LimnoTech

Water Environment | Scientists Engineers

Mass Balance Assessment of 2014 Synoptic Survey Results: January 5 Draft

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Spokane River Regional Toxics Task Force

2014 Workshop

January 13, 2014

Outline

- Synoptic survey
- Mass balance assessment
  - Approach and application
- Uncertainty analysis
  - Approach and application

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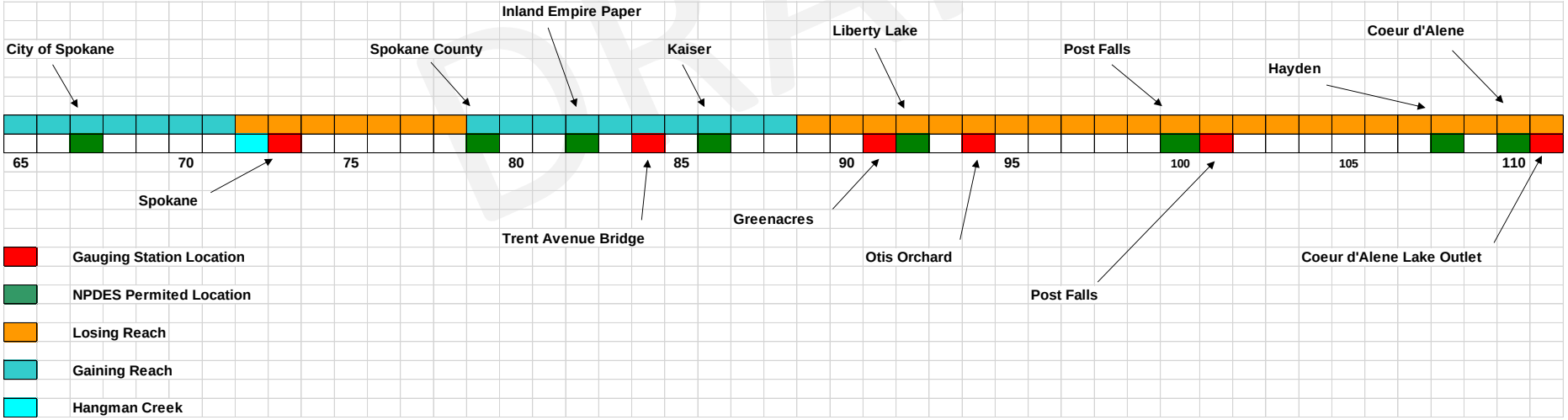
Intent of Synoptic Survey

- Support mass balance assessment
  - Measure river concentration at flow gaging locations
  - Measure all known dry weather sources
- Identify unknown sources between each station

  Unknown source = Downstream load – Upstream load – Known Load



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Synoptic Survey

- August 12-24, 2014
- Seven Spokane River stations, plus Hangman Creek
  - Each sampled seven times
- Seven point source discharges
  - Sampled three times

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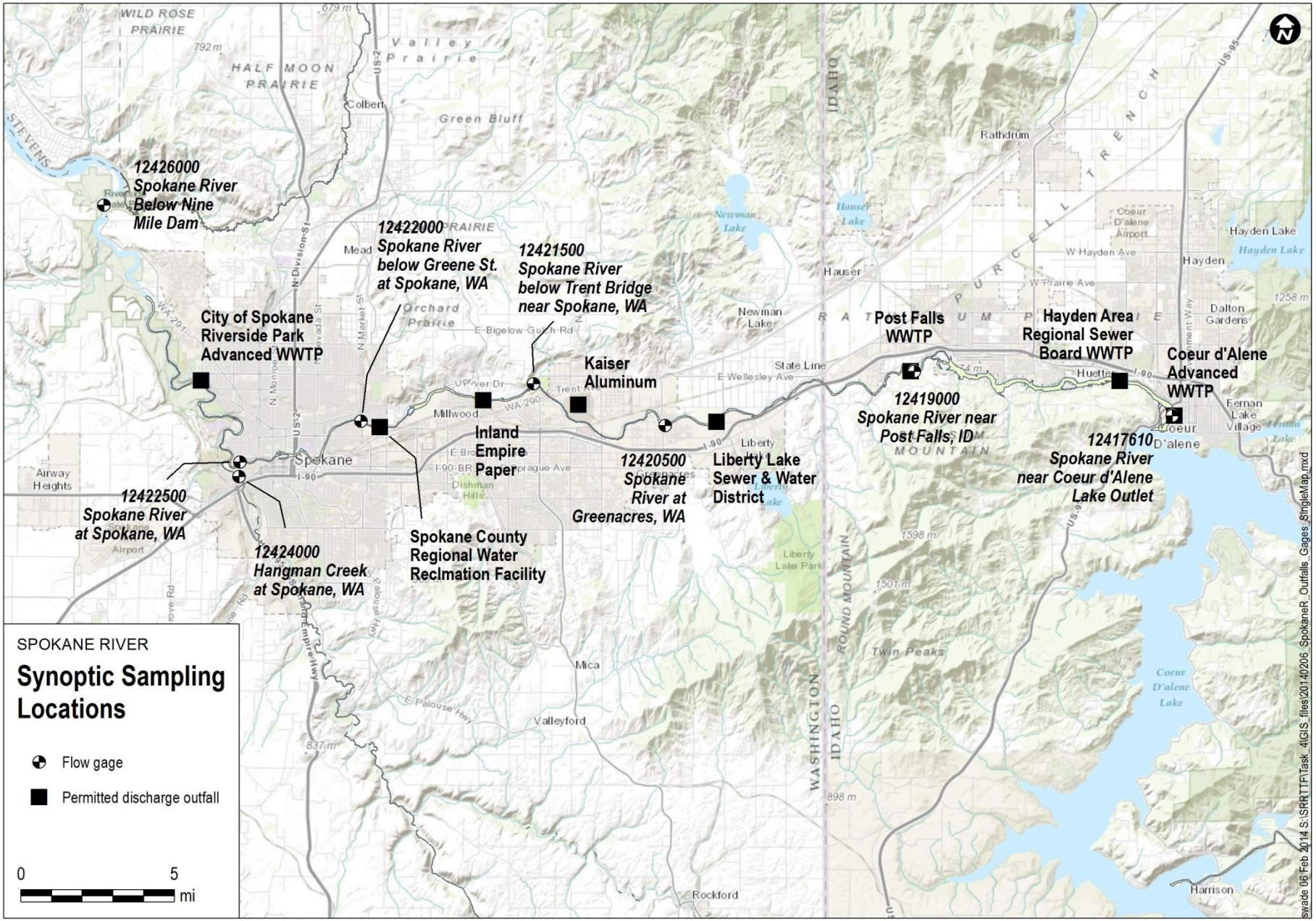
SPOKANE RIVER
Synoptic Sampling Locations
Flow gage
Permitted discharge outfall
0
5
mi
12426000 Spokane River Below Nine Mile Dam
12422000 Spokane River below Greene St. at Spokane, WA
12421500 Spokane River below Trent Bridge near Spokane, WA
City of Spokane Riverside Park Advanced WWTP
Kaiser Aluminum
Post Falls WWTP
Hayden Area Regional Sewer Board WWTP
Coeur d'Alene Advanced WWTP
12419000 Spokane River near Post Falls, ID
12417610 Spokane River near Coeur d'Alene Lake Outlet
Inland Empire Paper
12420500 Spokane River at Greenacres, WA
Liberty Lake Sewer & Water District
12422500 Spokane River at Spokane, WA
12424000 Hangman Creek at Spokane, WA
Spokane County Regional Water Reclmation Facility
swade 06 Feb 2014 S:\SRRTTF\Task_4\GIS_files\20140206_SpokaneR_Outfalls_Gages_SingleMap.mxd

Statistical Results and Mass Balance

- Mass balance
  - Approach
  - Results
- Uncertainty analysis
  - Approach
  - Results
- Conclusions

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Mass Balance Approach

- Measure flow (Q) and total PCB concentration (C) at paired upstream and downstream stations

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Mass Balance Approach

- alculate unmonitored load between stations
  - Unmonitored load =

    Downstream load – upstream load

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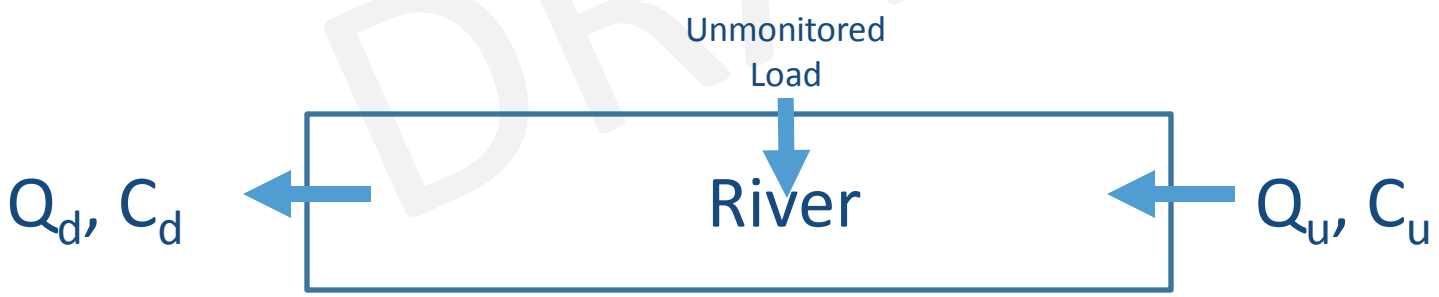
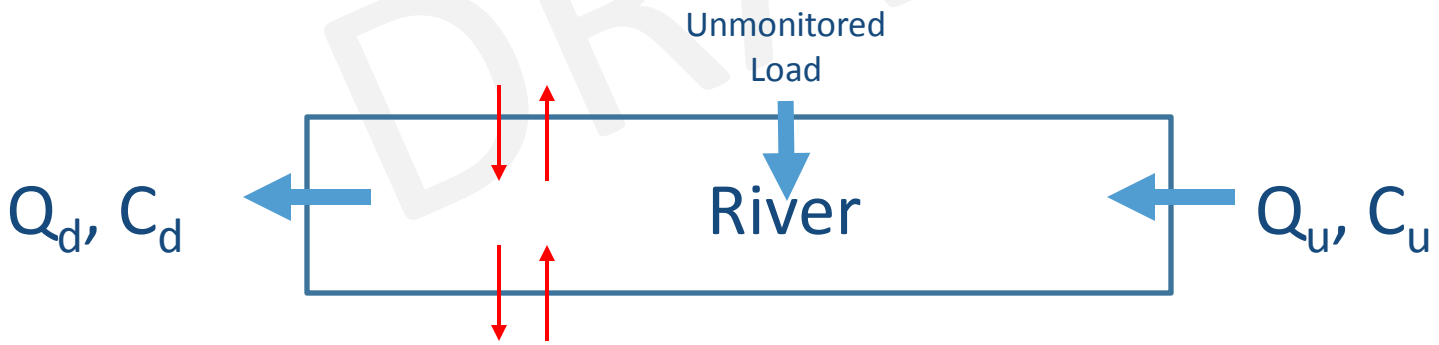


Mass Balance Approach

- But what about instream reaction processes?
  - Adsorption/settling, resuspension, volatilization
- Results from CE-QUAL-W2 model combined with typical PCB kinetic coefficients
  - Each loss component determined to be small



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Mass Balance Equations

- Load (W) = Concentration times flow
  - Downstream load = $Q_d * C_d$
  - Upstream load = $Q_u * C_u$
  - Unmonitored load ($W_?$) = $Q_d * C_d - Q_u * C_u$

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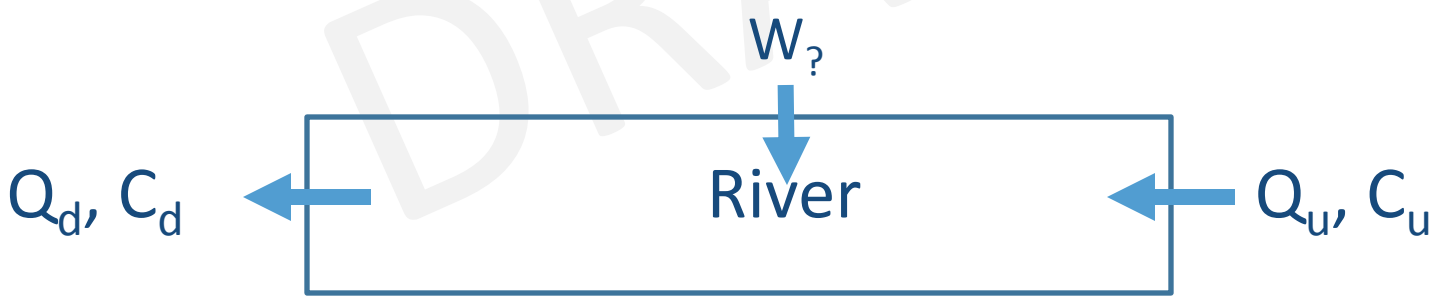


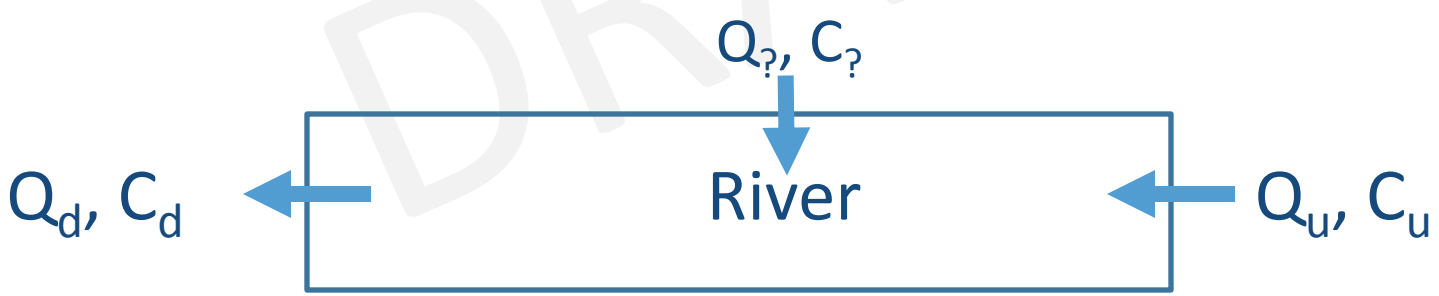
Unmonitored Load Components

- Calculate unmonitored flow and concentration

$$Q_? = Q_d - Q_u$$

$$Q_u * C_u + Q_? * C_? = Q_d * C_d$$

$$C_? = [Q_d C - Q_u * C_u]/Q_?$$



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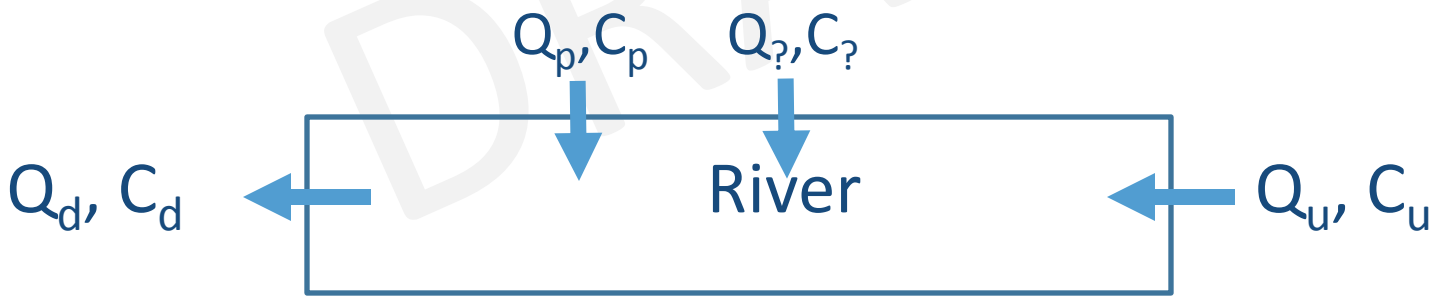
Expand to Consider Point Sources

- Equation can be expanded to consider point sources (and tributaries)
  - Unmonitored load = Downstream load – upstream load – point source load



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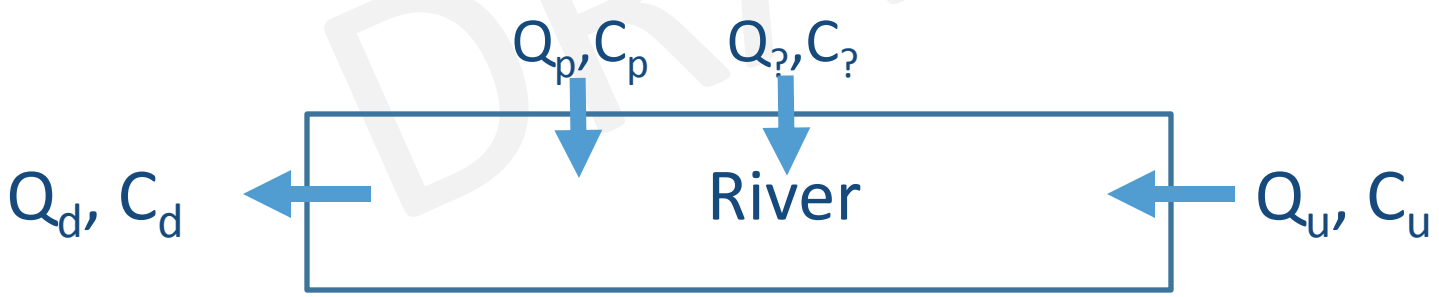
Equations with Point Sources

- Calculate unmonitored flow and concentration

$$Q_? = Q_d - Q_u - Q_p$$

$$Q_u * C_u + Q_? * C_? + Q_p * C_p = Q_d * C_d$$

$$C_? = [Q_d C_d - Q_u * C_u - Q_p * C_p]/Q_?$$



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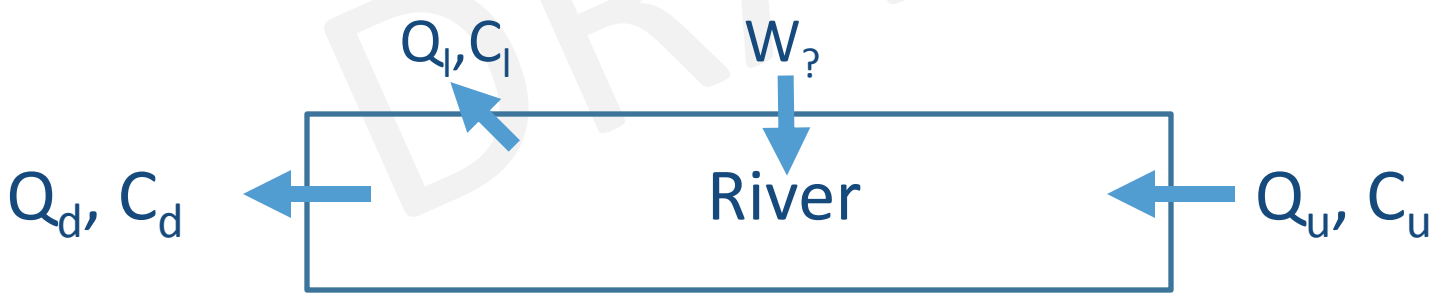
Losing Reaches

- Can estimate incremental loads in losing reaches

$$Q_u * C_u + W_? - Q_l * C_l = Q_d * C_d$$

$$W_? = [Q_d C_d - Q_u * C_u + Q_l * C_l]$$



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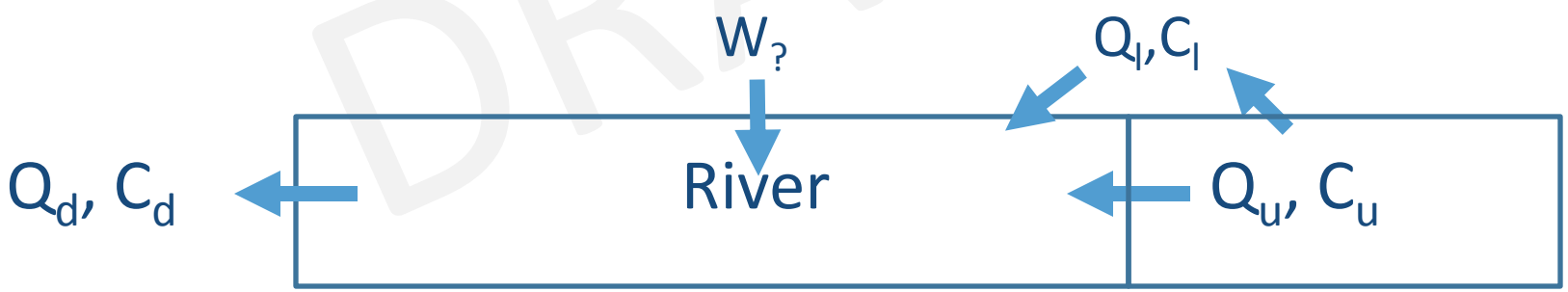
Re-Gaining Reaches

- Can separate out unknown load from return of load from upstream losing reaches

$$Q_u * C_u + W_? + Q_l * C_l = Q_d * C_d$$

$$W_? = [Q_d C_d - Q_u * C_u - Q_l * C_l]$$



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Mass Balance Application

- Compile data
  - Review for potential outliers
- Assessment using only known loads
- Assessment of unknown loads

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Mass Balance Data Sources

- River flows
  - USGS gages
  - Gravity
  - Nine Mile Dam
- Discharge flows
  - Provided by dischargers
- PCB concentrations
  - Synoptic survey

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River Flows

Flow (cfs)							
	8/12	8/14	8/16	8/18	8/20	8/22	8/24
Post Falls	637	648	632	809	916	815	733
Barker Rd.	-	271	347	484	572	-	323
Trent Ave.	927	923	919	989	1060	1050	948
Spokane	1030	1050	1080	1140	1250	1140	1140
Hangman Ck.	10	11	15	17	19	-	-
Nine Mile	1040	1040	1060	1190	1250	1080	1120

Discharge Flows

Discharge (cfs)			
	8/13	8/19	8/24
Coeur d'Alene	5.3	5.4	5.4
HARSB	0	0	0
Post Falls	3.8	3.9	4.0
Liberty Lake	1.1	1.1	1.2
Kaiser Aluminum	13.3	14.4	13. 8
Inland Empire Paper	11.3	10.9	11.0
Spokane County	11.8	11.6	11.6
City of Spokane	43.6	45.7	43.0

Discharge PCB Concentrations

Total PCB (pg/l)				
	8/13	**8/19**	**8/21**	**Composite**
City of Spokane	771/955	23404	1177	878
Spokane County	490	330/290	333	274
Inland Empire Paper	3627	2957	2636/2629	2766
Kaiser Aluminum	3276	4012	4625	2514
Liberty Lake	200	193	260	211
Post Falls	221	219	200	176
Coeur d'Alene	1227	534	531	668

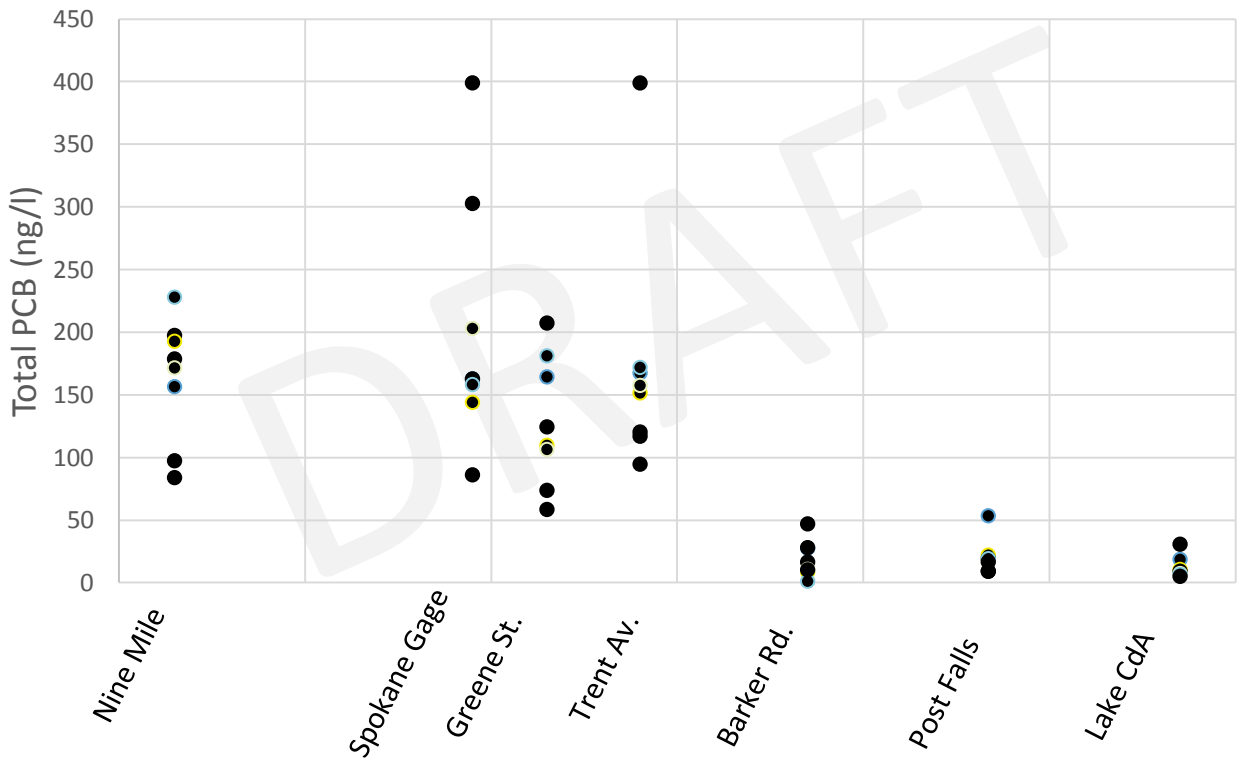
River PCB Concentrations

Total PCB (pg/l)								
	8/12	**8/14**	**8/16**	**8/18**	**8/20**	**8/22**	**8/24**	**Composite**
Nine Mile	156.5/197.4	192.8	178.6	171.5	227.9	97.4	83.9	135.8
Hangman Ck.	64.1	66.2	67.1/73.2	52.5	2443. 9	264. 6	35.4	95.4
Spokane Gage	162.8	162.7/144.0	302.8	203.0	158.2	399.0	86.1	137.2
Greene St.	164.3*	207.3	109.7	124.4/106.4	181.1	73.8	58.5	123.5
Trent Ave.	167.5	116.9	151.5	399.0	157.5/171.9	94.6	120.3	110.9
Barker Rd.	27.6	16.5	8.6	47.0	10.7	1.2/28.0	10.3	29.1
Post Falls	53.4	9.1	22.1	19.3	16.7	19.2	16.7/9.2	227.3
Coeur d'Alene	18.6	30.7	10.6	9.1	7.4	6.6	5.1**	11.4

* Collected 8/13
** Collected 8/23

River Concentrations

← Flow



Assessment Using only Known Loads

- Compute segment by segment mass balance
  - Use average flows and concentrations
  - Divide groundwater into two components
    - Returning lost river flow enters at the same concentration as when it left
    - “New” groundwater concentrations set at zero

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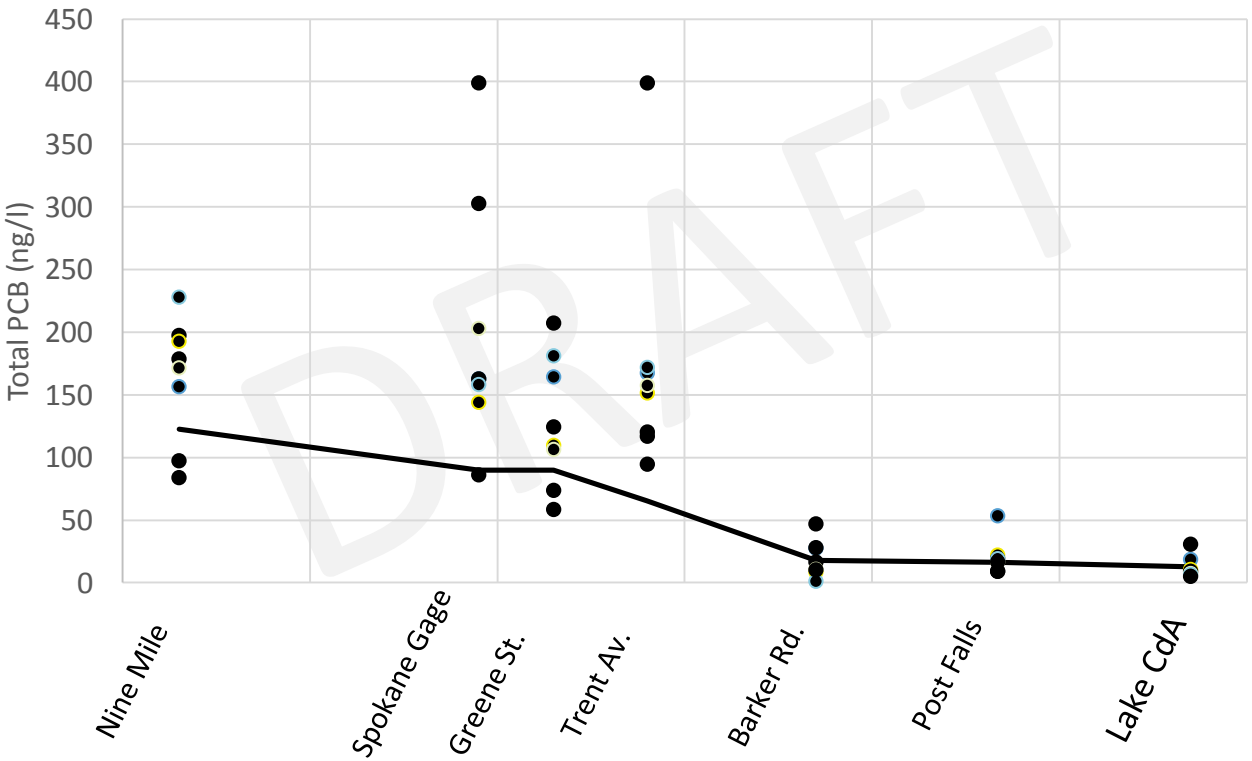
Mass Balance Using only Known Loads

← Flow

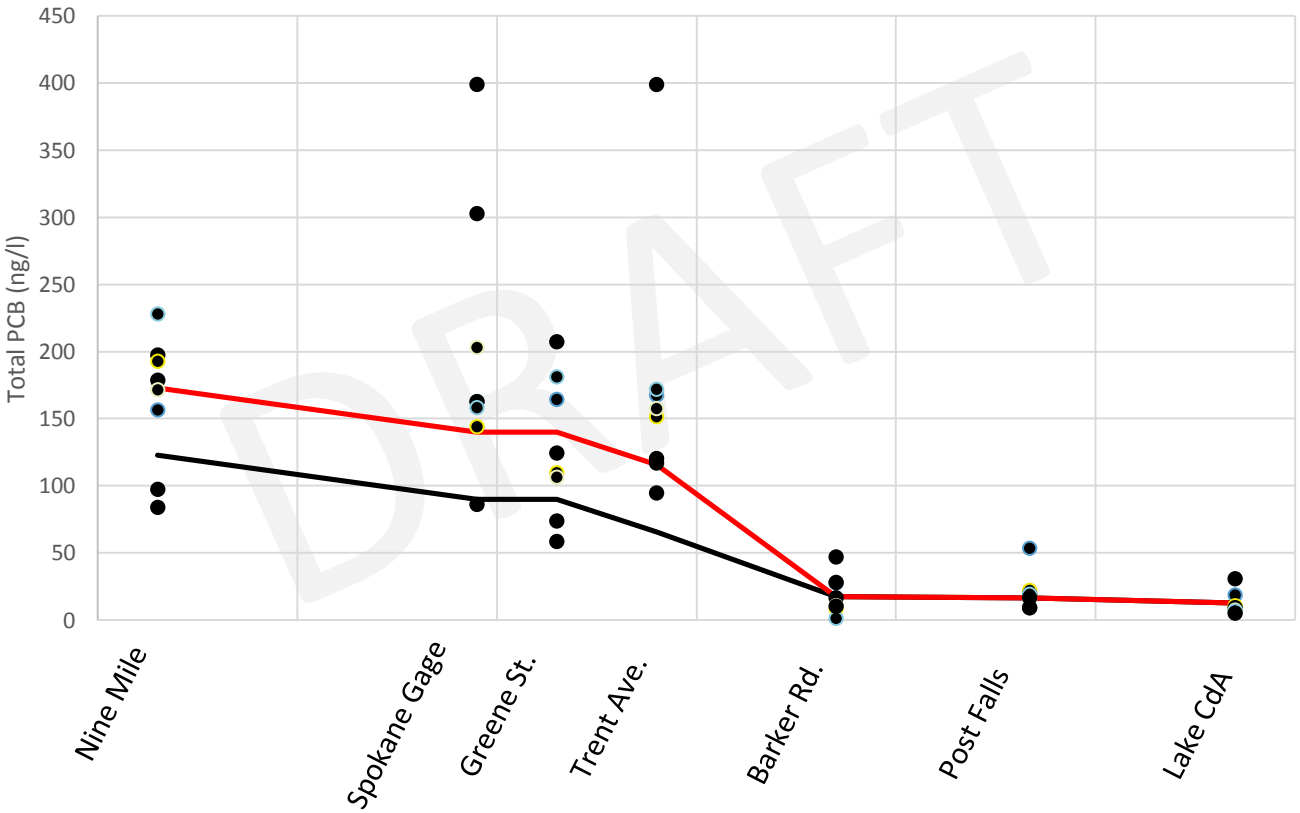


Best Estimate of Unknown Loads

River Section	Unknown Load (mg/day)
Coeur d'Alene to Post Falls	-0.5
Post Falls to Barker Road	1.3
Barker Road to Trent Avenue	166
Trent Avenue to Spokane Gage	-6.0
Spokane Gage to Nine Mile	-57

Mass Balance with Estimated Unknown Sources

← Flow



Consideration of Uncertainty

- Need to recognize uncertainty/variability in flows and concentrations
  - Uncertainty: Concentrations close to blanks
  - Variability: Concentrations and flows vary from day-to-day
- Re-state model inputs as probability distributions rather than single values
  - $W_i = Q_d * C_d - Q_u * C_u$

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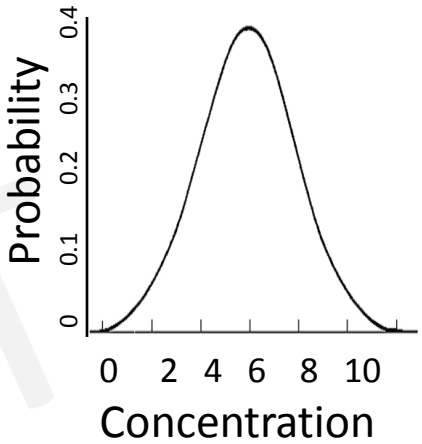
Probability Distributions

- Describe expected probability of occurrence of entire range of values



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Probability Distributions

- Higher uncertainty corresponds to broader curves

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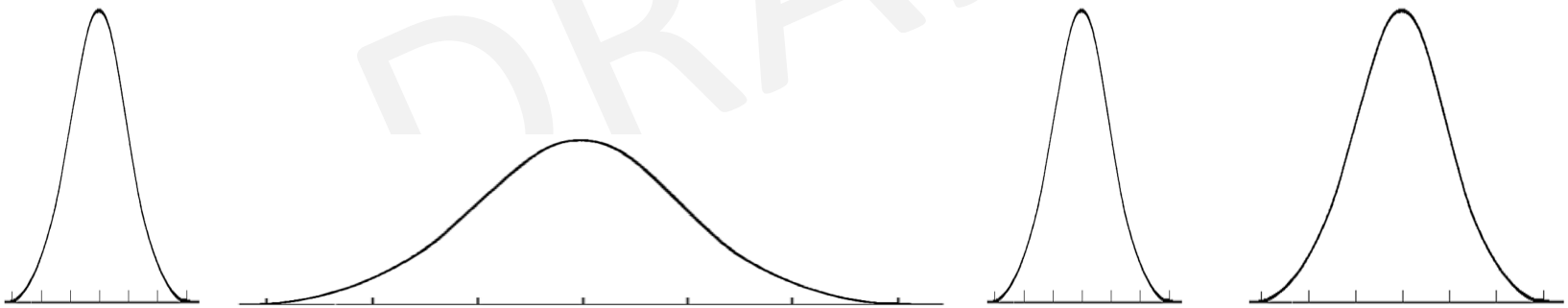
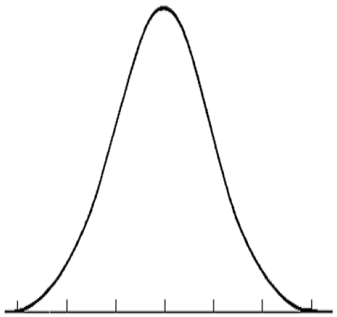


Q_d C_d Q_u C_d

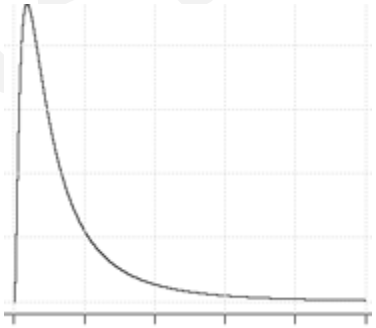
Defining Probability Distributions

- Need three pieces of information
  - Central tendency (mean)
  - Variance (spread)
  - Shape of distribution

Normal



Log-Normal



- Determined by goodness-of-fit testing

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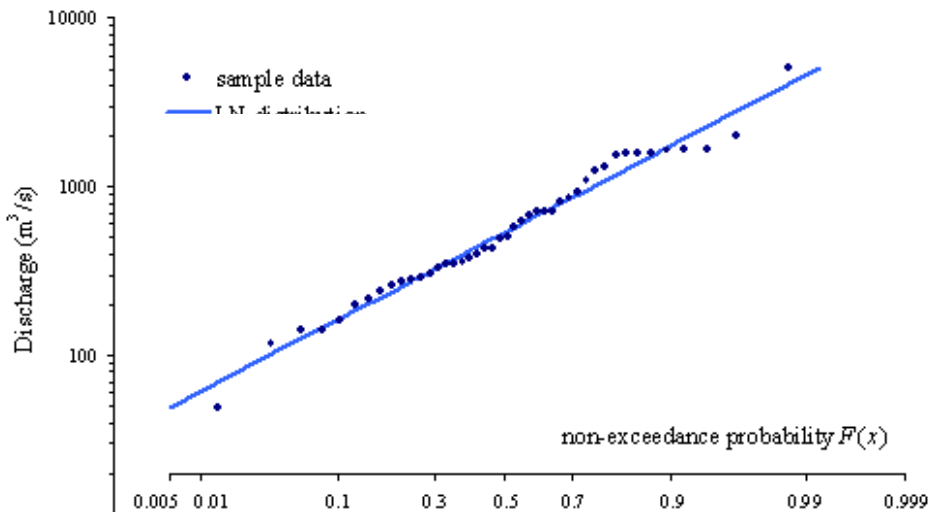
Goodness-of-Fit Testing

- Compare observed distribution of data to idealized distribution
  - Rank values
  - Plot on probability paper
  - Examine fit
- Process now applied via statistical packages



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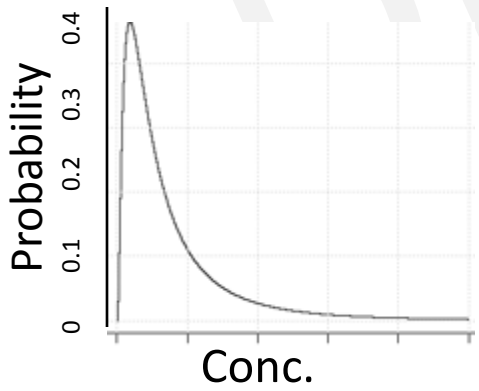
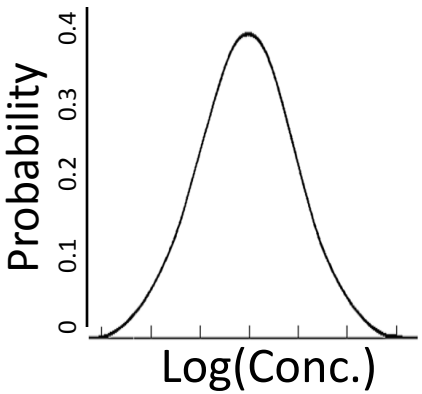
Normalizing Distributions

- Many statistical tests are based on the assumption that data follow a normal distribution
- Data are commonly “normalized” to make them fit a normal distribution
- For example, if data are log-normally distributed, taking the logarithm of the data values makes them normally distributed





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Defining Uncertainty in Model Inputs

- PCB Concentrations
  - Variability in day to day concentrations
  - Uncertainty due to lab and field contamination
- Flows
  - Variability in day to day flows

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Uncertainty in Concentration Inputs

- Uncertainty in concentration inputs has two components
  - Day to day variability at each station
  - Uncertainty due to contamination
    - Laboratory and field
- Each component will be evaluated separately, then combined

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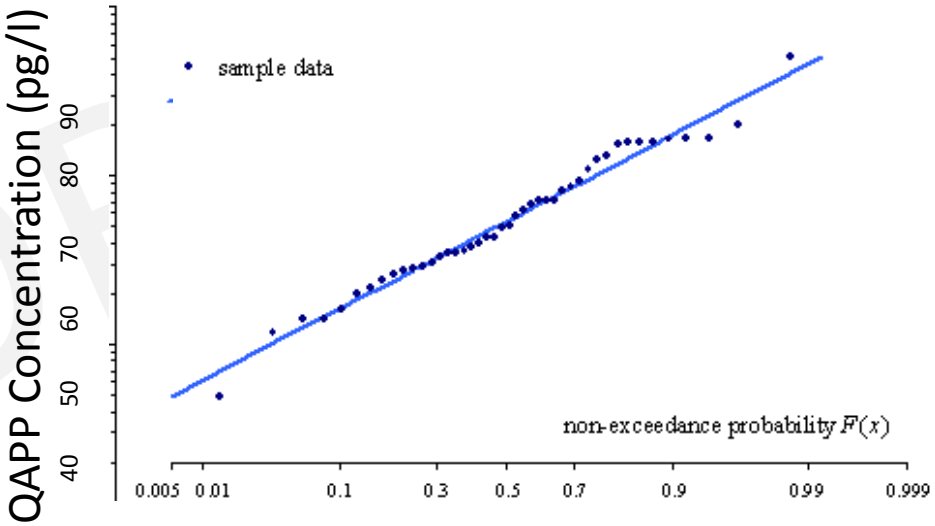
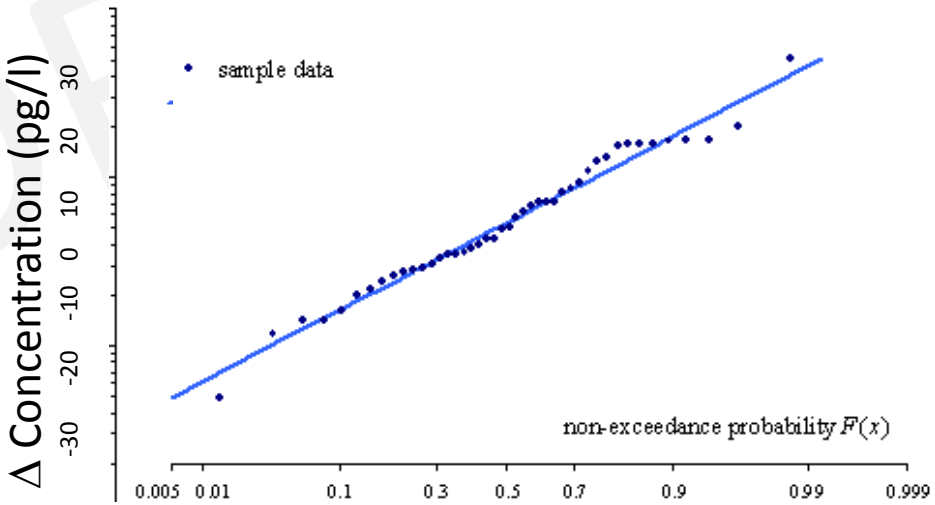
Daily Variability in Concentration

- Characterize day to day variability at each station using the blank-correction method defined in the QAPP



Uncertainty Due to Contamination

- Characterize uncertainty by using an alternate blank correction method (no exclusion, subtract maximum of field and lab blank)
  - Expressed as difference from the QAPP method



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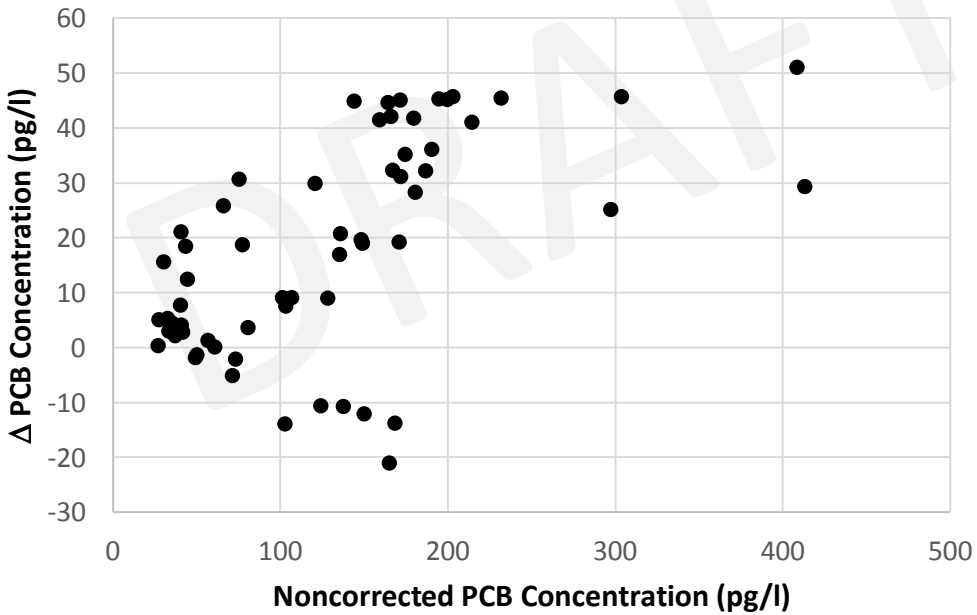
Uncertainty Due to Contamination

- Difference in results between alternative blank correction methods varied as a function of PCB concentration



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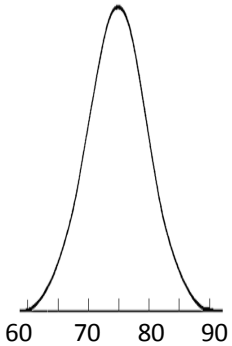
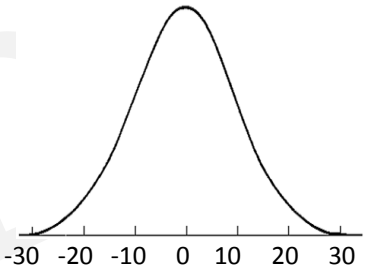
Combining Sources of Uncertainty

1. Select value representing daily variability
2. Select value representing incremental uncertainty due to contamination
3. Combine to generate total uncertainty



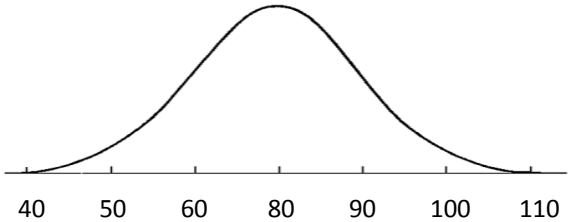
Daily Variability

+



Contamination Uncertainty

=



Total Uncertainty

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Defining Flow Uncertainty

- Characterize day to day variability at each station
  - Goodness of fit testing, normalize if necessary
- Assume measurement uncertainty is small
  - Can be added if anyone believes that it is important

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Defining Uncertainty in Results

- Characterize uncertainty in each model input
  - Using best-fit statistical distribution
- Use Monte Carlo analysis to characterize uncertainty in mass balance assessment

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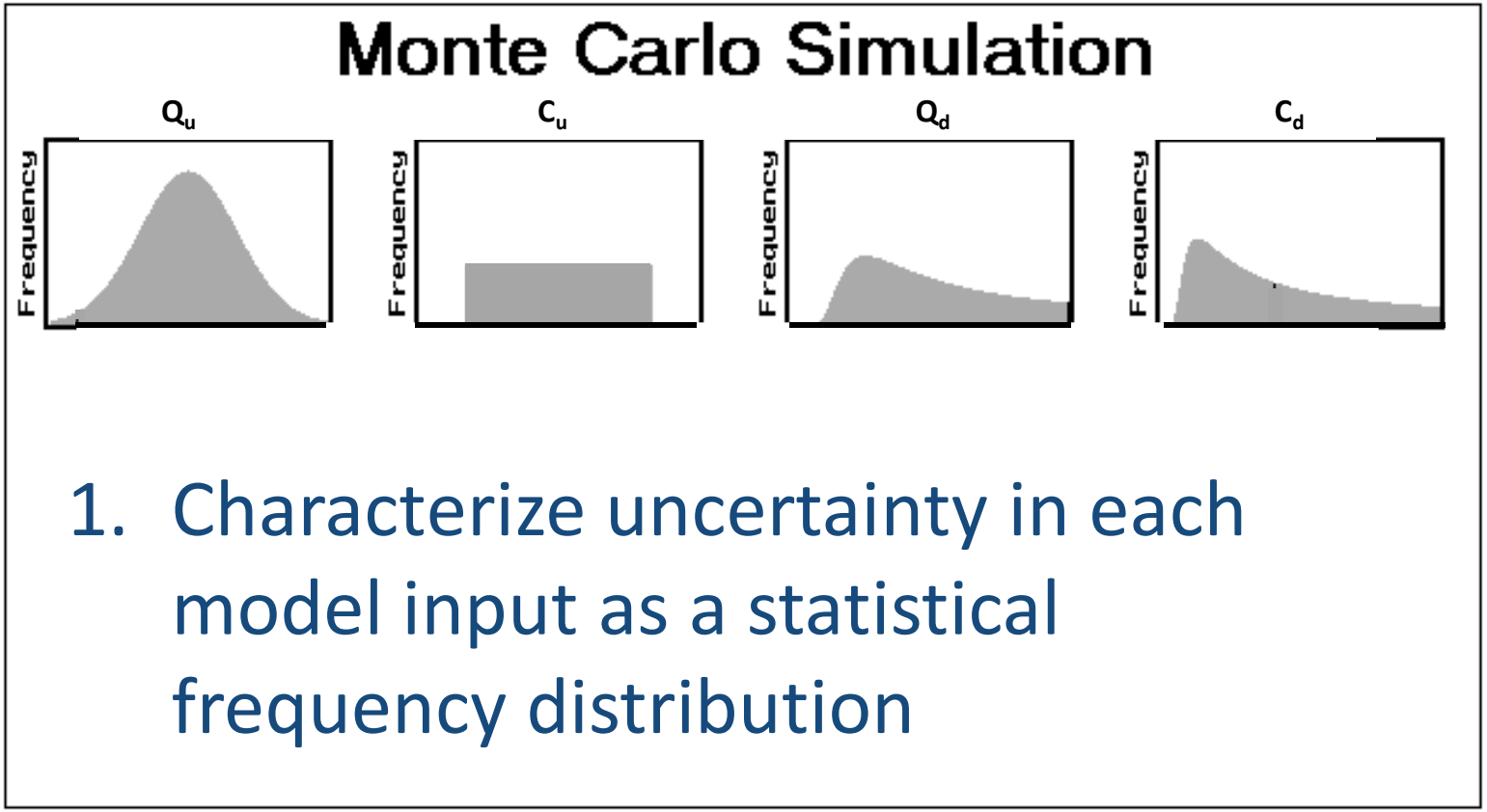
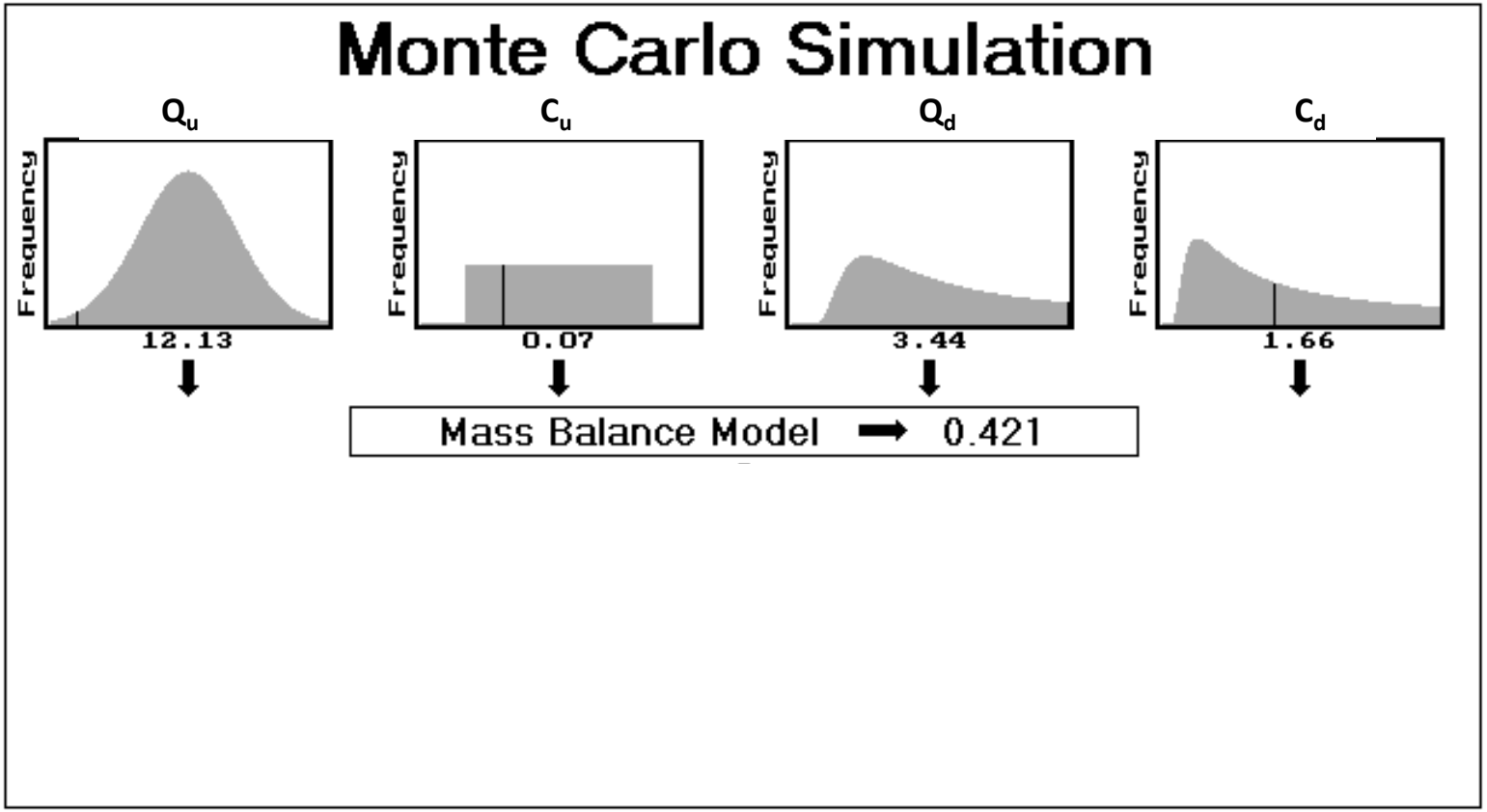
Defining Uncertainty in Results

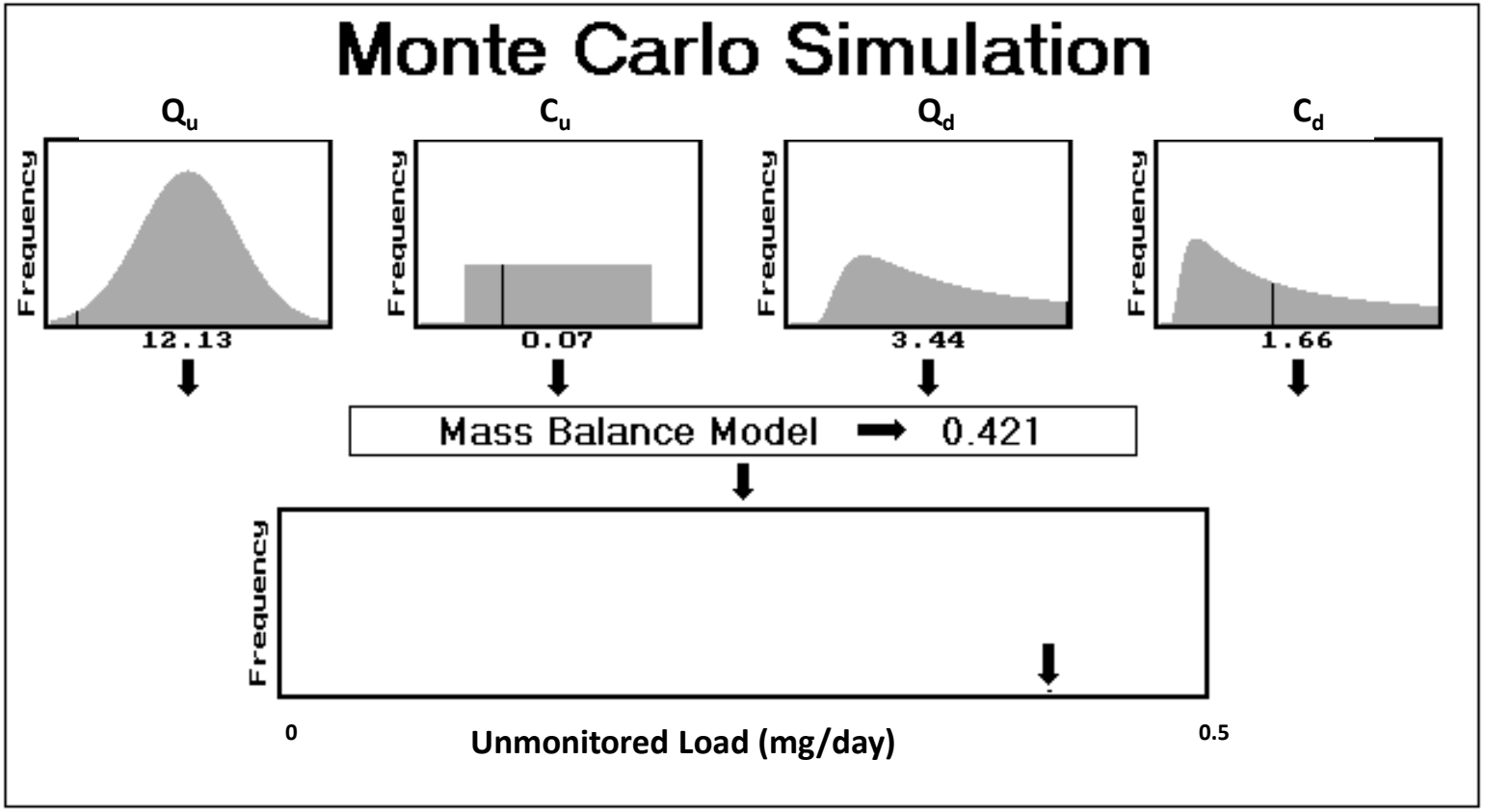


Defining Uncertainty in Results



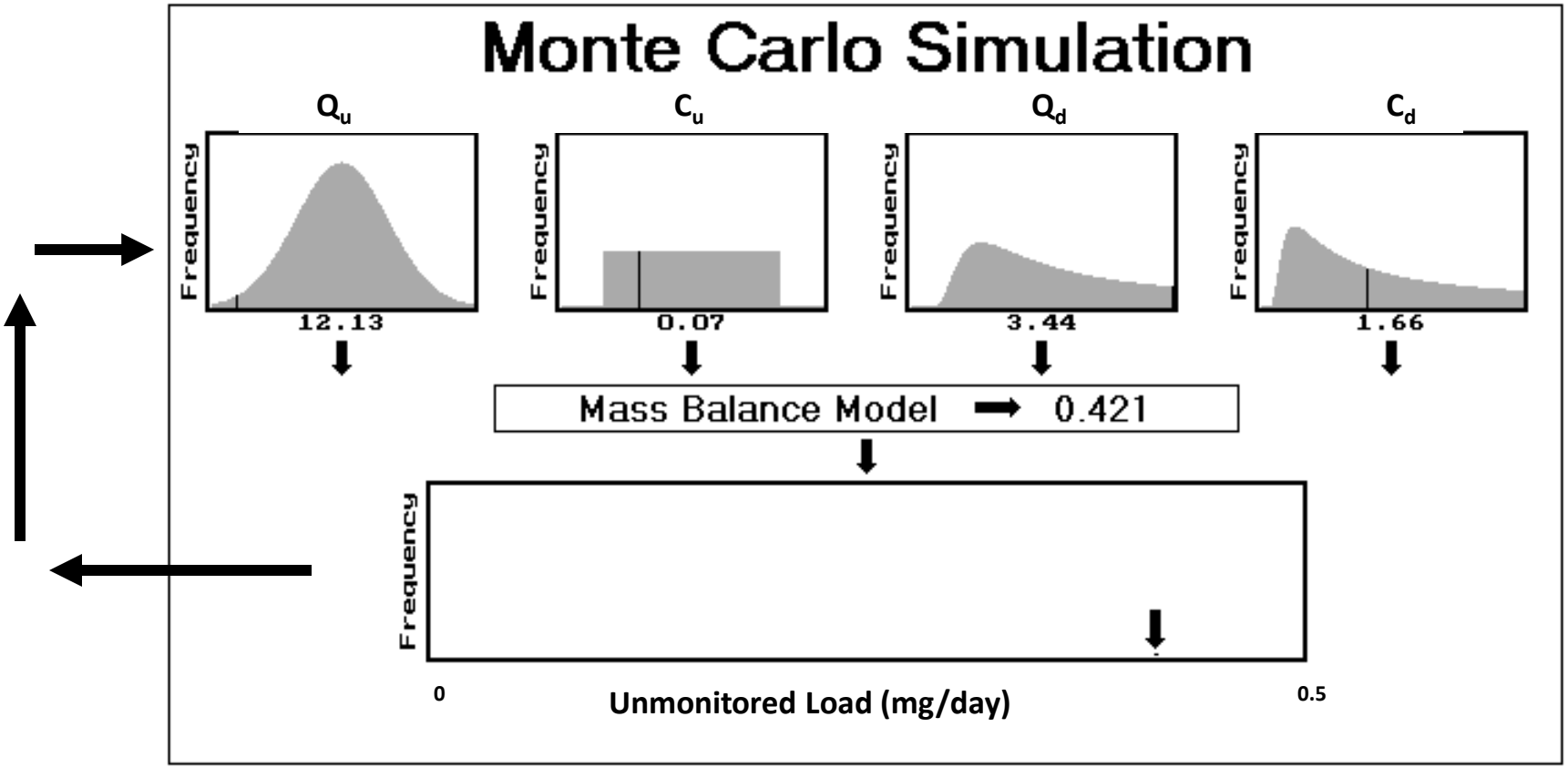
2. Randomly select inputs and run model

Defining Uncertainty in Results



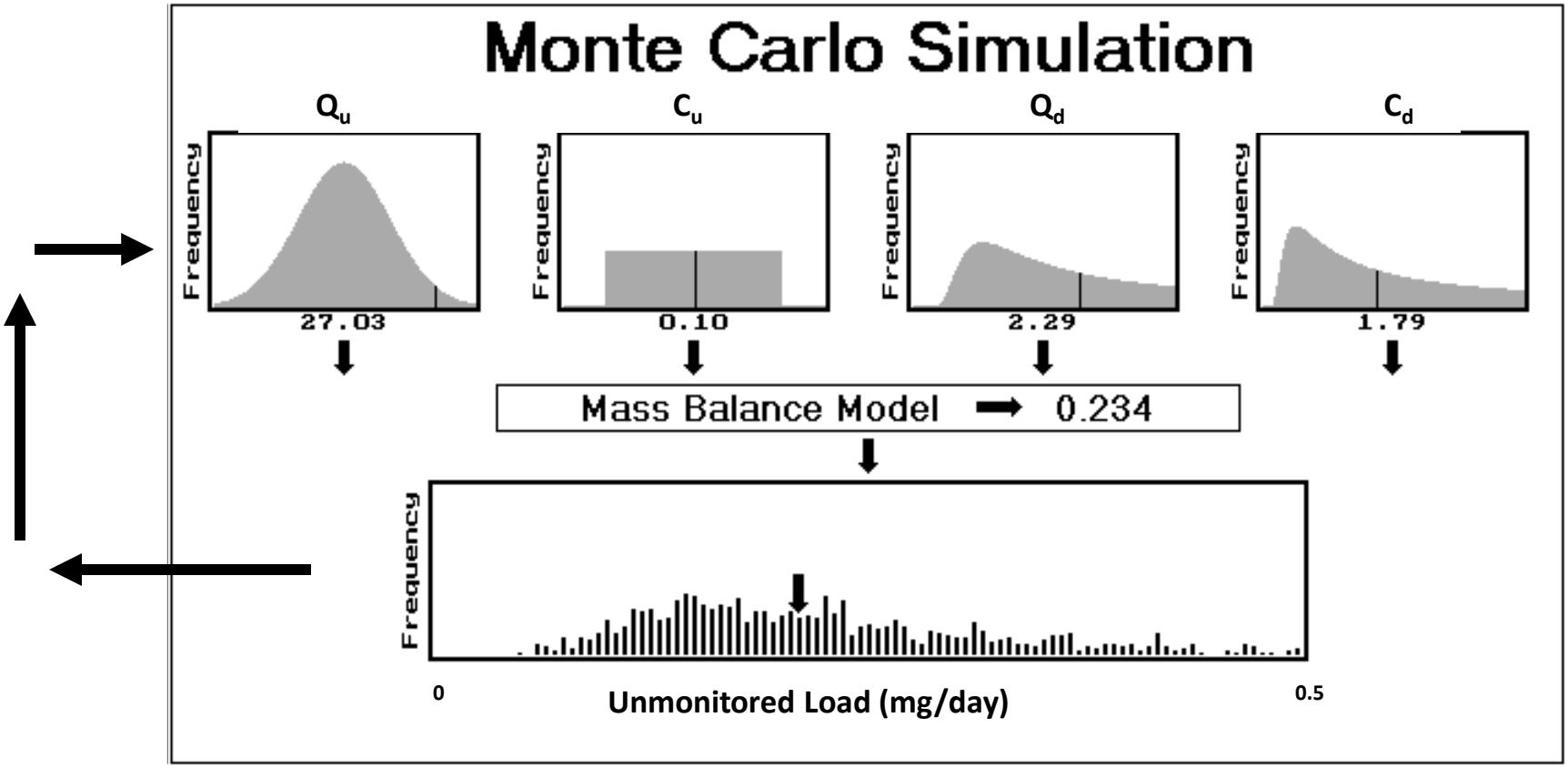
3. Tabulate results

Defining Uncertainty in Results



4. Repeat process

Defining Uncertainty in Results

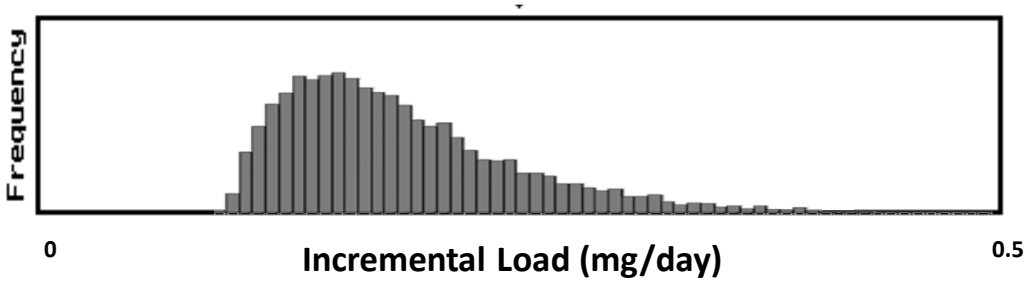


4. Repeat process

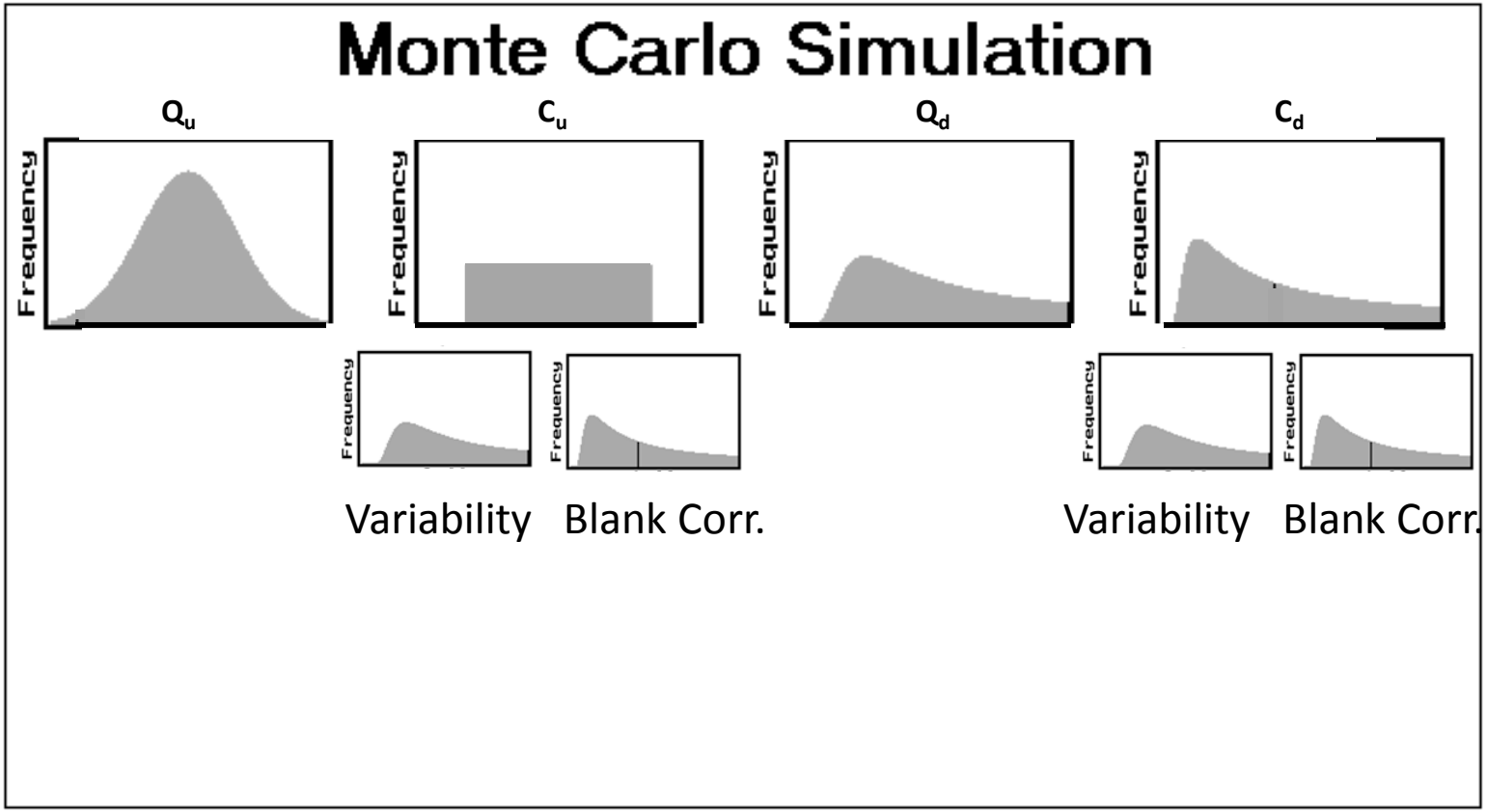
Defining Uncertainty in Results

Monte Carlo Simulation

5. Output distribution completely characterizes uncertainty
   - As long as inputs are characterized properly



Incorporating Blank Correction Uncertainty



Uncertainty Analysis Inputs: River Flows

Flow (cfs)				
	Mean	Std. Dev.	Distribution	Serial Correlation
Lake Coeur d'Alene*	735.6	109.8	Normal	0.92
Post Falls	741.3	109.8	Normal	1.0
Barker Rd.	399	124.4	Normal	0.92
Trent Ave.	973.7	60.4	Normal	0.94
Spokane	1118.6	73.8	Normal	0.84
Hangman Ck.	14.4	3.8	Normal	0.92
Nine Mile	1101.3	80.3	Normal	0.91

*Temporarily set at Post Falls flow minus average Coeur d'Alene WWTP flow

Uncertainty Analysis Inputs: River Concentrations

Total PCB (pg/l)			
	Mean	Std. Dev.	Distribution
Lake Coeur d'Alene	12.59	9.14	Normal
Post Falls	16.04	5.04	Normal
Barker Rd.	18.73	14.7	Normal
Trent Ave.	140	29.4	Normal
Spokane	152.8	38.1	Normal
Hangman Ck.	59.76	13.7	Normal
Nine Mile	163.2	49.6	Normal

Uncertainty Analysis Inputs: Discharge Flows

Flow (cfs)			
	Mean	Std. Dev.	Distribution
Coeur d'Alene	5.35	0.03	Normal
HARSB	0	0	Normal
Post Falls	3.89	0.12	Normal
Liberty Lake	1.12	0.04	Normal
Kaiser Aluminum	13.8	0.56	Normal
Inland Empire Paper	11.1	0.22	Normal
Spokane County	11.7	0.10	Normal
City of Spokane	44.1	1.44	Normal

Uncertainty Analysis Inputs: Discharge Concentrations

Total PCB (pg/l)			
	Mean	Std. Dev.	Distribution
Coeur d'Alene	533	3	Lognormal
Post Falls	214	12	Lognormal
Liberty Lake	218	36	Lognormal
Kaiser Aluminum	3949	673	Lognormal
Inland Empire Paper	2978	456	Lognormal
Spokane County	361	82	Lognormal
City of Spokane	972	209	Lognormal

Uncertainty Analysis Results

- Expressed as “excess unmonitored load”
  - i.e. screens out “re-gaining” load directly downstream of losing reaches

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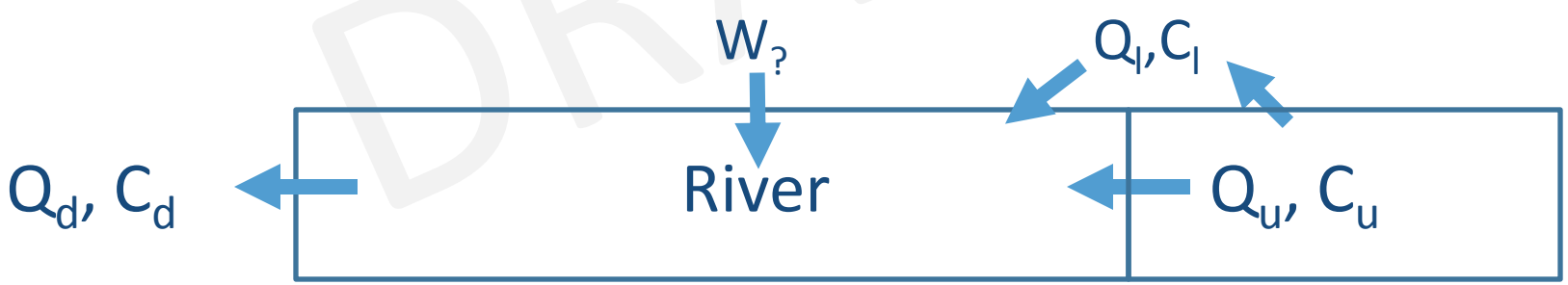
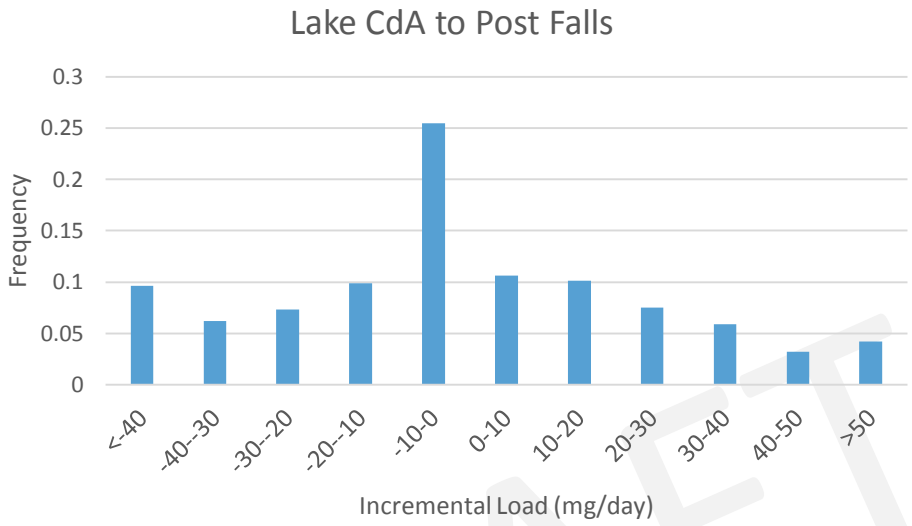
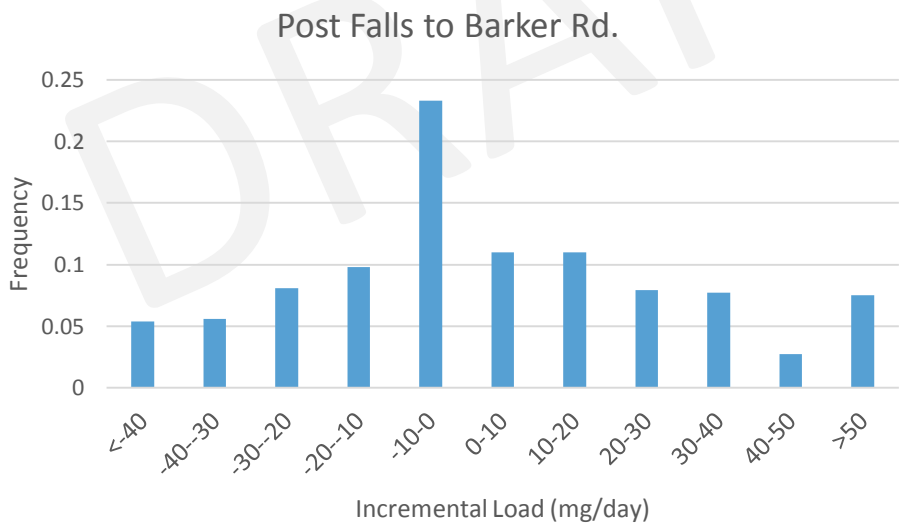


Incremental Load by Reach





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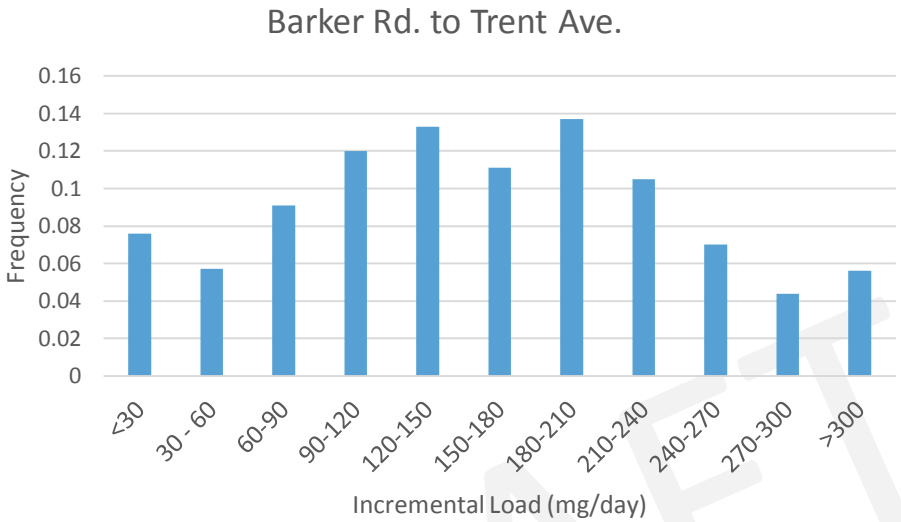
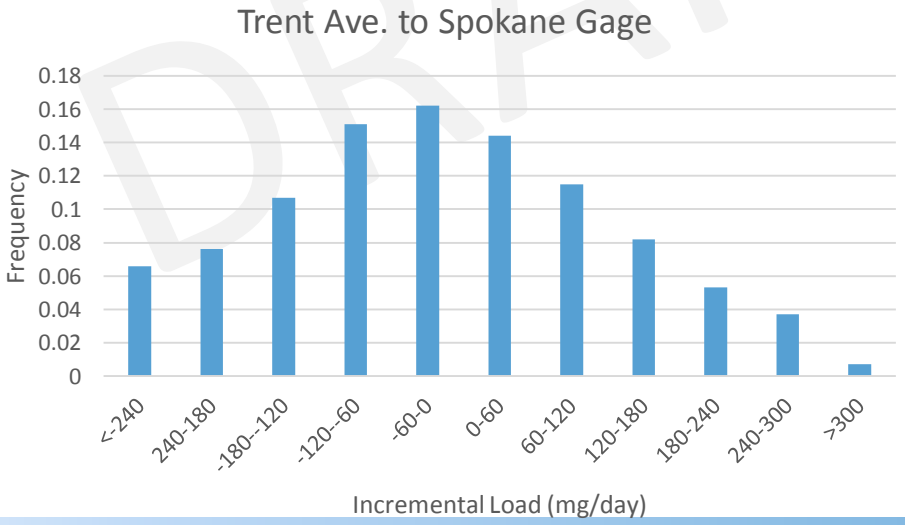
Incremental Load by Reach





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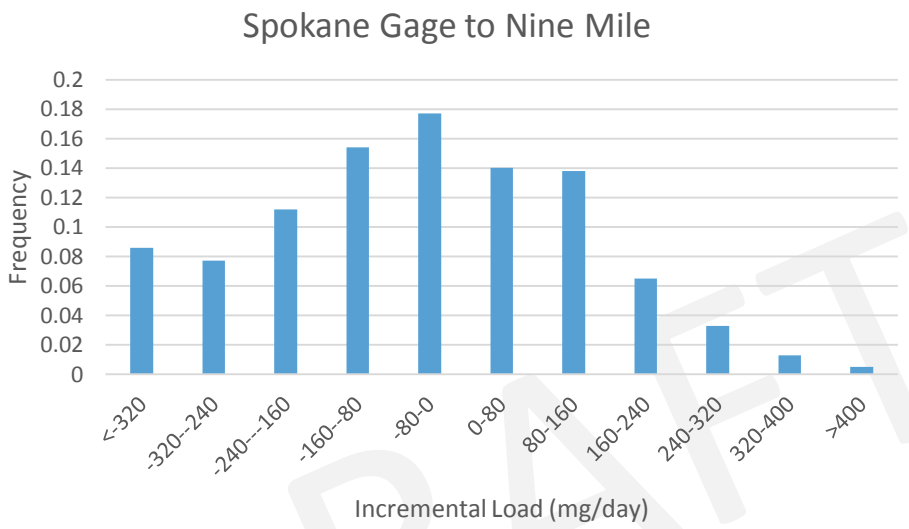
Incremental Load by Reach



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Best Estimate of Unknown Loads

River Section	Magnitude of Unknown Load
Coeur d'Alene to Post Falls	Very likely small
Post Falls to Barker Road	Very likely small
Barker Road to Trent Avenue	Very likely significant
Trent Avenue to Spokane Gage	Likely small
Spokane Gage to Nine Mile	Likely small

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