Screening Analysis

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Objectives

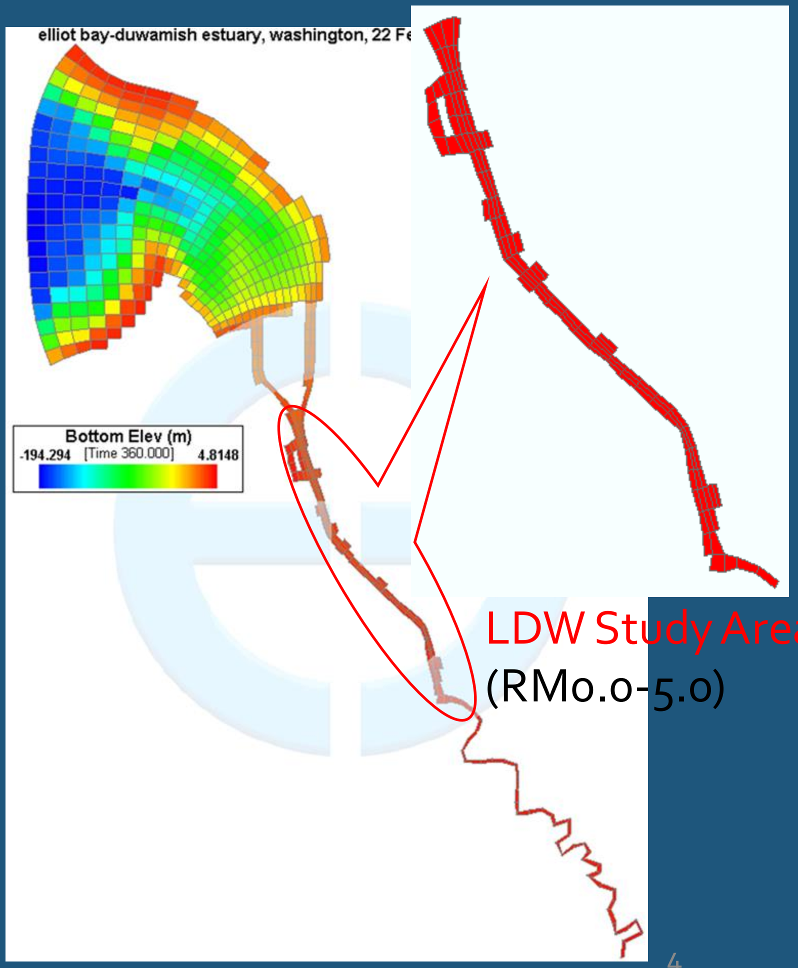
- Provide sediment size classification information for future Pollutant Loading Assessment (PLA) modeling.
- Evaluate the importance of different pathways.
- Preliminarily prioritize modeling parameters/processes.

Methods

- Scaling analysis
  - Mathematical analysis
- Mass Balance Model
  - Box model (Four compartments)
- Sensitivity analysis
  - EFDC model (King County, 2005)

Sensitivity Analysis Model

- Based on Existing King County's EFDC model
  - ➢Hydrodynamic
  - ➢Sediment Transport
  - ➢Toxic
- Averaged Outputs
  - Water level
  - Salinity
  - Water Age
  - PCBs concentration in Water Column
  - PCBs concentration in Sediment Bed
  - Suspended sediment concentration
  - Sediment Bed Thickness



Topics

- Sediment classification
  - Scaling analysis
  - Sensitivity analysis
- Pathway evaluation
  - Mass balance model
  - Sensitivity analysis
- Model Parameters
  - Sensitivity analysis

Highlights of results

- Three sediment classification (2 cohesive + 1 noncohesive) is recommended.
- Under existing condition, the sediment is the largest PCBs source to the water column. After the cleanup (PCBs = 2ppb), both lateral and green river will be significant sources.
- The PCBs in the water column is most sensitive to the modeling parameters that describe the pollutant transportation from sediment to water.

Sediment classification – Scaling analysis method

- Scaling Analysis
  - Is an analytical method that allows one to determine what parts of an equation control it’s outcomes (model results) for certain geophysical and geochemical conditions.

Sediment classification – Scaling analysis method

- Scaling Sorbed Chemical Deposition
  - Scalers that determine total chemical mass loss from settling solids.

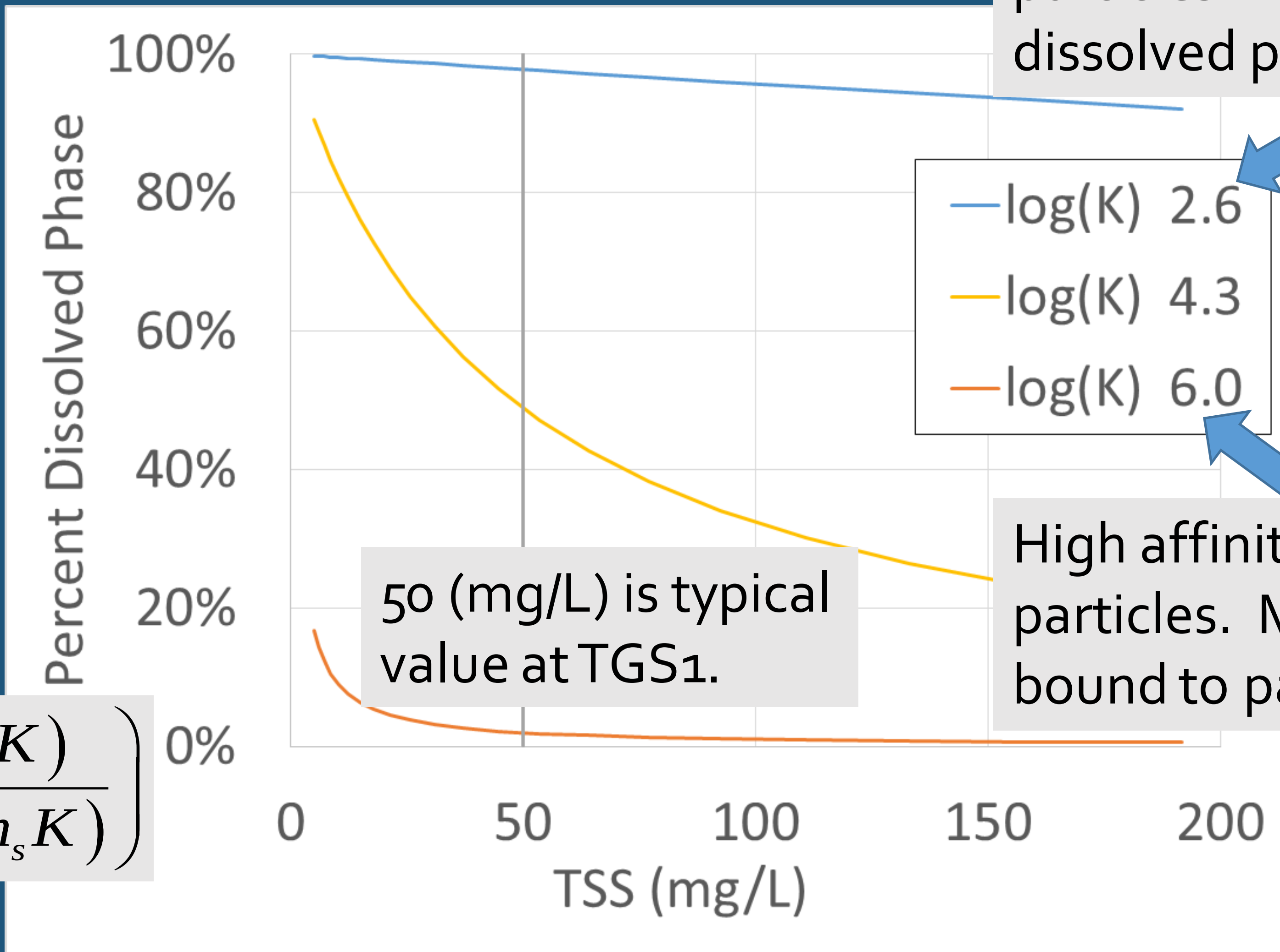
$$\left(\frac{L}{UH}\right)\left(\frac{w_s\left(m_s K\right)}{1+\left(m_s K\right)}\right)$$

Term describes physical characteristics of the waterbody.

Term describes physical and geochemical characteristics of the sediment type.

Sediment classification – Scaling analysis method

Low affinity for particles. Mostly in dissolved phase



High affinity for particles. Mostly bound to particulates

$$\left(\frac{(m_s K)}{1+(m_s K)}\right)$$

Sediment classification – Scaling analysis results

<table>
<tr><th colspan="4">Three Sediment Classes: Baseline</th><th colspan="5">Five Sediment Classes: Scenario 4</th></tr>
<tr><td>Sediment Class</td><td>Sand</td><td>Silt</td><td>Clay</td><td>Med Sand</td><td>Fine Sand</td><td>Coarse Silt</td><td>Med Silt</td><td>Clay</td></tr>
<tr><td>Percent of PCB mass contributed to sediment bed by class</td><td>5.3%</td><td>7.2%</td><td>0.0%</td><td>2.8%</td><td>2.8%</td><td>5.1%</td><td>4.7%</td><td>0.0%</td></tr>
<tr><td>Percent of Total PCB mass contributed to sediment bed</td><td colspan="3">12.5%</td><td colspan="5">15.5%</td></tr>
<tr><td colspan="4">Percent change in mass fluxed into sediment bed</td><td colspan="5">24%</td></tr>
<tr><td colspan="4">Percent change in PCB mass in water column</td><td colspan="5">-3.44%</td></tr>
</table>

Sediment classification – Scaling analysis results

- In the LDW, the water column PCB chemical mass is partitioned primarily into the dissolved phase under most conditions (TSS < 50 mg/l).
- Increasing the number of sediment classes increased the mass and characteristic settling velocity, which increased the chemical flux into the sediment bed.
- A small decrease is expected in the total PCB concentration in the water column.

Sediment classification – Sensitivity analysis method

- King County EFDC has 3 classes
- QEA Sediment Transport Model (STM) has 4 classes
- 360-Day (Day 0 - 360) cold-started EFDC runs

	Sediment Size Classification				
	Cohesive			Noncohesive	
Baseline (2+1)	Silt (< 4 µm) **1.0×10^{-10} m/s**	Silt (4-63 µm) **2.0×10^{-4} m/s**		Sand (63-500 µm) **0.04 m/s**	
Scenario 1 (1+1)	Clay and silt (< 63 µm) **1.0×10^{-4} m/s**			Sand (63-500 µm) **0.04 m/s**	
Scenario 2 (3+1)	Clay (< 4µm) **1.0×10^{-10} m/s**	Fine/Medium Silt (4-20 µm) **1.0×10^{-4} m/s**	Coarse Silt (20-63 µm) **3.0×10^{-4} m/s**	Sand (63-500 µm) **0.04 m/s**	
Scenario 3 (2+2)	Clay (< 4 µm) 1.0×10^{-10} m/s	Silt (4-63 µm) 2.0×10^{-4} m/s		Fine Sand (63-250 µm) 0.03 m/s	Medium Sand (250-500 µm) 0.05 m/s
Scenario 4 (3+2)	Clay (< 4 µm) 1.0×10^{-10} m/s	Fine/Medium Silt (4-20 µm) 1.0×10^{-4} m/s	Coarse Silt (20-63 µm) 3.0×10^{-4} m/s	Fine Sand (63-250 µm) 0.03 m/s	Medium Sand (250-500 µm) 0.05 m/s

Sediment classification – Sensitivity analysis results

Change in PCBs concentration compared to baseline scenario (2 cohesive +1 noncohesive)

	PCBs in Water Column	**Deposited Cohesive Mass**	**Particulate PCBs Conc.**	**PCBs in Sediment Bed**
Scenario **1** (1 cohesive + 1 non-cohesive)	-18%	4%	-31%	-2%
Scenario **2** (3 cohesive + 1 non-cohesive)	-6%	-1%	-6%	1%
Scenario **3** (2 cohesive + 2 non-cohesive)	-8%	0%	-8%	0%
Scenario **4** (3 cohesive + 2 non-cohesive)	-7%	-1%	-7%	1%

- Based on modeling result at Day 360

Sediment classification – Sensitivity analysis results

- Reducing the number of cohesive sediment from 2 to 1 will change the output significantly.
- Using more than three sediment classifications did not significantly improve the model performance.
  - ~7% change in the PCBs concentration in water column.
  - ~1% change in the PCBs concentration in surface sediment bed.
- More sediment classes means additional model uncertainties and require additional data support and longer computational time.

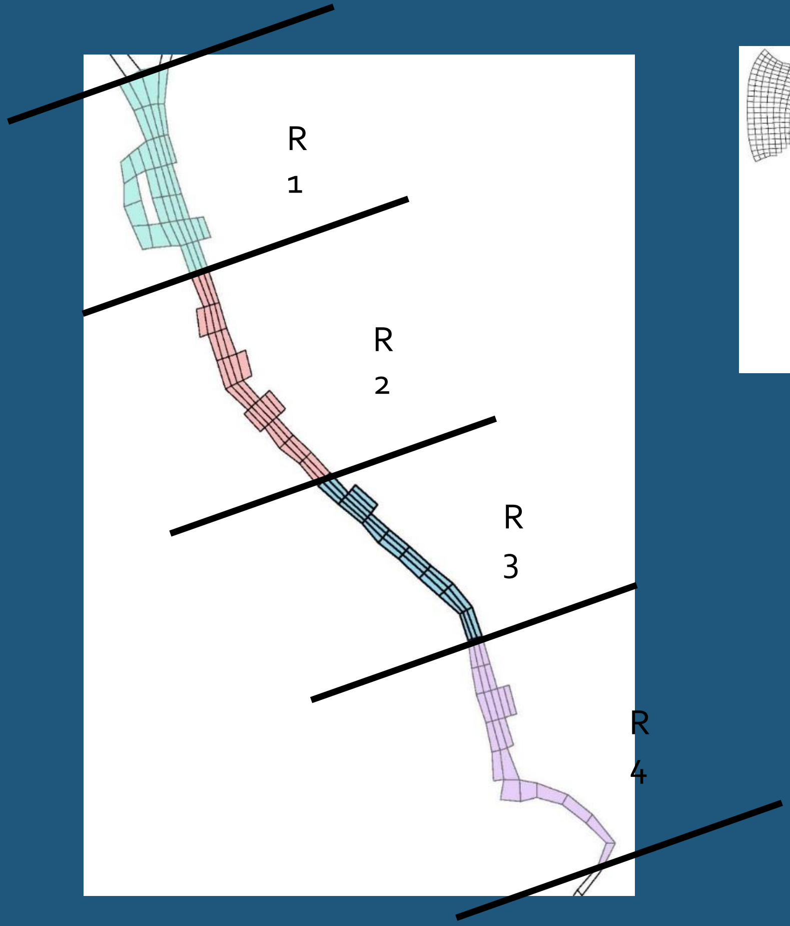
Three sediment classification is recommended for future PLA modeling unless more data for a specific class is available.

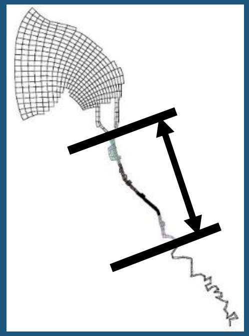
Sediment Classification

Q&A

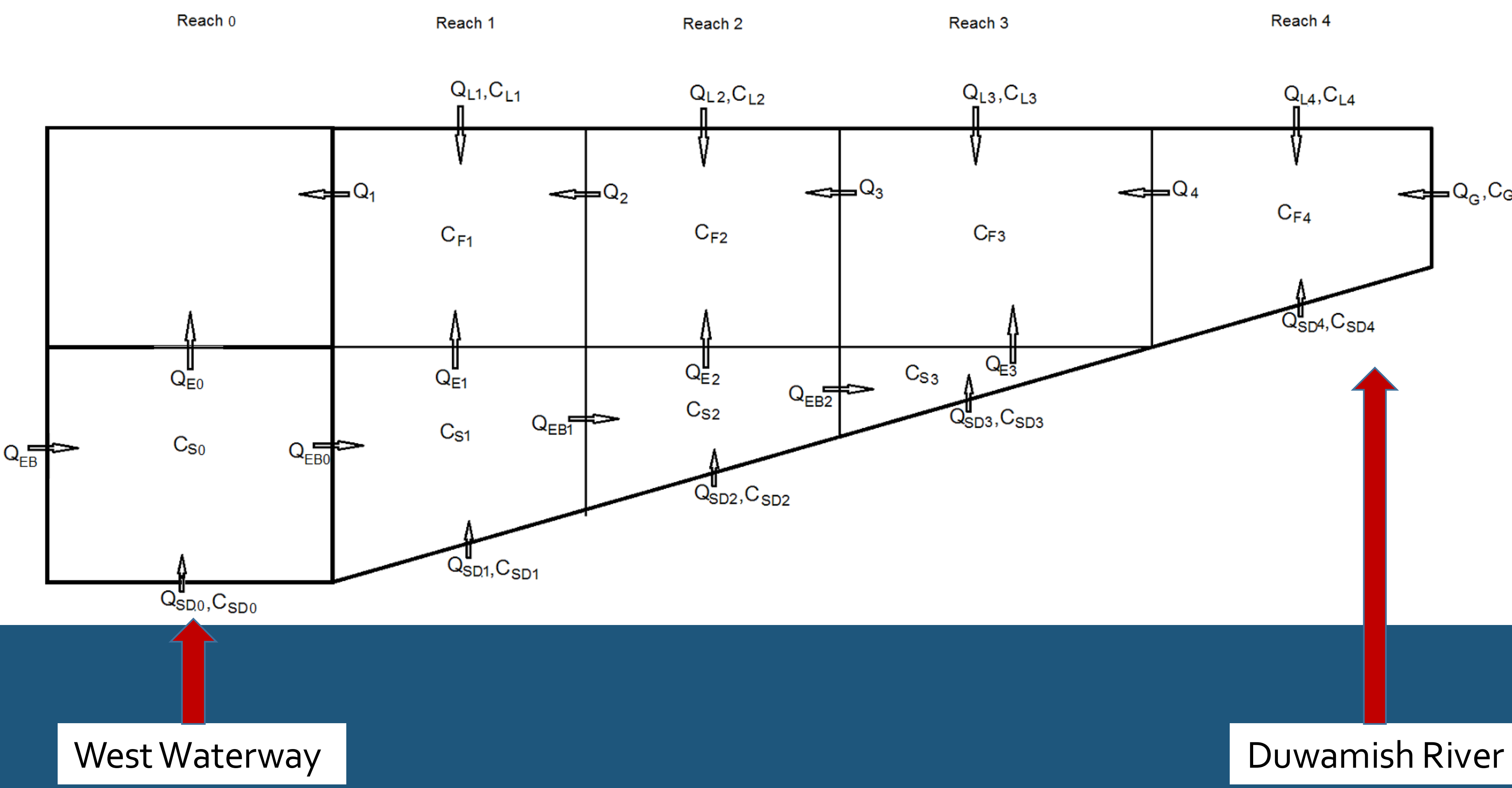
Pathway evaluation – Mass Balance Model Method

- Mass Balance Model
  - A simple four compartment model that describes the Lower Duwamish Estuary.
  - The four compartments were based on the four reaches used in the LDW Food Web Model.





Pathway evaluation – Mass Balance Model Method



Pathway evaluation – Mass Balance Model Method

- Box Concentrations
  - Concentrations for each box are characterized by the pathway concentration and the fraction of contributing pathway flow into the box.

Pathway evaluation – Mass Balance Model Method

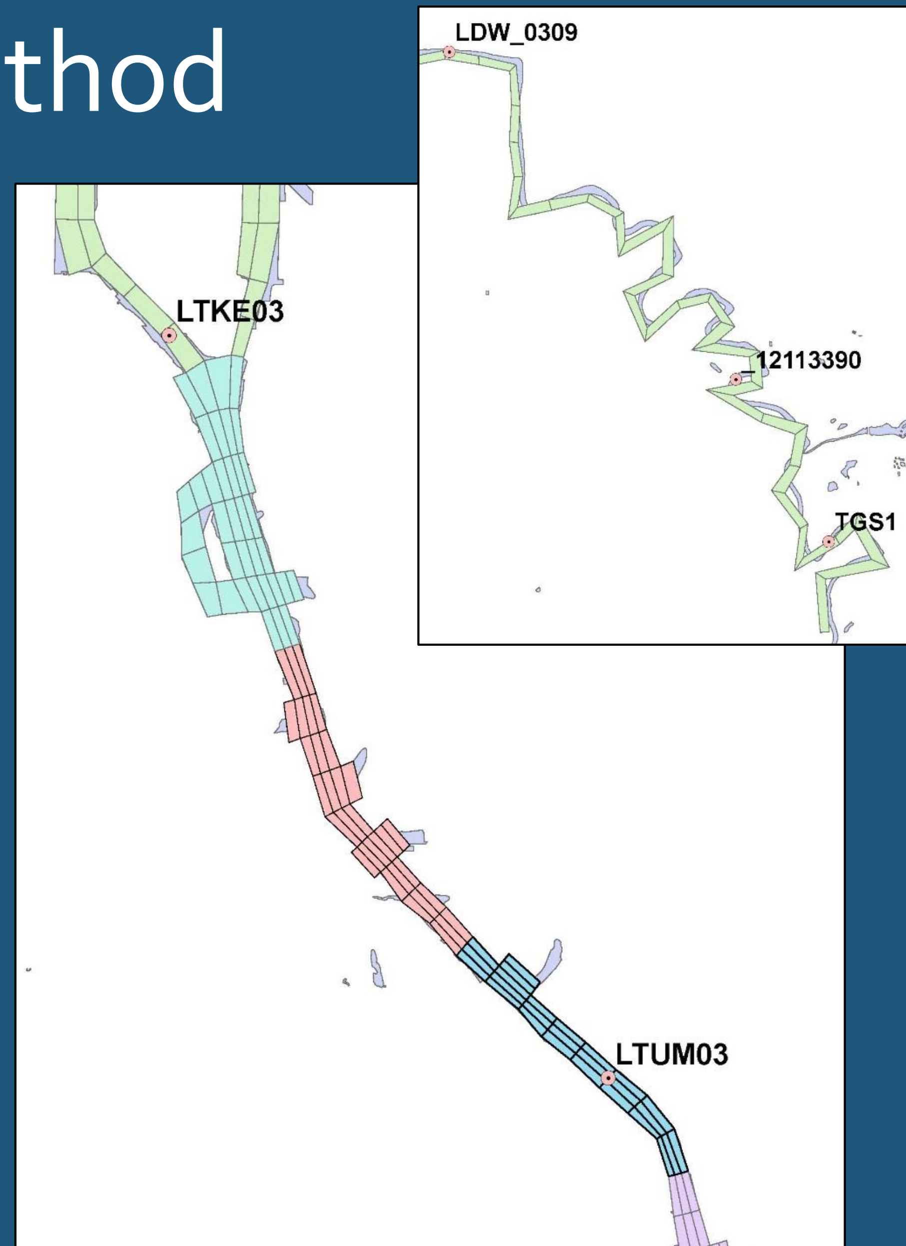
- Mass Balance Model
  - Quantified pathways
    - Q_L, Laterals (Municipal Stormwater, CSOs, and Streams)
    - Q_G, Green River
    - Q_E, Entrainment
    - Q_{EB}, Elliott Bay
  - Unquantified pathway
    - Q_{SD}, Sediment
  - Values for the quantified pathways were obtained from existing sources.

Pathway evaluation – Mass Balance Model Method

- Values for the quantified pathways were obtained from existing sources.
  - Nairn, Bruce, 2009. EFDC Calibration Process for Predicting PCB water concentrations in Lower Duwamish.
  - Narin, Bruce, 2007. CSO data provided to LDWG
  - King County TM 750: Sediment Deposition and Contamination Potential from Treated CSO Discharges
  - Seattle Public Utilities, 2007. Lower Duwamish Waterwater way: Lateral Load Analysis for Stormwater and City-Owned CSOs.
  - Ecology, 2015. S 96th Street and Hamm Creek Sediment Trap and Creek Sampling Data Report.
  - USGS, 1972. Determination of Mass Balance and Entrainment in the Stratified Duwamish River Estuary: Paper 1873-F.
  - USGS, 2018. Suspended-Sediment Transport from the Green-Duwamish River to the Lower Duwamish Waterway, Seattle, Washington, 2013–17: File Report 2018–1029
  - Ecology's Leido's database (extent of Duwamish PCB data used for this effort).

Pathway evaluation – Mass Balance Model Method

- Porewater flow velocity calibrated to PCB data at sites LTKE03 and LTUM03.
- Used flow weighted PCB concentration in surface layer and at Green River boundary (TGS1) and the corresponding average flow.



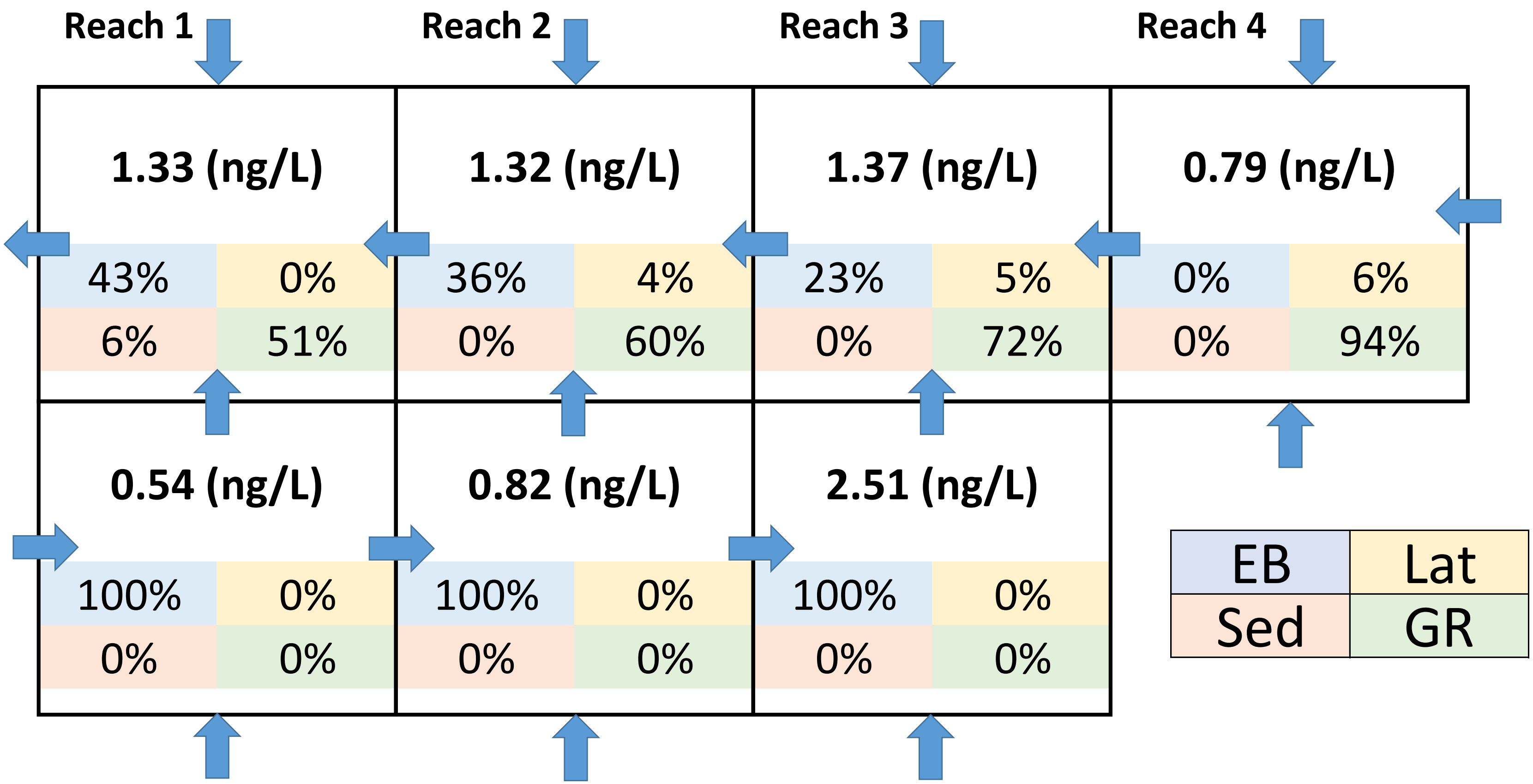
Pathway evaluation – Mass Balance Model Method

- Calibrated porewater flow was $5x10^{-8}$ m/s.

Station	Depth	PCB (pg/L)
TGS1	Whole	2880 - 38
LTUM03	Surface	1615 - 398
	Bottom	3117 - 132
LTKE03	Surface	2048 - 591
	Bottom	1814 - 215

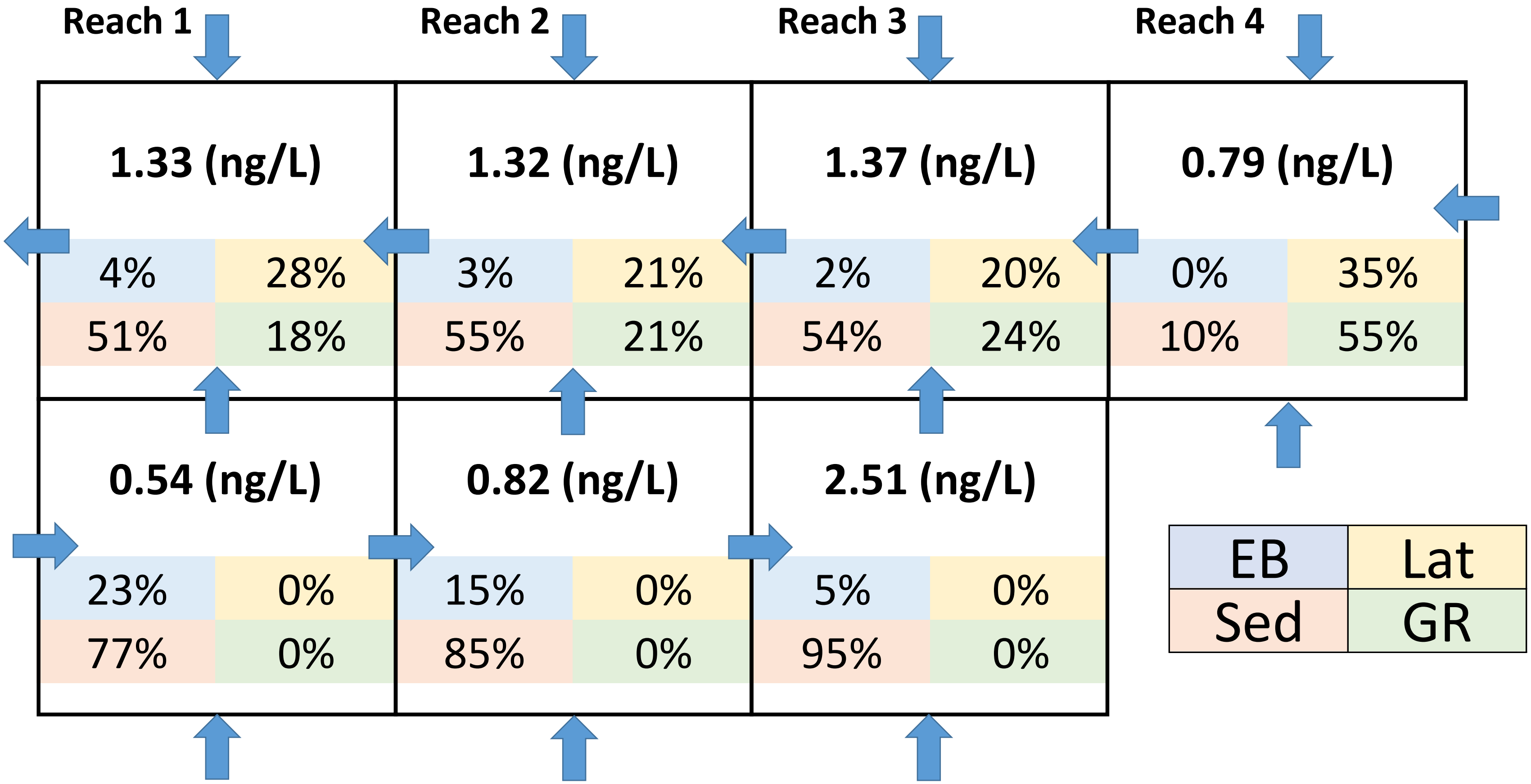
Pathway evaluation – Mass Balance Model Results

Existing Conditions and Percent Influence by Flow



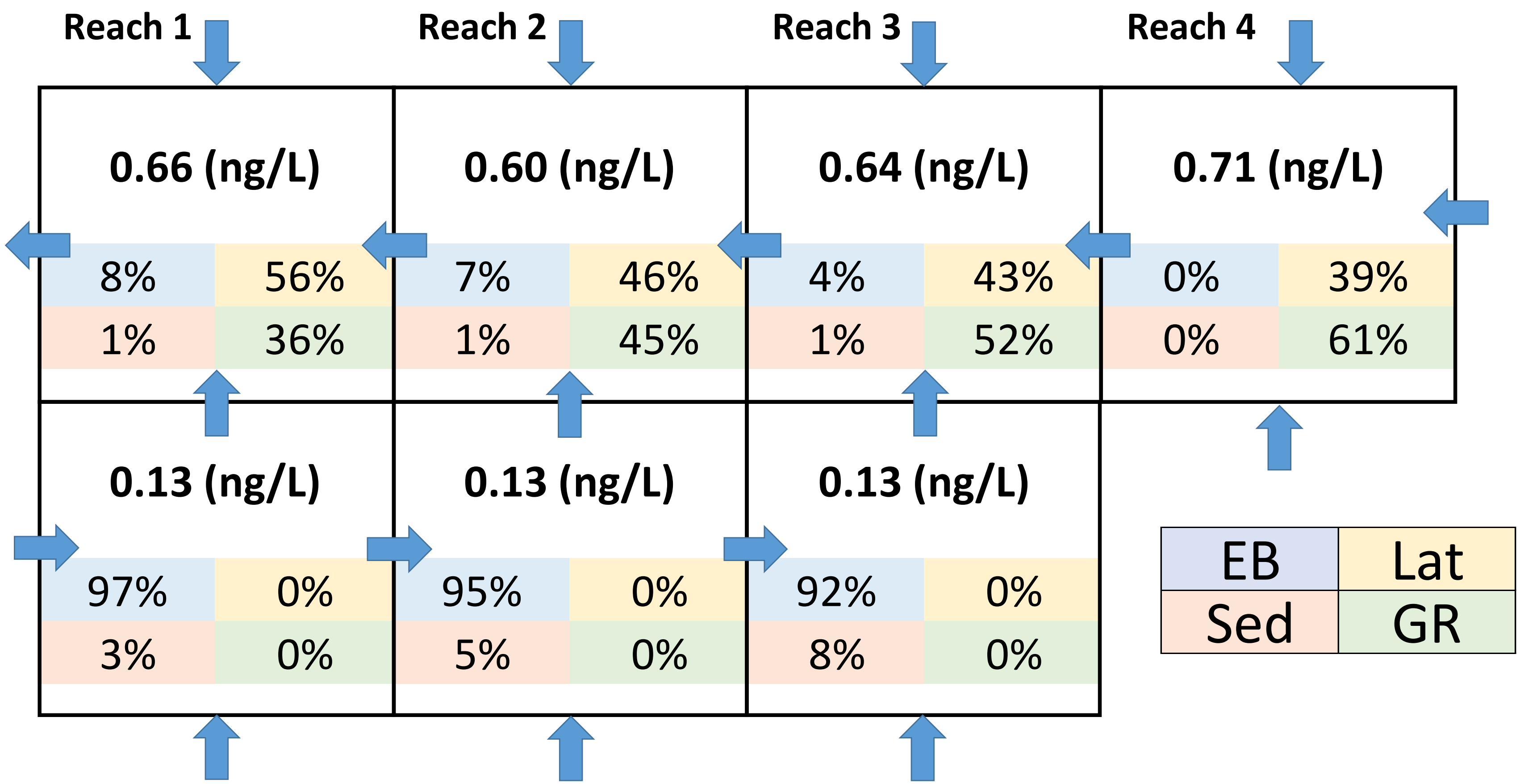
Pathway evaluation – Mass Balance Model Results

Existing Conditions and Percent Influence by Concentration



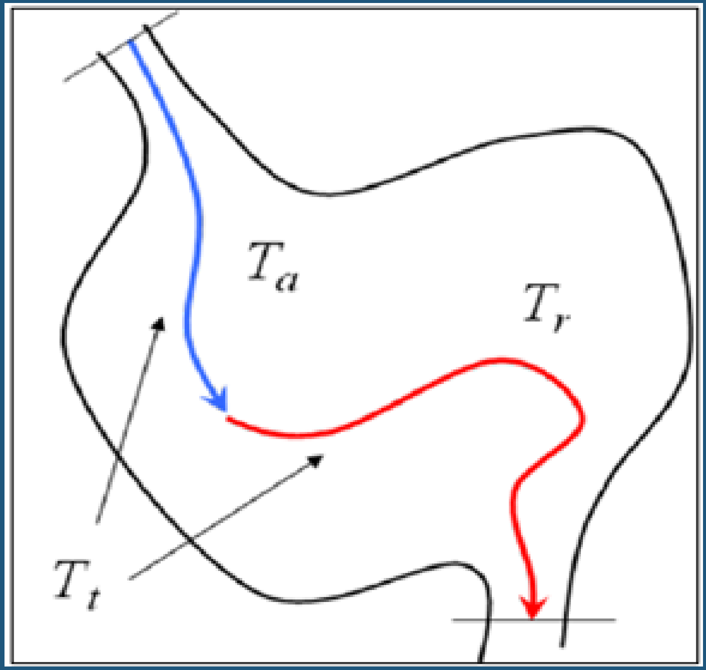
Pathway evaluation – Mass Balance Model Results

Sediments at 2 ug/Kg and Percent Influence by Concentration

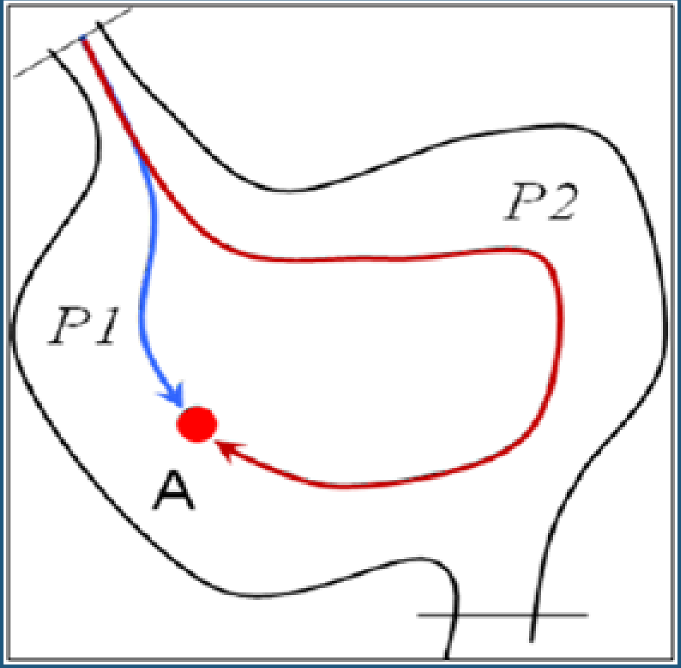


Pathway evaluation – Sensitivity analysis

Water Age



Water Age (T_a), Residence Time (T_r), and Transit Time (T_t) of a water parcel (Li, 2010)



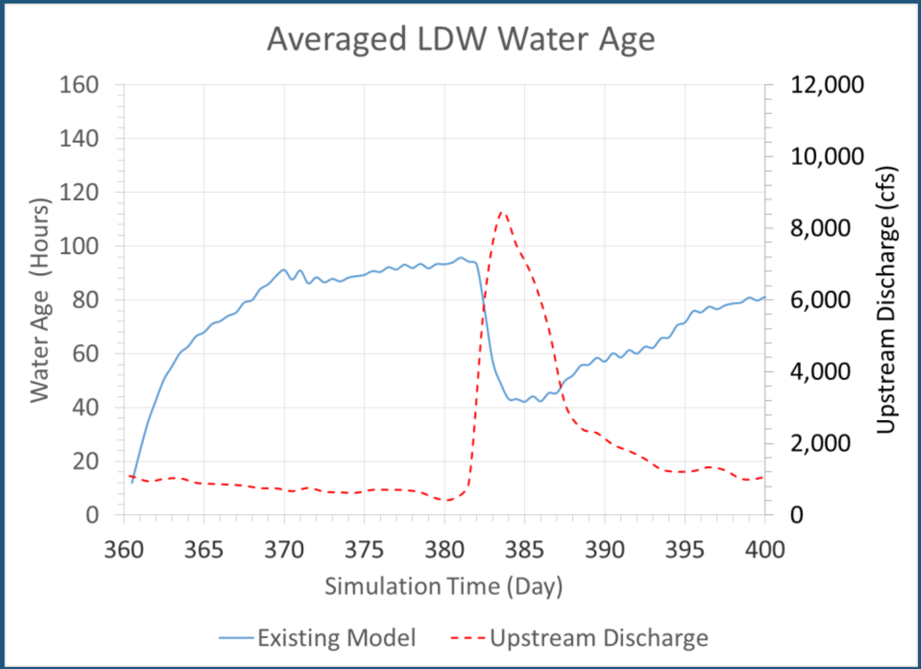
Two water parcels move from the entrance of the domain to Location A through Path P1 and Path P2, respectively

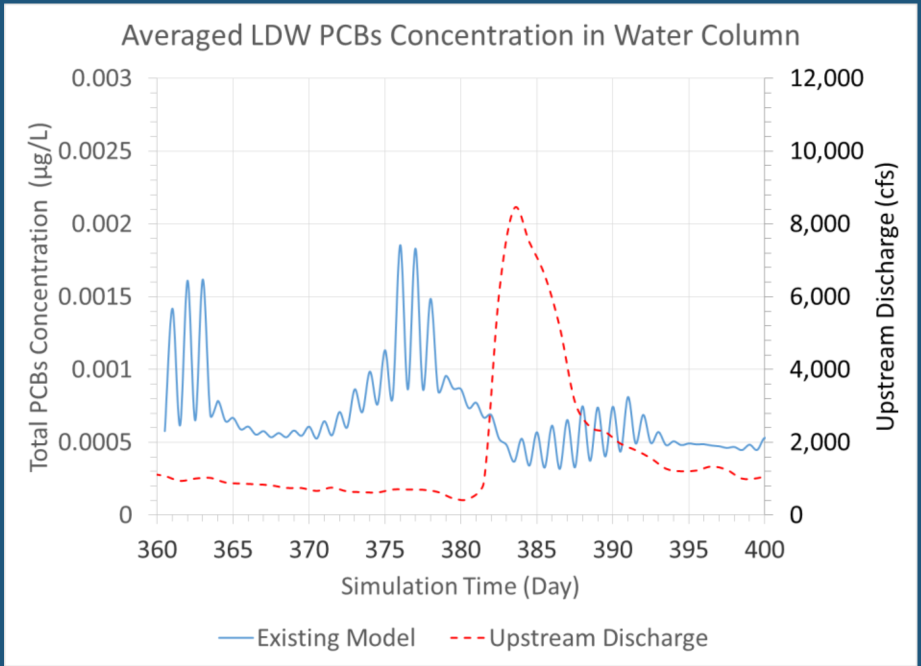
Li, H., 2010. Concepts and Applications of Water Transport Times Scales for Coastal Inlet Systems. US Army Corps of Engineers, ERDC/CHL CHETN-IV-77.

Pathway evaluation – Sensitivity analysis

Water Column

Existing model condition
(Day 360 → 400, with two animations in the next slide)



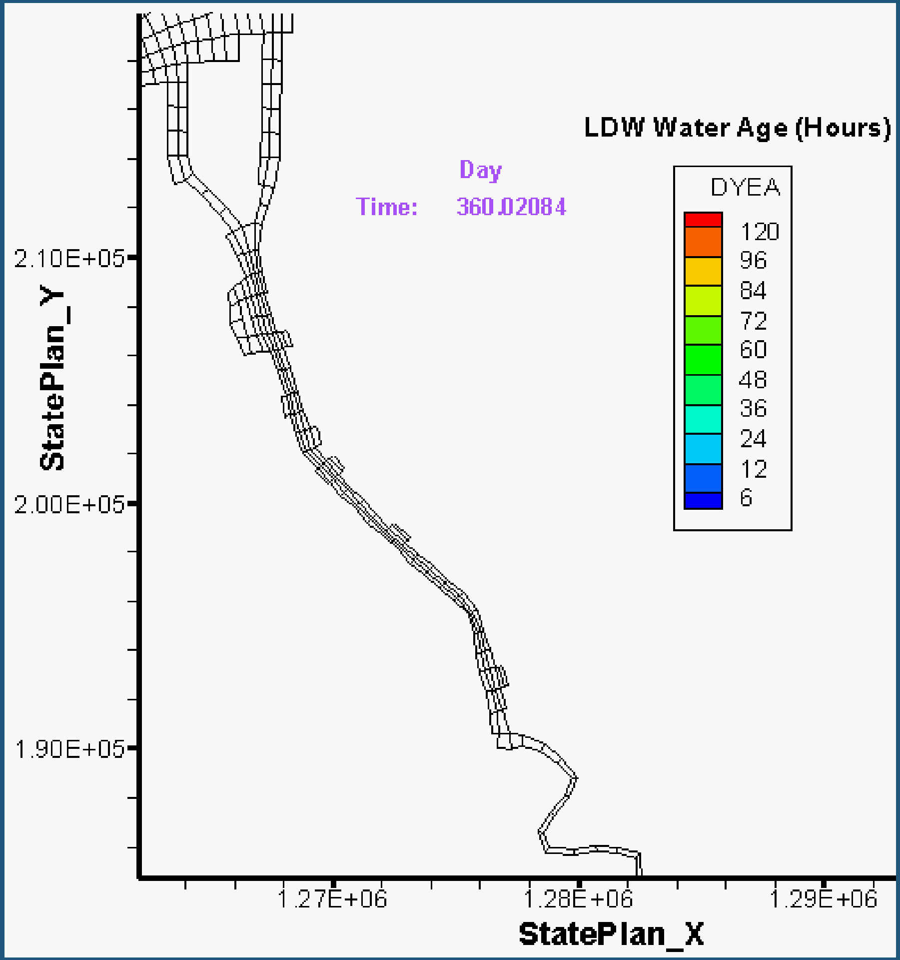


Water Age

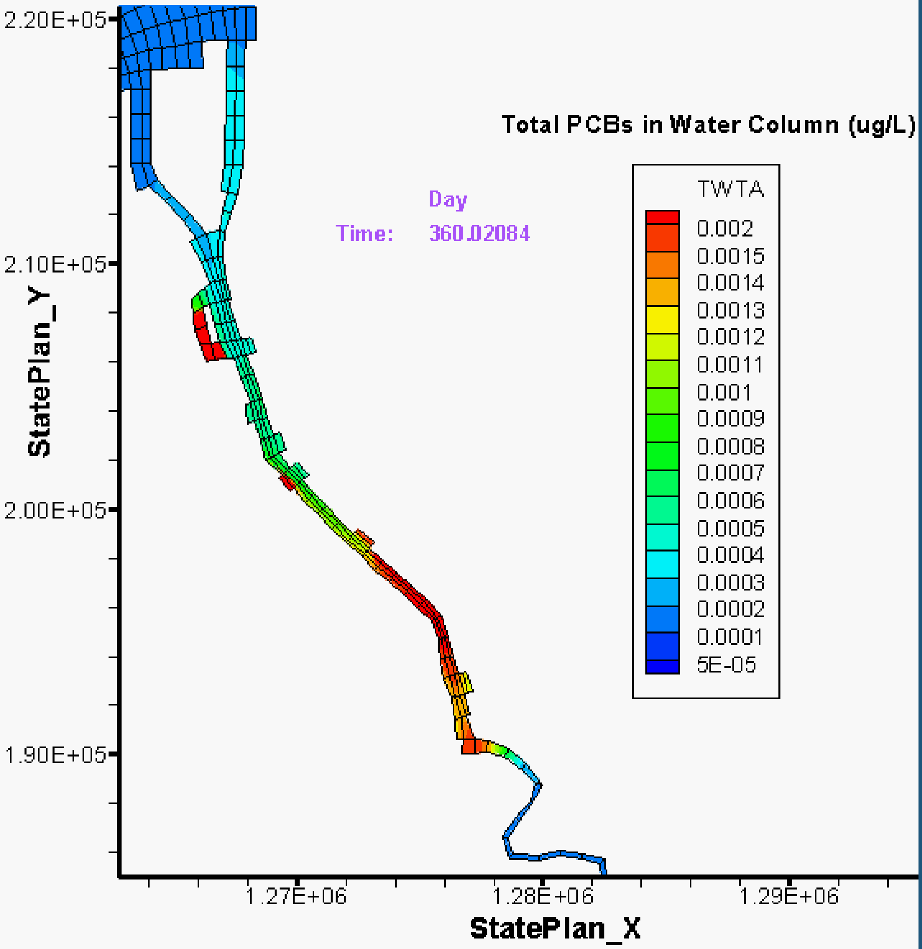
PCBs at water column

Pathway evaluation – Sensitivity analysis

Existing model **Water Column**



Water Age



PCBs Concentration

Pathway evaluation – Sensitivity analysis Method

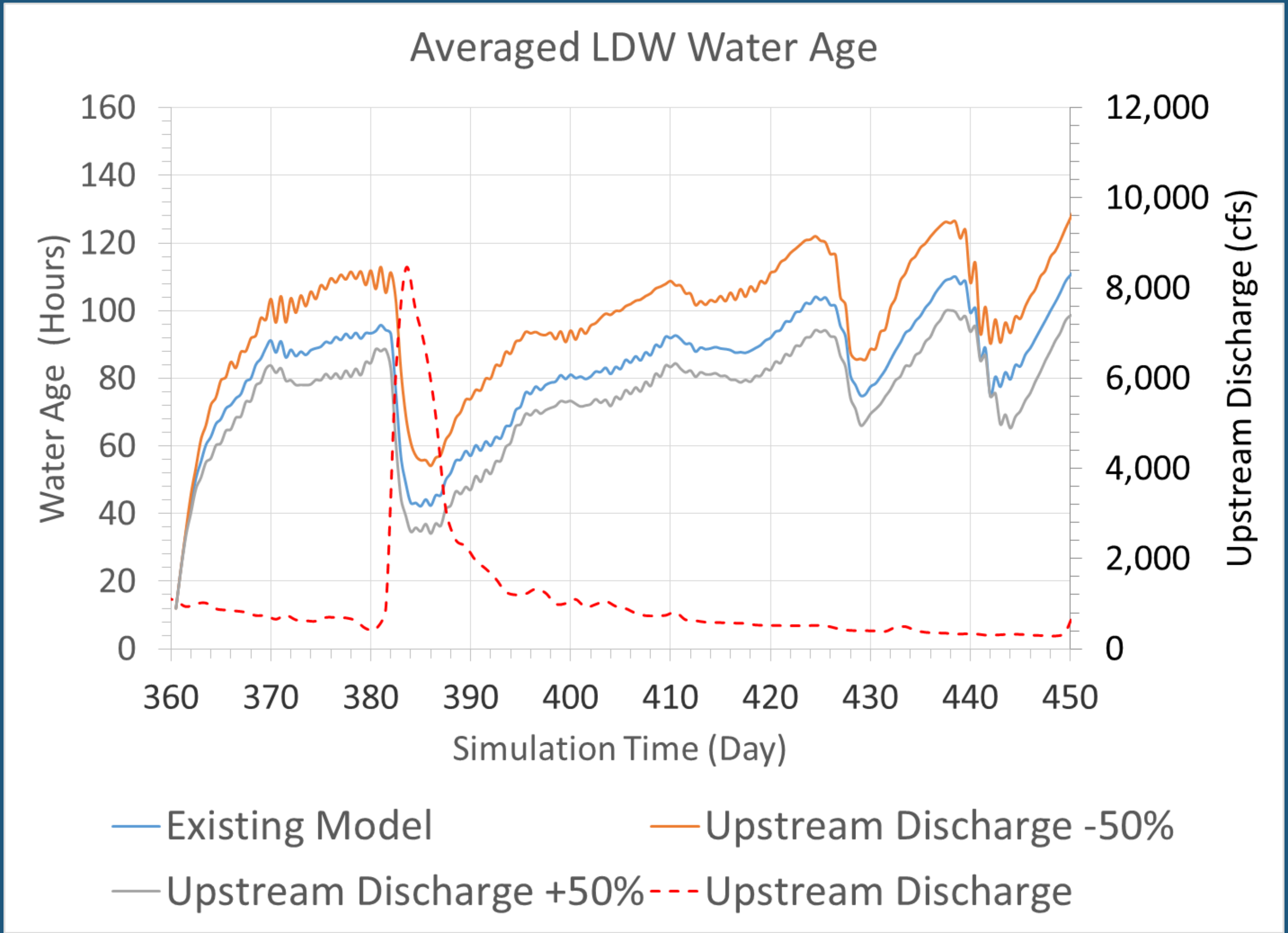
Upstream Scenarios:

- discharge (-/+50%)
- cohesive sediment concentration (-/+50%)
- PCBs concentration (-/+50%)
- steady-state flow scenarios
  - average, 90th and 10th percentile discharge

Open boundary Scenarios:

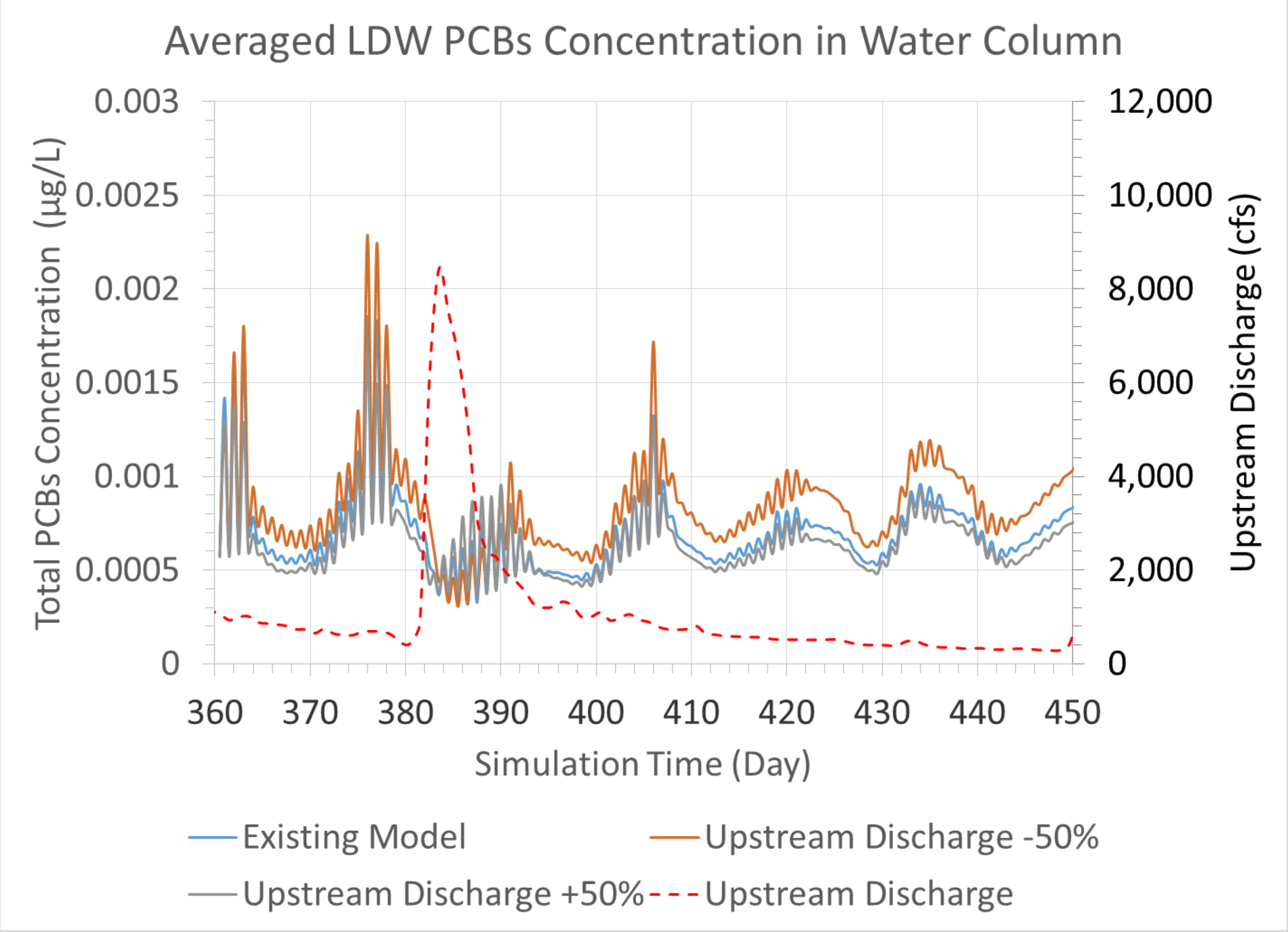
- steady-state flow scenarios
  - median, 90th and 10th percentile water surface elevation

Upstream Discharge –Water Age



Upstream Discharge – PCBs

Water Column



Steady-State Upstream Flow and Open Boundary elevation scenarios

Scenarios

Upstream Flow Scenarios	Upstream Discharge (cfs)	Open Boundary Elevation (ft MSL)
1. Average	1,340	0.00
2. Wet (90th percentile)	2,720	0.00
3. Dry (10th percentile)	280	0.00
Open Boundary Scenarios	**Upstream Discharge (cfs)**	**Open Boundary Elevation (ft MSL)**
4. Median Stage	1,340	0.72
5. High Stage (90th percentile)	1,340	4.12
6. Low Stage (10th percentile)	1,340	-5.37

PCBs

Upstream Flow Scenarios	PCBs Concentration in Water Column			PCBs Concentration in Surface Sediment Bed		
	Total (μg/L)	Dissolved (μg/L)	Particulate (μg/kg)	Total (μg/L)	Dissolved (μg/L)	Particulate (μg/kg)
1. Average	0.001698	0.001596	8.778431	598.99	0.063221	387.09
2. Wet	0.001406	0.001299	7.143484	598.51	0.063204	386.81
% Change	-17.20%	-18.61%	-18.62%	-0.08%	-0.03%	-0.07%
3. Dry	0.002736	0.002606	14.33208	602.50	0.064076	388.90
% Change	61.13%	63.28%	63.26%	0.58%	1.35%	0.47%
Open Boundary Scenarios	**PCBs Concentration in Water Column**			**PCBs Concentration in Surface Sediment Bed**		
	Total (μg/L)	Dissolved (μg/L)	Particulate (μg/kg)	Total (μg/L)	Dissolved (μg/L)	Particulate (μg/kg)
4. Median Stage	0.002467	0.002292	12.60506	599.78	0.063579	387.70
% Change	45.29%	43.61%	43.59%	0.13%	0.57%	0.16%
5. High Stage	0.002527	0.002356	12.95909	609.25	0.06384	393.90
% Change	48.82%	47.62%	47.62%	1.71%	0.98%	1.76%
6. Low Stage	0.010326	0.009651	53.05556	610.95	0.063545	395.04
% Change	508.13%	504.70%	504.39%	2.00%	0.51%	2.05%

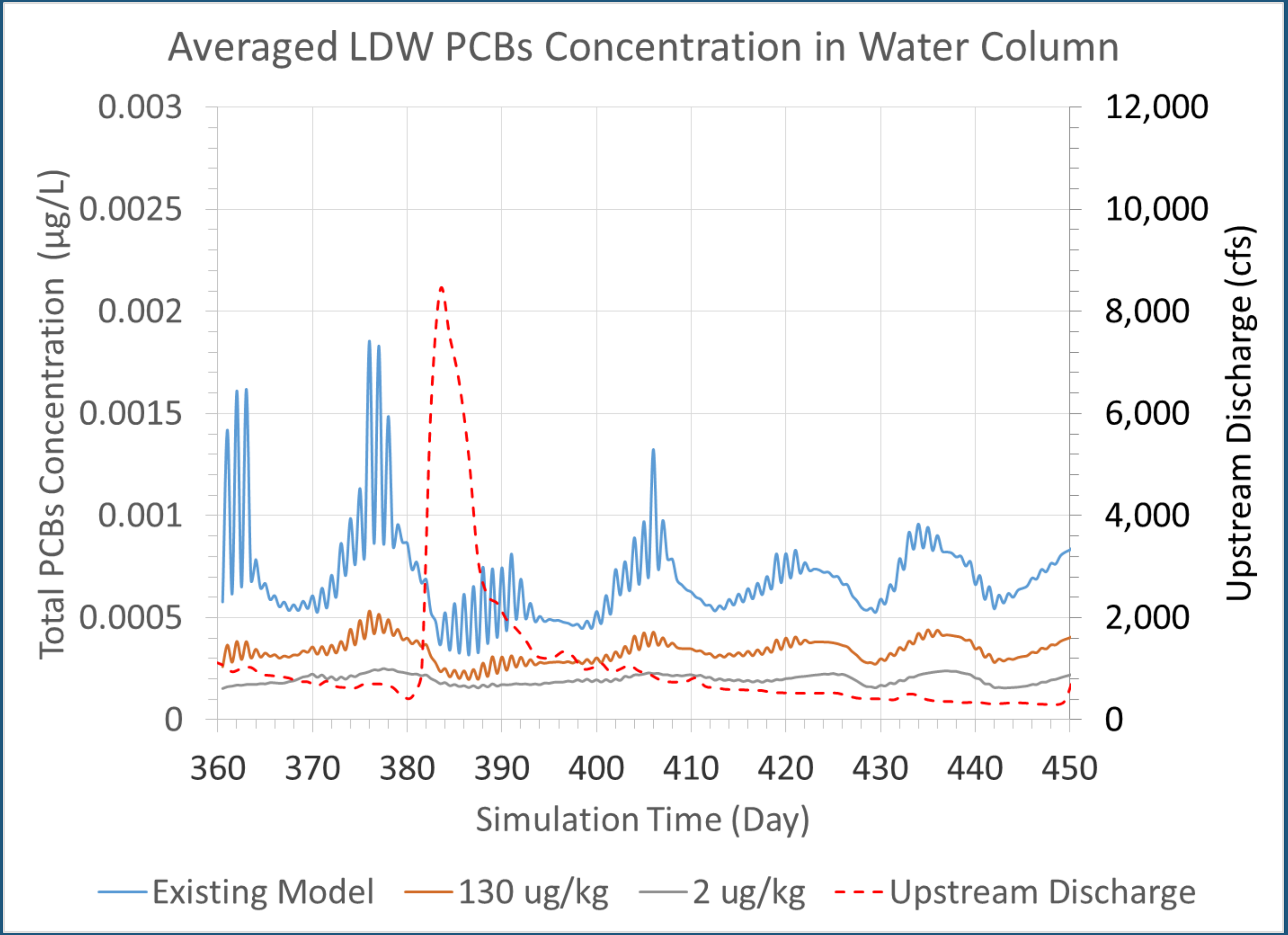
Pathway evaluation – Sensitivity analysis Method

PCBs in sediment bed and lateral PCBs source

		No lateral flow	PCBs Concentration (µg/L) in Lateral Source					
			0	0.01	0.014	0.03	0.1	0.2
PCBs concentration in Sediment bed	Current Model Values	Existing model	✓	✓	✓	✓	✓	✓
	130 µg/kg (RAL)	✓	✓	✓	✓	✓	✓	✓
	2 µg/kg (cleanup level)	✓	✓	✓	✓	✓	✓	✓

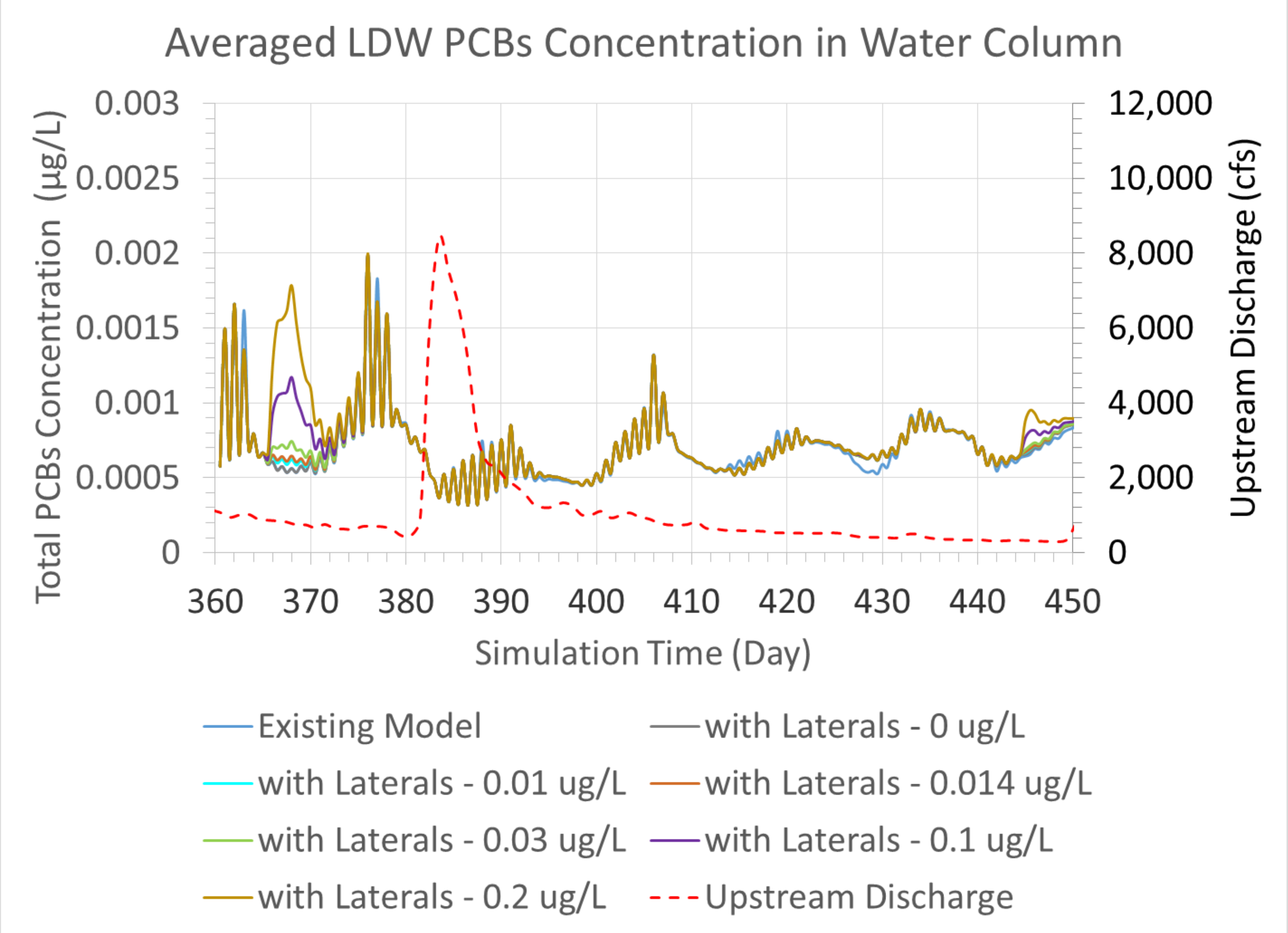
Sedient Bed PCBs Concentration Sensitivity – No Laterals

Water Column



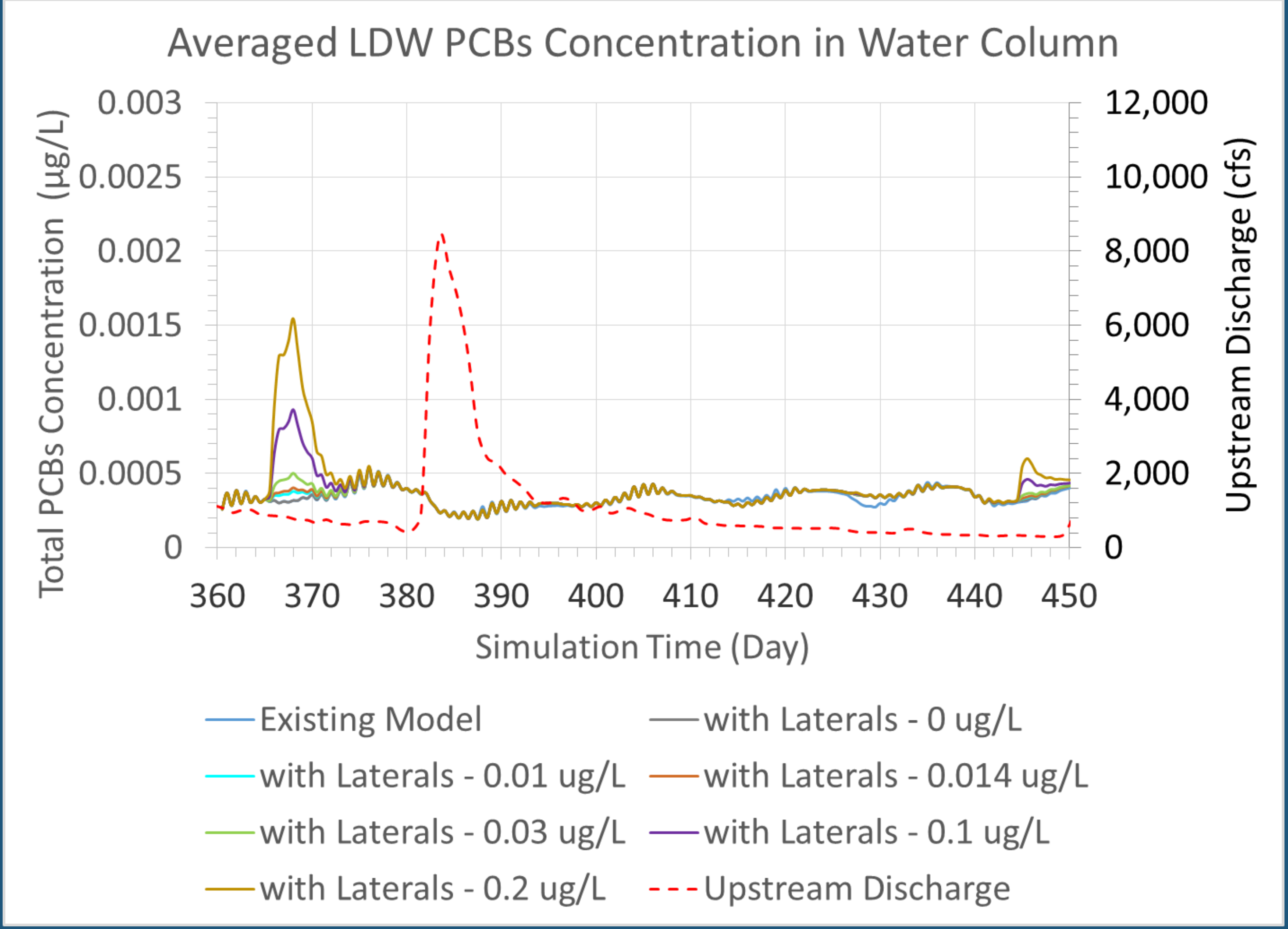
Lateral Sources (Existing Model Condition)

Water Column



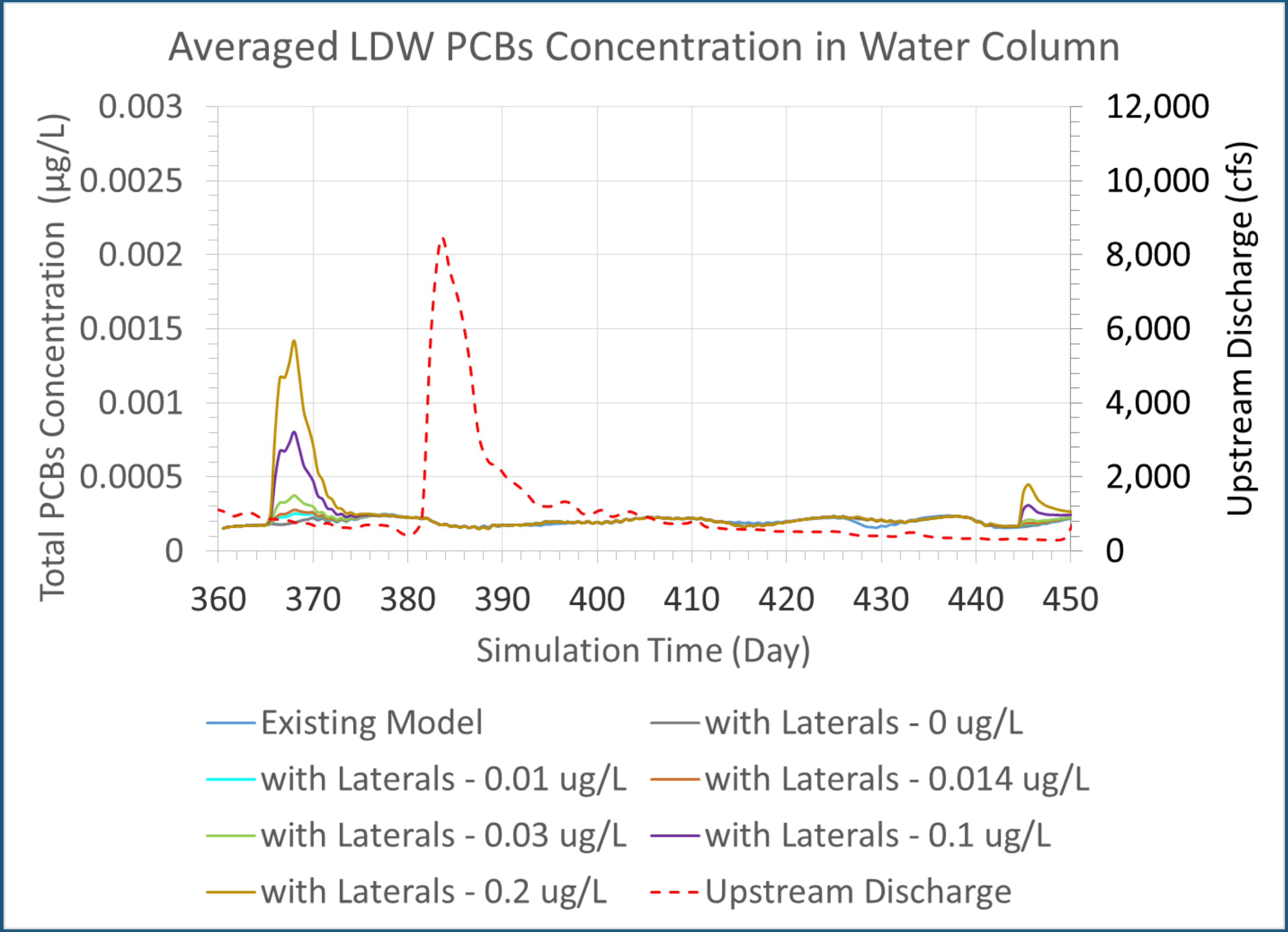
Lateral Sources (sediment PCBs conc. = 130 µg/kg dw)

Water Column



Lateral Sources (sediment PCBs conc. = 2 µg/kg dw)

Water Column



Pathway evaluation – Sensitivity analysis Results

- Upstream boundary scenarios
  - High Sensitive: upstream discharge (especially low flow condition)
  - Moderate Sensitive: upstream cohesive (water column and bed); upstream PCBs
- The downstream open boundary elevation
  - will influence water column PCBs concentration
  - Low water level period is of more environmental concern

Pathway evaluation – Sensitivity analysis Results

- Sediment Bed PCBs concentration scenarios
  - The most sensitive PCBs source to LDW water column: 60%↓ in the bed PCBs results in ~40%↓ in the water column PCBs at Day 400
  - Water column PCBs for higher bed PCBs is more sensitive to the flow condition
  - The peak PCBs results from joint actions of flow and bed-water exchanges
- Episodic Lateral Sources scenarios
  - with PCBs ≥ 0.03 µg/L, the lateral loadings are significant sources to the entire LDW water column for merely ~10 days in the 90-Day simulation
  - Sediment bed PCBs, from 130 → 2 µg/kg dw, has much less impact on the lateral triggered peak concentration (98%↓ → < 20%↓ in the water column)
  - Lateral source dominates gradually as sediment bed PCBs decreases

Pathway evaluation

Q&A

Modeling Parameters Sensitivity Analysis Method

1. Sediment Transport Parameters

Model Parameter
Settling Velocity (m/s), W_s
Critical Shear Stress for Deposition (Pa), τ_{cd}
Critical Shear Stress for Resuspension (Pa), τ_{ce}
Sediment Bed Reference Surface Erosion Rate (g/m^2-s), ER
Critical Shear Stress for Noncohesive (Pa), τ_c

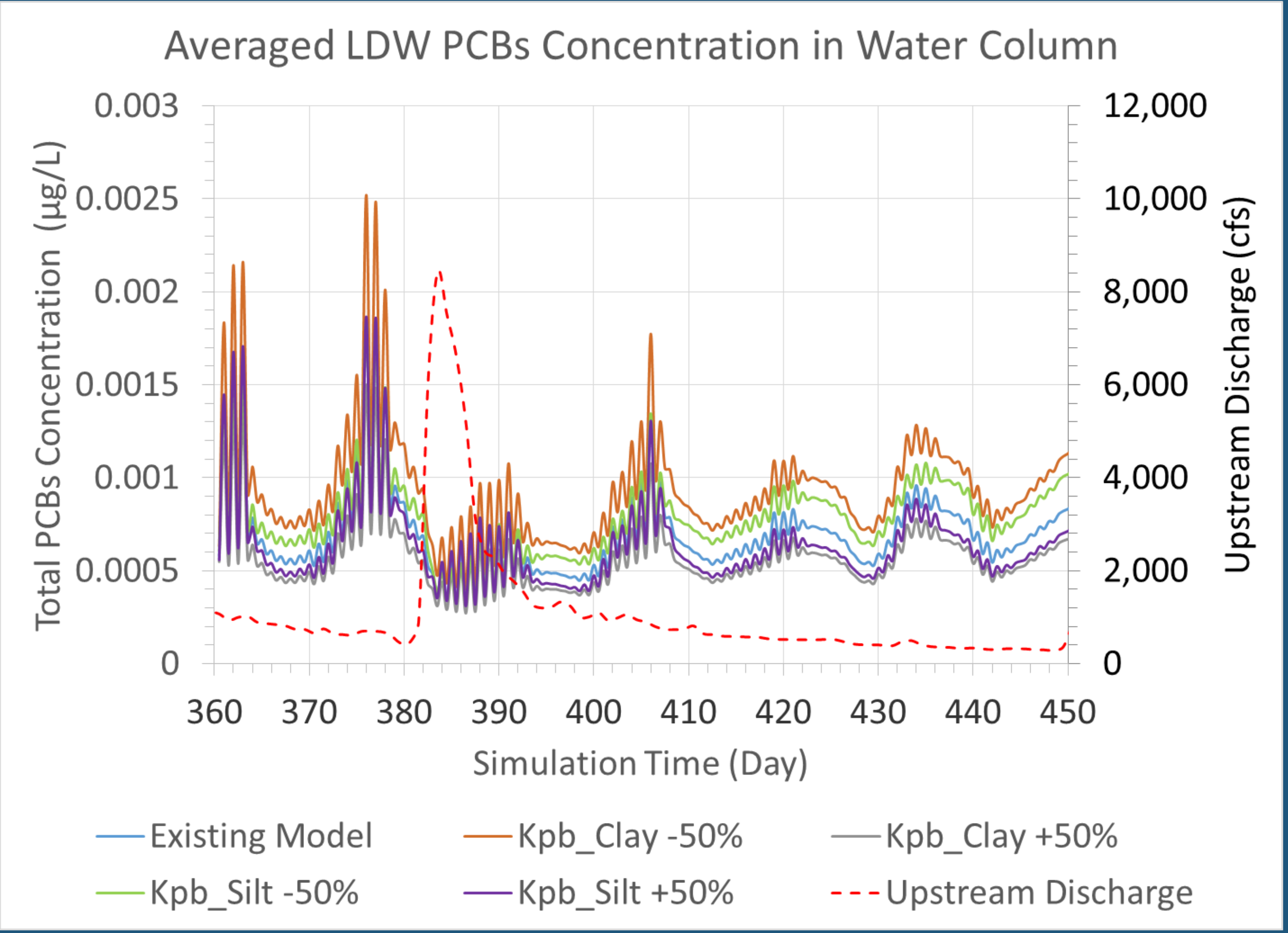
2. Toxic Parameters

Model Parameter
Partitioning Coefficient at Water Column (L/mg), K_{pw}
Partitioning Coefficient at Sediment Bed (L/mg), K_{pb}
Sediment-Water Interface Flux Rate (m/s), D_{bw}
Particle Mixing Diffusion Coefficient in Sediment Bed (m^2/s), D_{pb}
Particle Mixing Depth (m), D_{pm}

* All the above parameters are important to the model performance
* One parameter at a time

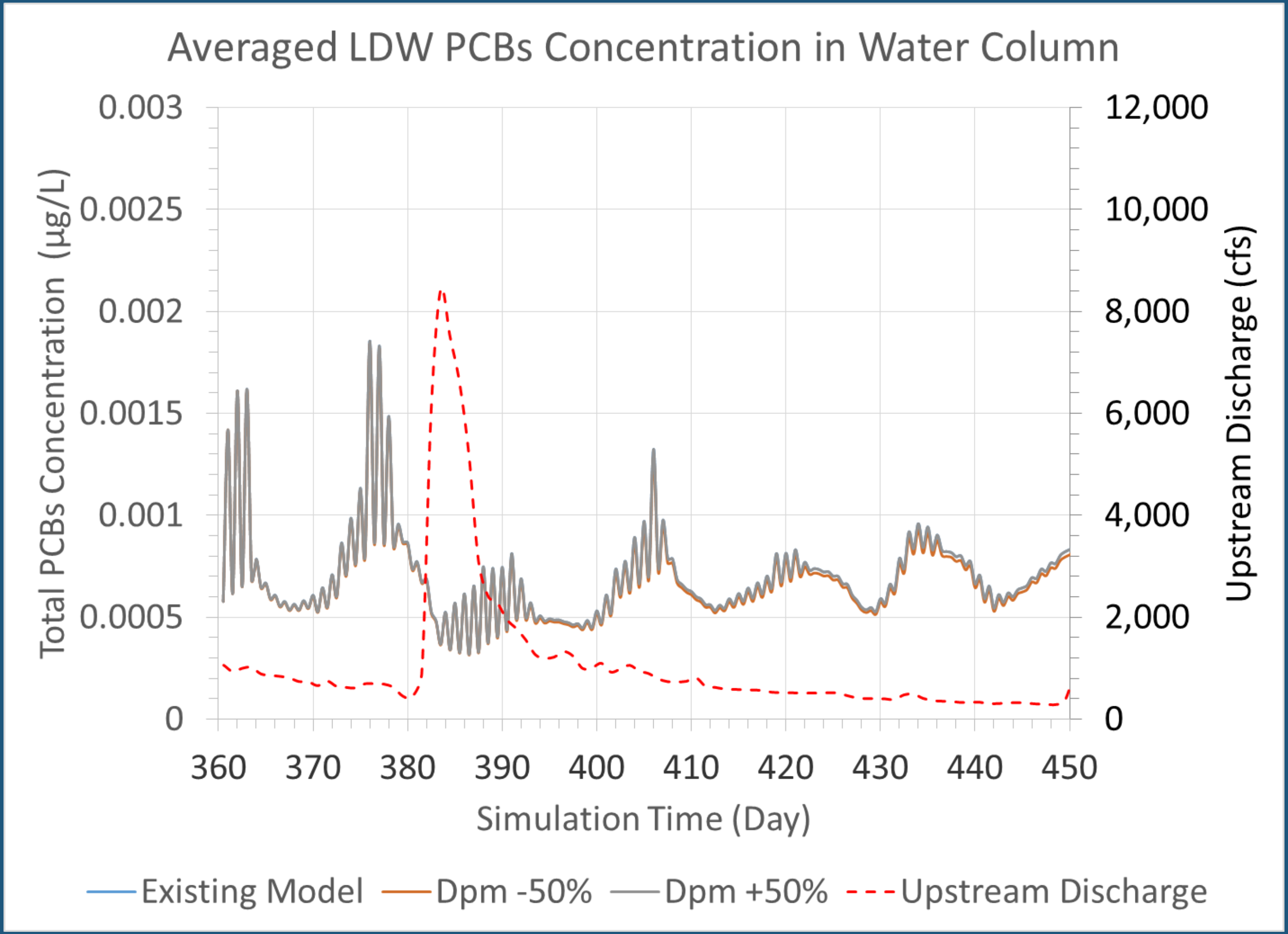
Partitioning Coefficient at Bed

Water Column



Particle Mixing Depth

Water Column



Modeling Parameters Sensitivity Analysis Results

Most sensitive

- Partitioning coefficient at sediment bed (K_{pb}) – affects both sediment bed and water column
- Sediment-Water column interface flux (D_{bw})
- Critical shear stress for resuspension (τ_{ce})

- Settling velocity (W_s)
- Erosion rate (ER)
- Partitioning coefficient at water column (K_{pw})

- Critical shear stress for deposition (τ_{cd})
- Particle mixing depth (D_{pm})

- Particle mixing diffusion coefficient within sediment bed layers (D_{pb})
- Critical shear stress for noncohesive (τ_c) – PCBs is not attached to noncohesive in this model

Least sensitive

Modeling Parameters

Q&A