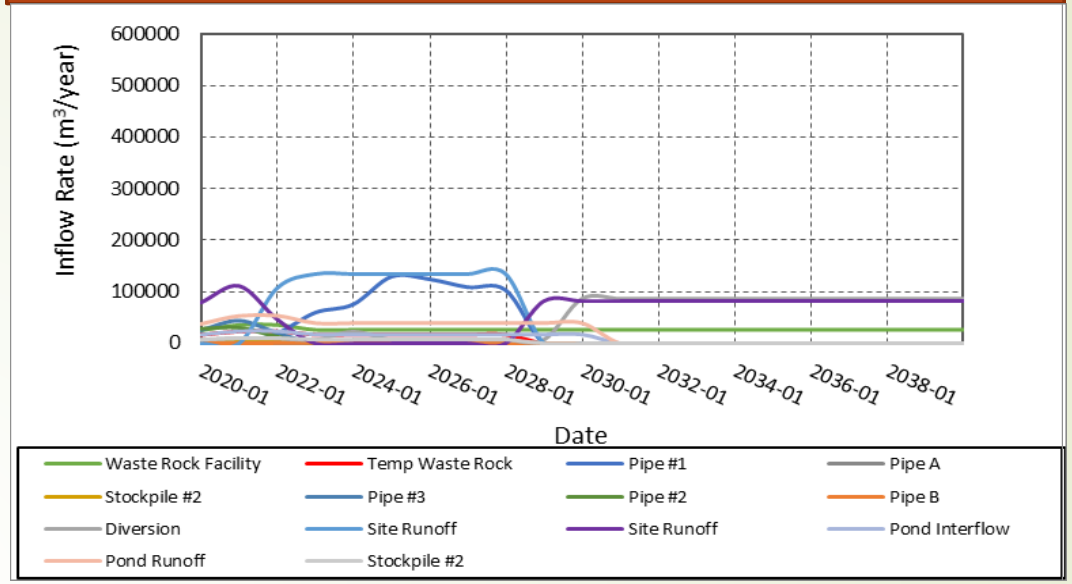
Predicted Monthly Outflows



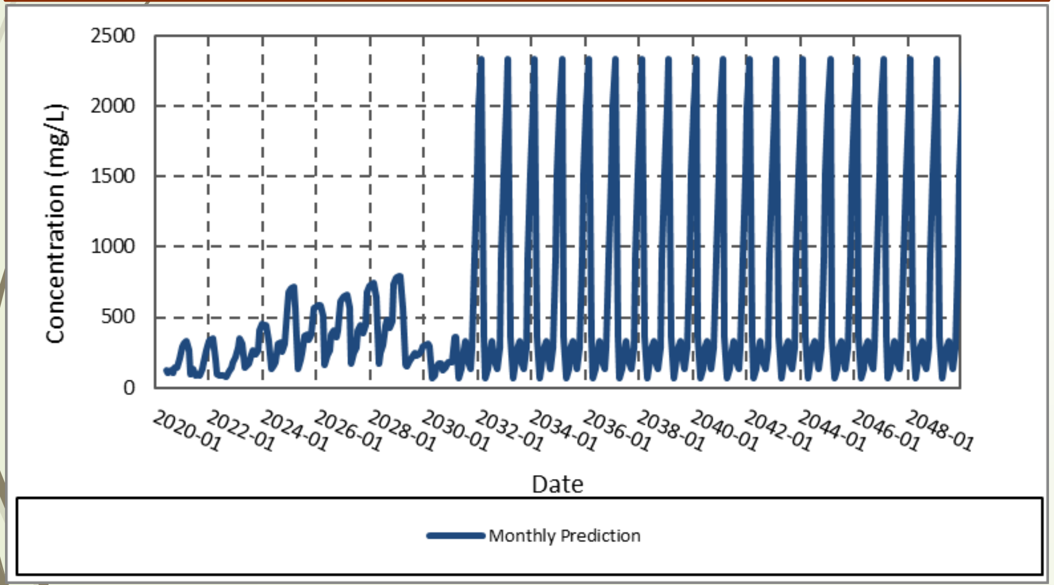
Transparency

- Complexity – too much makes transparency impossible
- Back of envelop calculations
  - Flow into the pond = 195000 m3/year
  - Annual Load = 26195 kg/yr

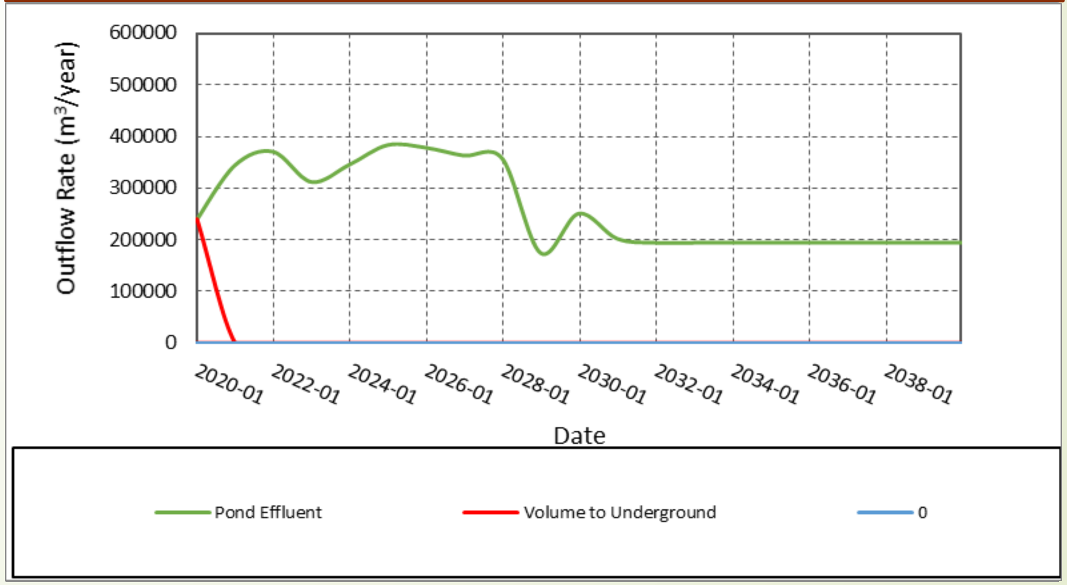
Predicted Annual Inflows



Predicted Monthly Average Conc.



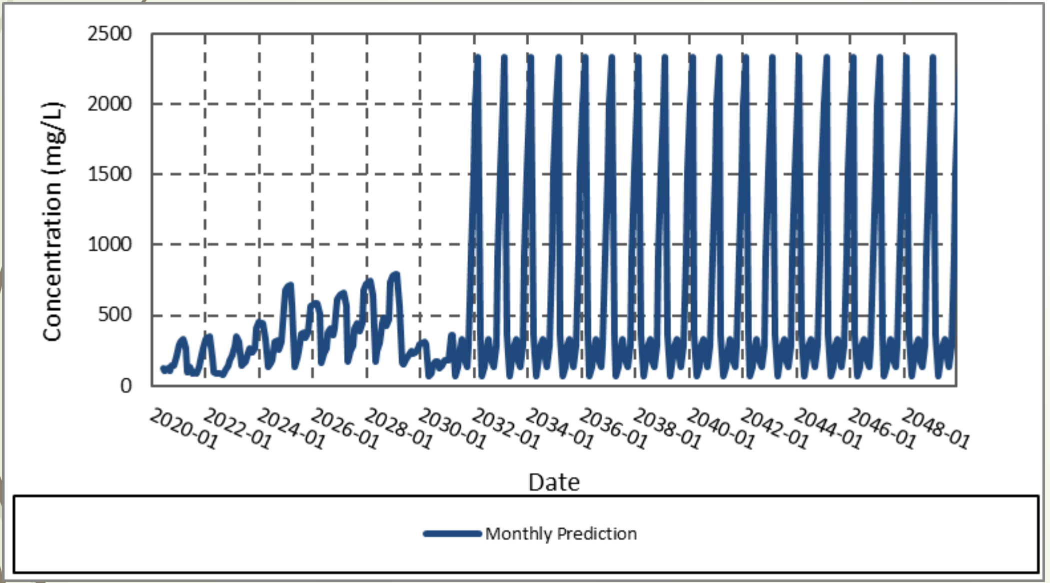
Predicted Annual Outflow



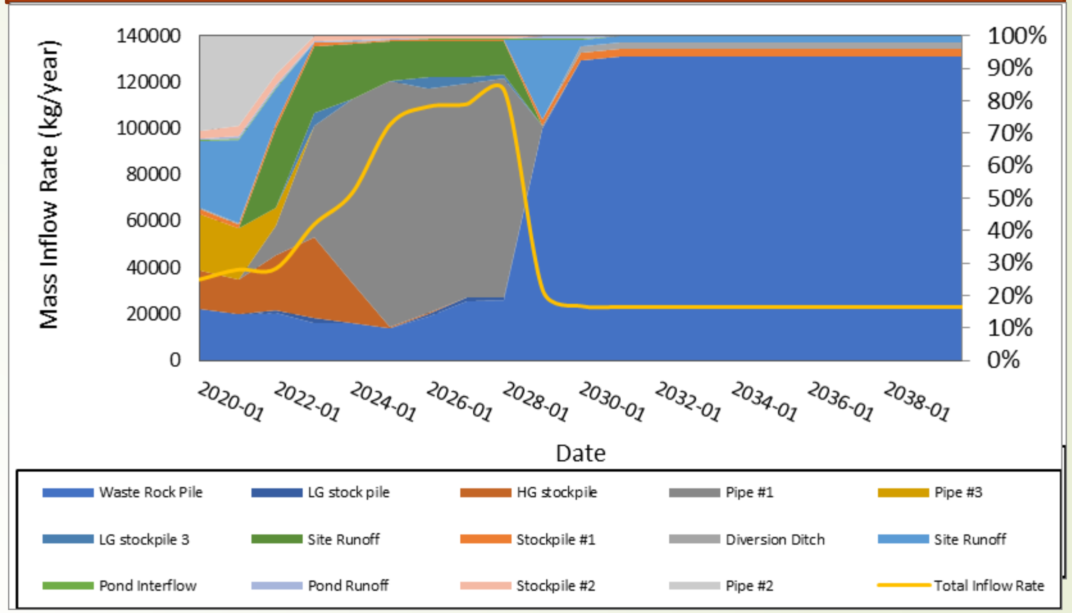
Transparency

- Complexity – too much makes transparency impossible
- Back of envelop calculations
  - Closure Flow Rate = 195000 m3/year
  - Closure Annual Load = 26195 kg/yr

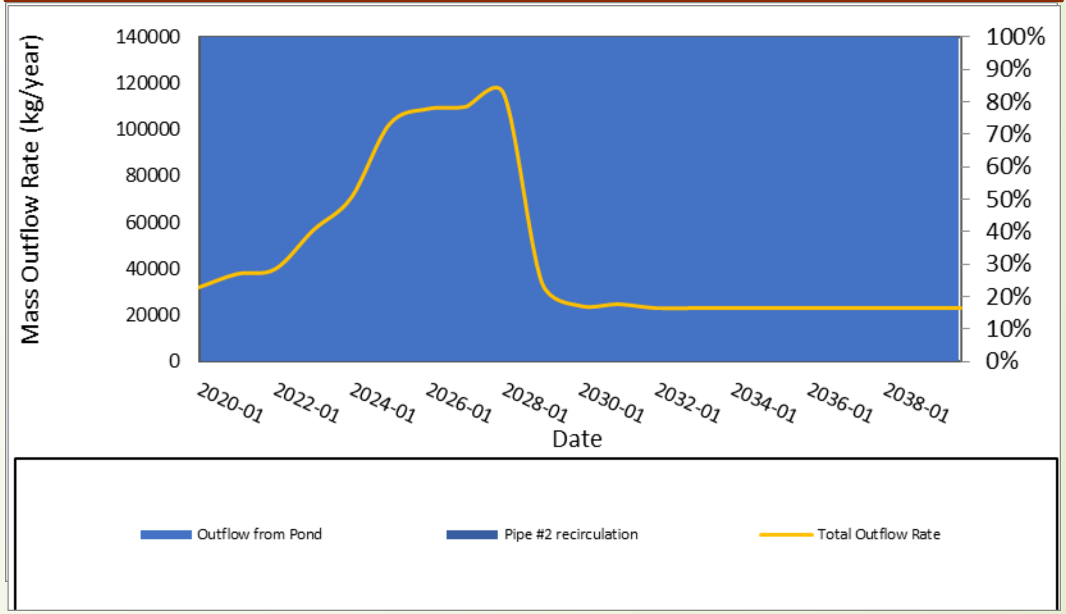
Predicted Monthly Average Conc.



Predicted Annual Load Inflows



Predicted Annual Load Outflow



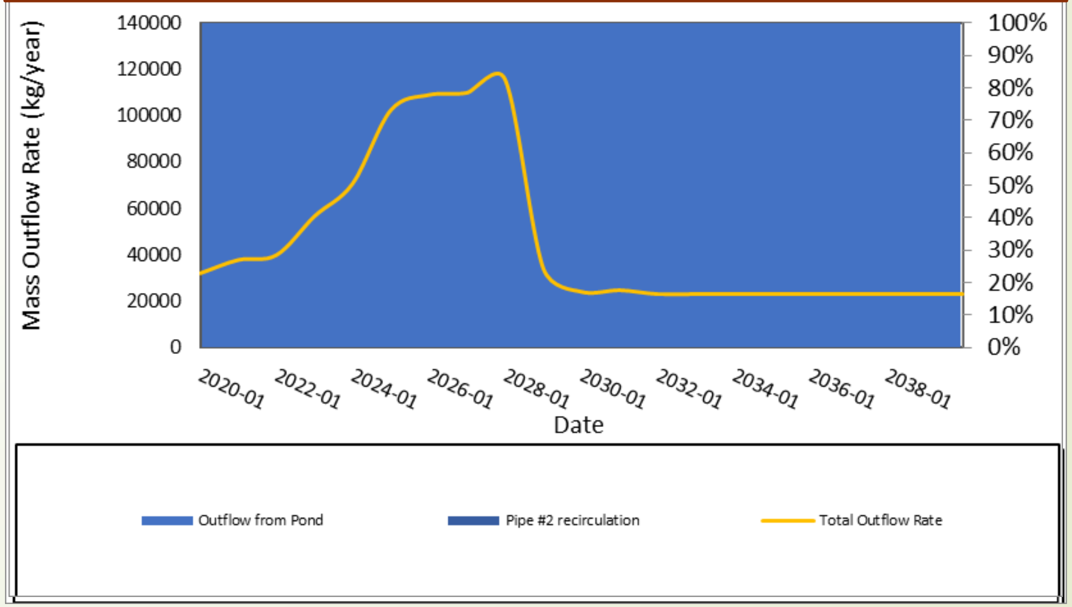
Provide transparency within your model

- Check the loads at downgradient node

  - Downstream
  - Upstream

Predicted Annual Load Inflows d/s

Predicted Annual Load Outflow



Summary

- Always ask – is this useful? How much can we really rely on it?
- Modelling
  - Know your science and system
  - Adjust and update as needed – models are always wrong
  - Understand uncertainty (sensitivities)
  - Be transparent and logical
  - Never blindly trust your model
- Managing Model Uncertainty
  - Collect data (sufficient quality and quantity)
  - Source control
    - BMP and BAT
    - Reduced loads
  - Continency plans
- Reviewing WQMs
  - Does the model make sense
    - First principles
    - logical
    - transparent
  - Focus on risks not the absolute concentrations

"Potential weaknesses of models include assumptions regarding input parameters, a lack of site specific data, and limited verification. ***Models are tools to assist with the prediction of drainage chemistry and loadings, but cannot substitute for good, site specific measurements and understanding.*** *Modeling predictions need to be validated before they can be accepted." – MEND 2009 (P20-1)*

To Err is Human

- In 1999 NASA lost a Mars orbiter because one team used metric and the other did not (125 million dollars)
- Solar helispheric observatory lost all communication with earth – conversation factor from Imperial to metric units
- Air Canada ran out of fuel mid flight (no fatalities) due to fuel calculation error – first plane to use metric
- Christopher Columbus – miscalculated the circumference of the earth – used Roman miles instead of nautical miles – had assumed the Bahamas was Asia

This is an illustration
https://www.snopes.com/fact-check/misaligned-bridge-photo/