Linkage Analysis

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Se TMDL Workshop #2

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Purpose

- Identify and discuss an alternative approach for the linkage analysis

Key Points of Consensus

- TMDL is to be developed for freshwater portion of watershed only (not Bay)
  - Assumed that concentration/load reductions in watershed will reduce loads to Bay

- TMDL will not include site-specific objectives (SSOs) – those will follow later in process
  - Discussion today is focused on TMDL, not SSOs

Overview of Key Issues

- Can the linkage analysis be simplified?

A linkage analysis…

- "…establishes the cause-and-effect relationship between pollutant sources and the water body response." (EPA Draft Handbook for Developing TMDLs, Dec 2008)
- Supports the development of allocations to achieve TMDL targets

Source: EPA Draft Handbook for Developing TMDLs, Dec 2008

- Helps establish relationship to beneficial use attainment (in our case, protection of birds and fish)

Considerations

- Linkage analysis could vary greatly in level of complexity and elegance
- By contrast, our implementation tools and actions are discrete
- Goal is for TMDL adoption and development to support both near-term and long-term implementation and management actions, and for taking action even in face of scientific uncertainty

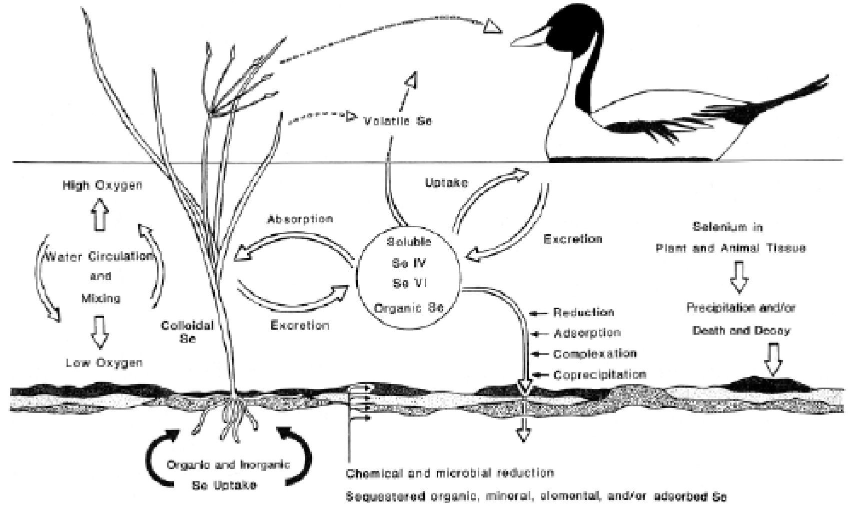


Figure 9-1. **Selenium immobilization processes in an aquatic ecosystem (Source: Lemly and Smith, 1987).**

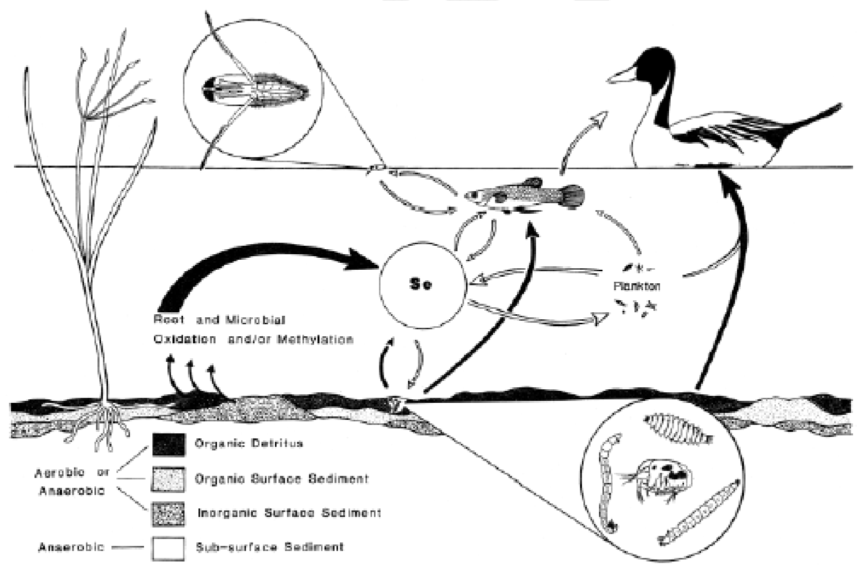
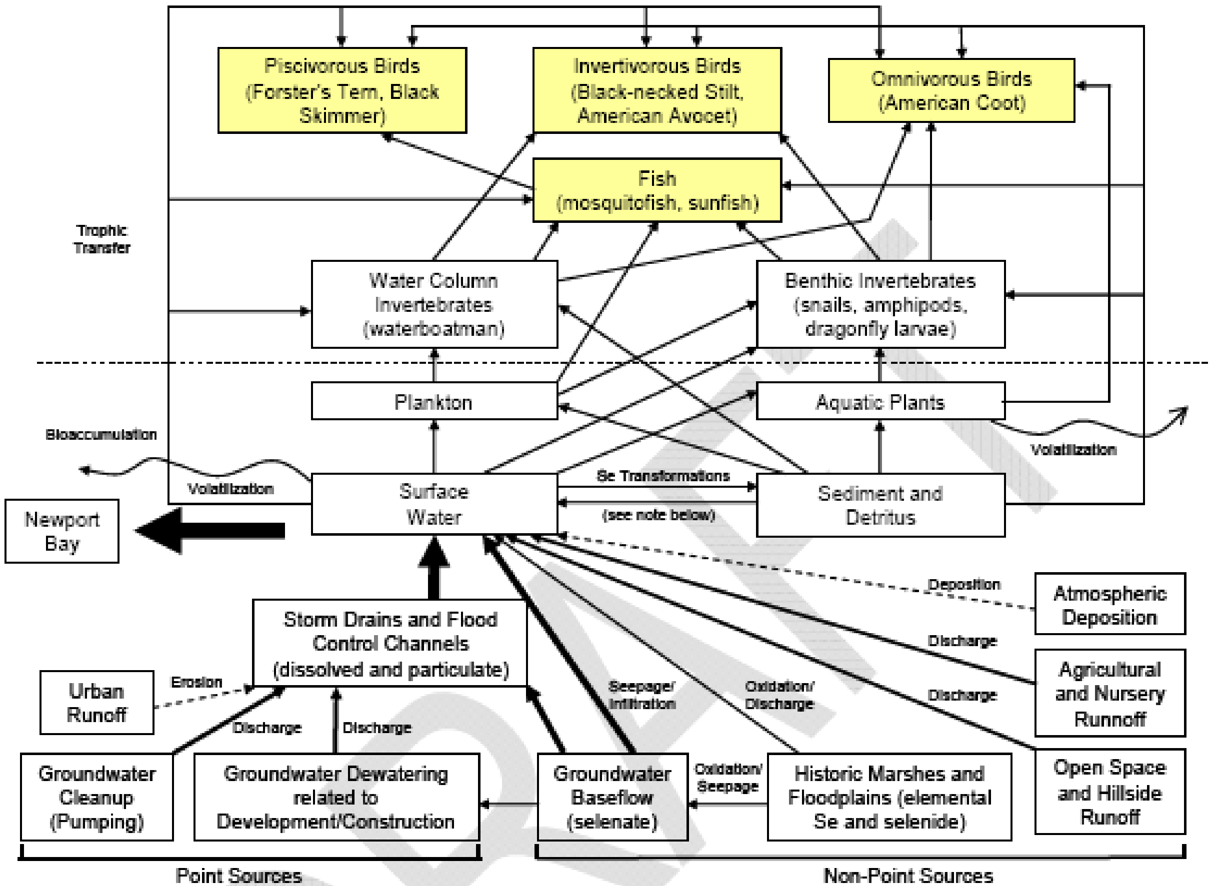


Figure 9-2 **Selenium mobilization processes in an aquatic environment (Source: Lemly and Smith, 1987).**

Source: 2009 RWQCB Draft Staff Report



Notes:

Shaded Boxes = assessment species for effects

Weight of line from source indicates significance of contribution of selenium to the watershed (e.g., dotted line indicates insignificant contribution, whereas a heavy line indicates significant contribution).

Figures 1 and 2 provide details on selenium transformations between sediment and surface water (e.g., bacterial processes), as well as details on loss due to volatilization.

Figure 9-3: Conceptual Model, Exposure Pathways, and Food-Web Relationships for Freshwater Habitats in the Newport Bay Watershed (Source: CH2MHill, 2009b).

Source: 2009 RWQCB Draft Staff Report

Option A: current biodynamic model approach

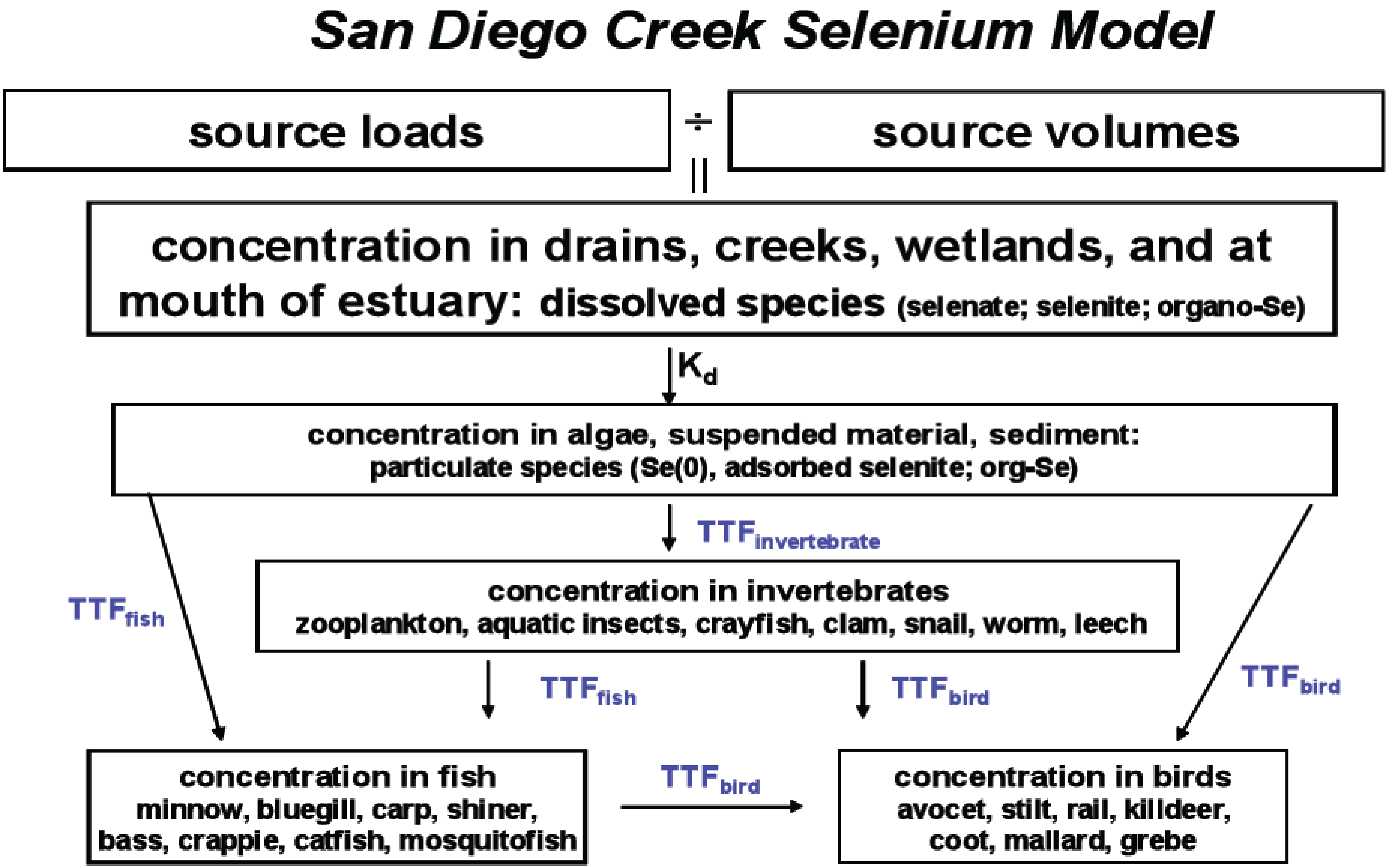


Figure 2. Conceptual model for the San Diego Creek watershed illustrating linked factors that determine the effects of Se on ecosystems.

Source: Presser and Luoma (2009)

Key Issue:
Option A is Elegant but Complex

- Uses both literature and measured values
- Can become conservative if use conservative values for all parameters
- Model needs to be reset after each implementation action is taken (model new equilibrium state)
- There may be a high amount of variability:
  - From one part of system to another (e.g., BCW v. PCW and SDC)
  - Selenium chemistry and mobilization
  - Kd values
  - Seasonality/flow dependence
  - Diet

Potential Modification: Option B – Elegant but Simple

$$[Se]_{fish} = [Se]_{water} \times \left[\frac{[Se]_{particulate}}{[Se]_{water}}\right] \times \left[\frac{[Se]_{inverts}}{[Se]_{particulate}}\right] \times \left[\frac{[Se]_{fish}}{[Se]_{inverts}}\right]$$

$$= [Se]_{water} \times \boldsymbol{K_d} \times \boldsymbol{TTF_{inverts}} \times \boldsymbol{TTF_{fish}}$$

$$= [Se]_{water} \times \boldsymbol{\alpha},$$

where $\boldsymbol{\alpha} = [\boldsymbol{K_d} \times \boldsymbol{TTF_{inverts}} \times \boldsymbol{TTF_{fish}}]$

(Other formulations may include preyfish, fish, birds, etc., but form of equation will be similar)

Option B is simplified

- Consistent with how EPA evaluates other bioaccumulatives
- Can focus primarily on data measured locally
  - Water column Se measurements
  - Concentrations in bird eggs and fish in assessment areas
  - No need for detailed, complex measurements of Kd or food items
  - Model does not need to be reset after each implementation action (no new equilibrium state)
- Potential advantages in near-term
  - α aggregates and minimizes uncertainty (e.g., no need to estimate individual proportions of various dietary items)
  - α can be adjusted to reflect management actions (e.g., anticipated changes in Kd)

Variability in Kd appears to drive much of variation

Table 9-1A

***K_ds Used by Regional Water Board Staff in the Newport Bay Watershed Biodynamic Model*[1]**

Water Body	Median Kd	75th%ile Kd
Peters Canyon Wash	178	279
Lower San Diego Ck	136	238
IRWD wetlands	226	271
UCI wetlands	786	825
San Diego Ck- All Sites	159	279
Santa Ana Delhi Channel	74	127
Big Canyon Wash	1,469	1,803
Upper Bay water column*	139	188
Upper Bay benthic**	6,920	8,423
Lower Bay water column	359	401
Lower Bay benthic	18,513	23,750
All Bay Sites water column	212	353
All Bay Sites benthic	11,600	17,770

Table 9-1B

K_ds used in modeling by USGS*[2] *(Presser and Luoma, 2009; Tables 18-20)

SDC subwatershed (freshwater)	
Upper watershed	200
Lower San Diego Creek	320
IRWD wetlands	400
UCI wetlands	1,000
Newport Bay (saltwater)	
near mouth of estuary	200
upper bay	1,000
upper/lower bay	10,000
lower bay	20,000

[1] Most of the selected K_ds for the freshwater areas match the K_ds in Tables 2a and 2b in the USGS report (Presser and Luoma, 2009).

[2] USGS staff used their best professional judgment in selecting these K_ds.

* Water column particulate-based K_ds

** Bed sediment-based K_ds

Lower San Diego Creek Selenium Data

Date	Site Description	Species/Type	Basis	Value	Units
1/1/2005	SDC at Campus Dr.	Surface Water	Diss.	28	µg/L
7/14/2004	SDC at Campus Dr.	Surface Water	Diss.	16	µg/L
7/20/2004	SDC at Campus Dr.	Surface Water	Diss.	14	µg/L
7/27/2004	SDC at Campus Dr.	Surface Water	Diss.	15	µg/L
7/6/2004	SDC at Campus Dr.	Surface Water	Diss.	18	µg/L
			Surface Water Average	**18.2**	**µg/L**
1/1/2005	San Diego Creek	Sediment	Dry Wt.	0.17	mg/kg
7/1/2004	SDC Basin 2	Sediment	Dry Wt.	0.68	mg/kg
7/1/2004	SDC Basin 2	Sediment	Dry Wt.	3.12	mg/kg
7/1/2004	SDC Basin 2	Sediment	Dry Wt.	2.26	mg/kg
			Sediment Average	**1.56**	**mg/kg**
1/1/2005	SDC	Crayfish	Dry Wt.	5.84	mg/kg
7/1/2004	San Diego Creek	Corixids	Dry Wt.	13.6	mg/kg
			Benthic Invertebrate Average	**9.72**	**mg/kg**
1/1/2005	SDC	Common carp	Dry Wt.	11	mg/kg
1/1/2005	SDC	Mixed fish	Dry Wt.	8.95	mg/kg
7/1/2004	San Diego Creek	Mosquitofish	Dry Wt.	17	mg/kg
			Whole-body Fish Average	**12.32**	**mg/kg**

Biodynamic Model (A) vs. Bioaccumulation Factor (B)

Lower San Diego Creek data

Water [Se] (µg/L)	Sediment [Se] (µg/g)	Invertebrate [Se] (µg/g)	Fish [Se] (µg/g)	Bird Egg [Se] (µg/g)
18.2 (14 - 28) n = 5	1.56 (0.68 - 3.12) n = 4	9.72 (5.84 - 13.6) n = 2	12.3 (8.95 - 17.0) n = 3	6.87 (3.6 - 14.5) n = 11

Biodynamic model predictions using mean and 75th percentile of site data

Mean						75th percentile					
				Protective C_{water} (µg/L)						Protective C_{water} (µg/L)	
K_d	TTF_{inv}	TTF_{fish}	TTF_{bird}	Fish	Bird	K_d	TTF_{inv}	TTF_{fish}	TTF_{bird}	Fish	Bird
85.6	6.24	1.27	0.71	**7.37**	**21.1**	138	4.71	1.20	0.62	**6.43**	**19.9**

BAF predictions using mean of site data

		Protective C_{water} (µg/L)	
BAF_{fish}	BAF_{bird}	Fish	Bird
677	378	**7.39**	**21.2**

Note: preliminary results should be updated with current data

Sand Creek, Colorado

- Results are straight forward
  - Similar between sites and overall model

Site	Water [Se] (µg/L)	Sediment [Se] (mg/kg)	Invert [Se] (mg/kg)	Fish [Se] (mg/kg)	Fish Tissue Threshold (mg/kg)	K_d	TTF_{inv}	TTF_{fish}	Protective C_{water} (µg/L)
SW1	6.63	0.25	5.94	10.9	7.9	37.7	23.8	1.83	**4.8**
SW2-1	12.7	0.41	7.46	22.6	7.9	32.3	18.2	3.03	**4.4**
Both Sites	9.77	0.33	6.7	18.1	7.9	33.8	20.3	2.71	**4.3**

- **What if you use the default values from P&L (2010)?**

Site	Water [Se] (µg/L)	Sediment [Se] (mg/kg)	Invert [Se] (mg/kg)	Fish [Se] (mg/kg)	Fish Tissue Threshold (mg/kg)	K_d	TTF_{inv}	TTF_{fish}	Protective C_{water} (µg/L)
SW1	6.63	0.25	5.94	10.9	7.9	1000	2.8	1.0	**2.8**
SW2-1	12.7	0.41	7.46	22.6	7.9	1000	2.8	1.0	**2.8**
Both Sites	9.77	0.33	6.7	18.1	7.9	1000	2.8	1.0	**2.8**

St. Charles River, CO

- 7 sites had matched data
- Results NOT so straight forward
  - Lots of variability between sites and overall model
  - Which value(s) do you pick to represent the segment?

Site	Water [Se] (µg/L)	Sediment [Se] (mg/kg)	Invert [Se] (mg/kg)	Fish [Se] (mg/kg)	Fish Tissue Threshold (mg/kg)	K_d	TTF_{inv}	TTF_{fish}	Protective C_{water} (µg/L)
SC-1	1.32	1.13	6.24	7.29	7.9	852	5.53	1.17	**1.4**
SC-2	2.39	2.16	12.3	12.5	7.9	903	5.70	1.02	**1.5**
SC-3	1.99	0.97	8.58	9.25	7.9	489	8.84	1.08	**1.7**
SC-4	1.68	1.29	6.28	9.84	7.9	770	4.87	1.57	**1.3**
SC-6	119	6.90	29.8	46.8	7.9	57.8	4.32	1.57	**20.1**
SC-8	21.7	13.3	17.0	44.1	7.9	613	1.28	2.60	**3.9**
SC-9	14.9	7.38	26.7	34.5	7.9	495	3.62	1.29	**3.4**
All Sites	24.0	4.73	16.1	24.5	7.9	198	3.40	1.52	**7.7**

- **Use of P&L (2010) default values would result in C_{water} =2.8 µg/L for all sites here too**
  - Sometimes more conservative, sometimes not

Validation

- Can the site-specific models be validated?
  - I.e., use the model to predict fish or invertebrate tissue [Se]
- Validation was attempted using multiple approaches
  - Suggested by P&L (2010)
    - $C_{inv} = C_{sed} * TTF_{inv}$
    - $C_{fish} = C_{inv} * TTF_{fish}$
    - $C_{fish} = C_{sed} * TTF_{inv} * TTF_{fish}$
  - Used different combinations of data
    - E.g., use a model derived from 2009-2010 data to predict 2011 [Se]
- Models developed using site-specific data or default values could not consistently be validated
  - Predicted values were often off by 50% or more
  - Both over-estimated and under-estimated

Biodynamic Model and BAF

Sand Creek biodynamic model results

Site	Water [Se] (µg/L)	Sediment [Se] (mg/kg)	Invert [Se] (mg/kg)	Fish [Se] (mg/kg)	Fish Tissue Threshold (mg/kg)	K_d	TTF_{inv}	TTF_{fish}	Protective C_{water} (µg/L)
SW1	6.63	0.25	5.94	10.9	7.9	37.7	23.8	1.83	**4.8**
SW2-1	12.7	0.41	7.46	22.6	7.9	32.3	18.2	3.03	**4.4**
Both Sites	9.77	0.33	6.7	18.1	7.9	33.8	20.3	2.71	**4.3**

Sand Creek BAF results

Site	Water [Se] (µg/L)	Fish [Se] (mg/kg)	Fish Tissue Threshold (mg/kg)	BAF	Protective C_{water} (µg/L)
SW1	6.63	10.9	7.9	1644	**4.8**
SW2-1	12.7	22.6	7.9	1780	**4.4**
Both Sites	9.77	18.1	7.9	1853	**4.3**

Biodynamic Model vs BAF

Biodynamic Model: C_{water} (µg/L) = $$\frac{C_{predator}}{K_d \times TTF_{consumer} \times TTF_{predator}}$$

$$= \frac{C_{predator}}{\frac{[Se]\ Particulates}{[Se]\ Water} \times \frac{[Se]\ Inverts}{[Se]\ Particulates} \times \frac{[Se]\ Fish}{[Se]\ Inverts}}$$

$$= \frac{C_{predator}}{\frac{[Se]\ Fish}{[Se]\ Water}}$$

BAF: $\mathbf{C_{water}}$ **(µg/L) =** $$\frac{C_{predator}}{BAF} = \frac{C_{predator}}{\frac{[Se]\ Fish}{[Se]\ Water}}$$

Summary

- Recommend Option B:
  - Focus measurements on water and tissue concentrations
  - Use data to be collected to evaluate impacts of management actions