AQUATIC ECOSYSTEM-SCALE SELENIUM MODELING FOR INVERTEBRATES, FISH, AND BIRDS

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November 2008

Re-evaluation of the State of the Science for Water Quality Criteria

Edited by Mary Reiley, W. Stubblefield, W. Adams, D. DiToro, P. Hodson, R. Erickson, and F.J. Keating, 2003

<u>SETAC Workshop in 1998</u>

Fish Tissue Criteria

Wildlife Criteria

Not traditional organism to water, but organism to food

} relevant to selenium

Ecosystem-Scale Methodology

Conceptualize ecosystem

Site-specific food web structure

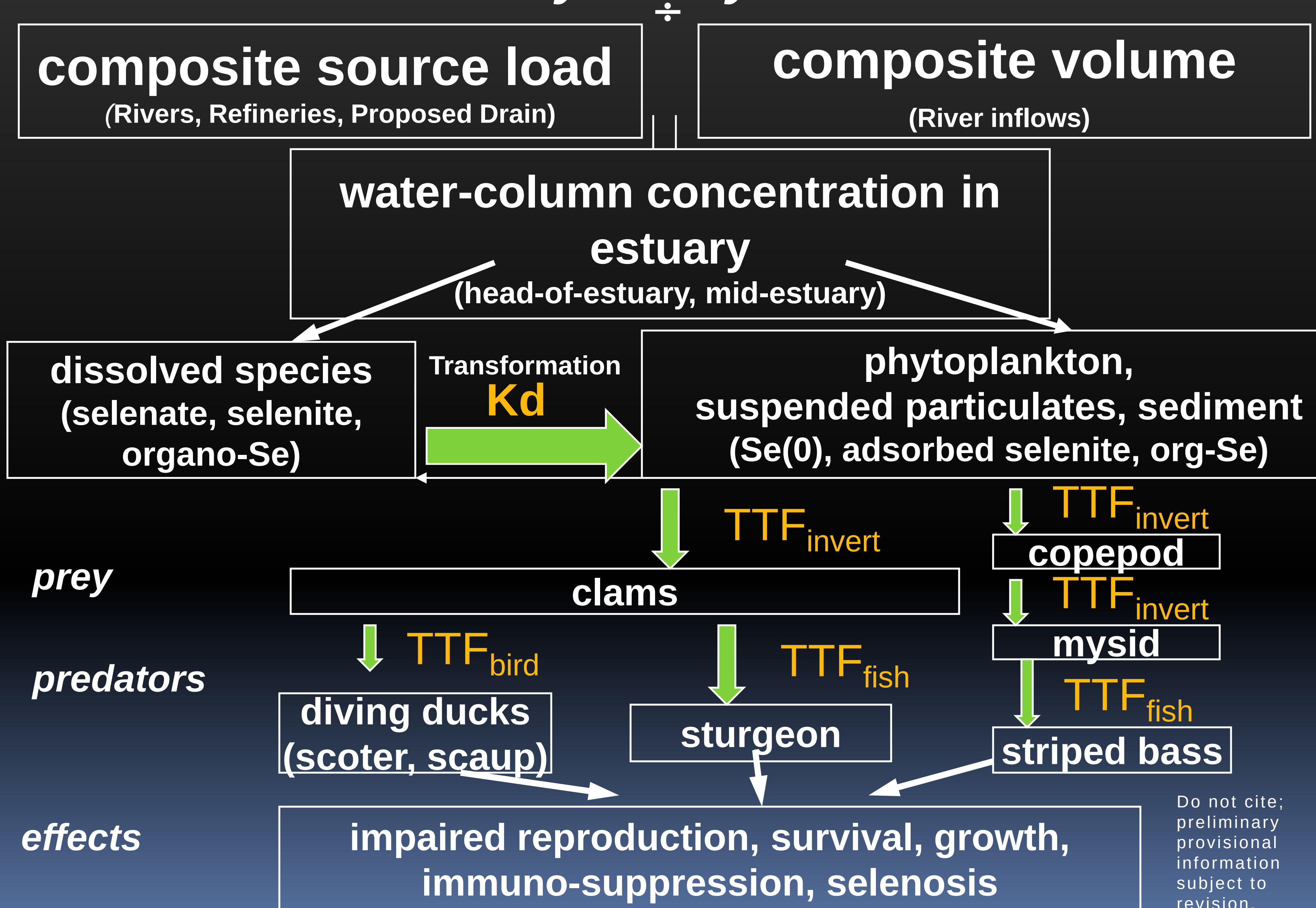
Quantify processes for each step

mass balance—partitioning (Kd)

biodynamics—diet and tissue (TTF)

All solids in dry weight

San Francisco Bay Ecosystem-Scale Model



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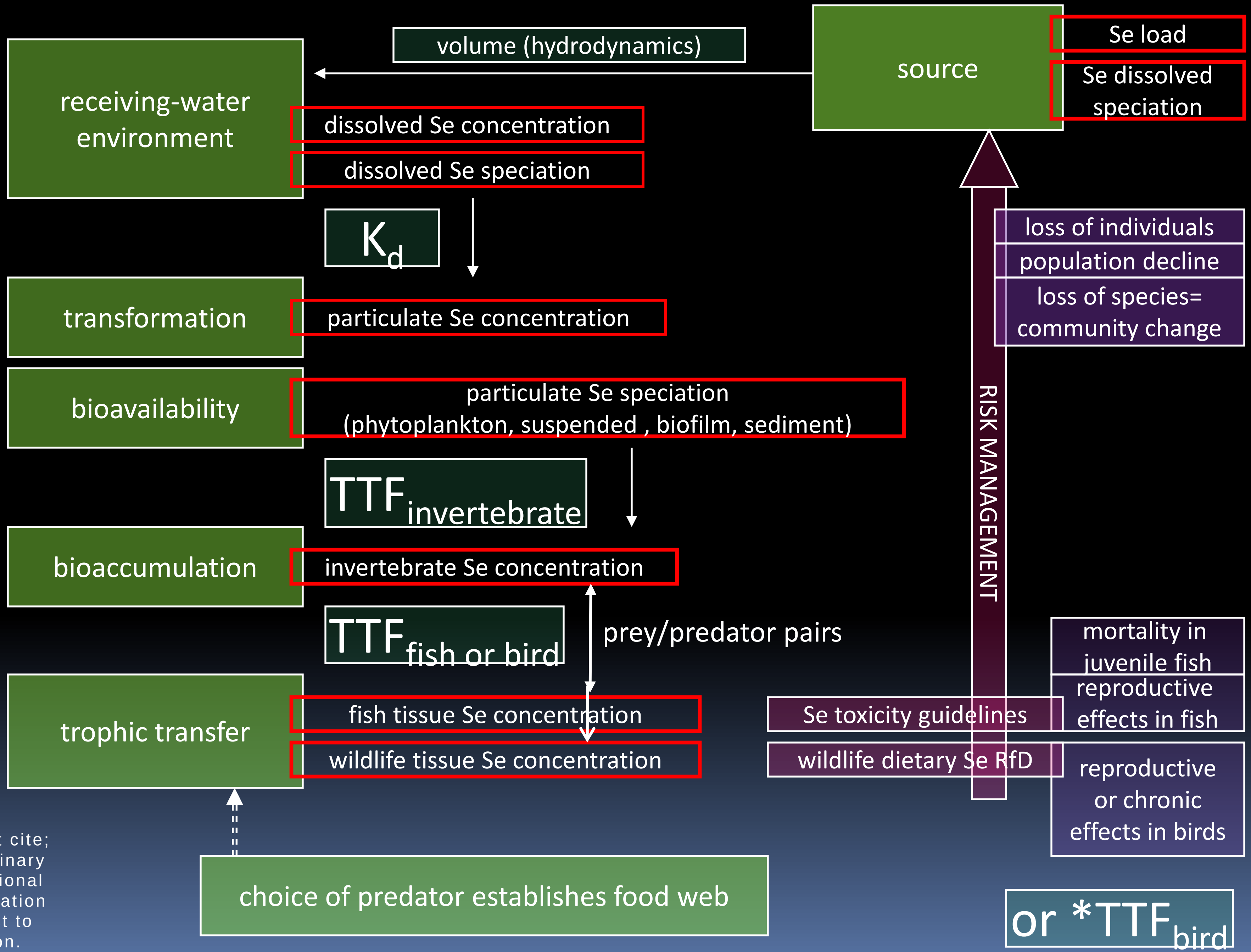
Ecosystem-Scale Selenium Model (Biodynamic)



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Data Needs: source speciation

- agricultural drainage—selenate
- mountaintop coal mining/valley fill leachate in streams—selenate;
- copper mining discharge—selenate
- oil refinery effluent—selenite
- fly-ash disposal effluent—selenite
- pond-treated agricultural drainage—organic-Se
- terminal lakes—selenite and organo-Se
- phosphate mining overburden leachate in streams—selenate at maximum flow; selenite and organo-Se during minimum flow.

Data Needs: receiving-water partitioning/ transformation environment

Biogeochemical kinetic speciation models or

K_d = particulate Se concentration*/ water-column Se concentration

to represent dynamics of transformations within water and particulate matter

*average particulate = suspended sediment, phytoplankton, detritus, bio-film, bed sediment, attached plants

Data Needs: laboratory-derived physiological parameters for invertebrates

Biodynamics

Kinetic Trophic Transfer Factors (simplified)

$$C_{invertebrate} = (AE)\ (IR)\ (C_{particulate})/k_e$$

$$TTF_{invertebrate} = (AE)\ (IR)/k_e$$

$$C_{invertebrate} = (TTF_{invertebrate})\ (C_{particulate})$$

AE = assimilation efficiency

IR = ingestion rate

k_e = efflux rate

Primary Source of Se is Dietary

Dissolved pathway + Dietary pathway

$$\text{bivalve concentration} = \frac{(0.3\text{ ppb})\ (0.003\text{ L/g/day})}{0.025} + \frac{(0.5\text{ ppm})\ (45\%)\ (0.25\text{ g/g/day})}{0.025}$$

$$2.29\text{ ppm, dw} = 0.036 + 2.25$$

1.6% from dissolved

$$\text{zooplankton concentration} = \frac{(0.1)\ (0.024)}{0.155} + \frac{(0.5)\ (50\%)\ (0.42)}{0.155}$$

$$0.72\text{ ppm, dw} = 0.016 + 0.677$$

2.3% from dissolved

$$\text{mysid concentration} = \frac{(0.1)\ (0.027)}{0.25} + \frac{(0.5)\ (73\%)\ (0.45)}{0.25}$$

$$0.78\text{ ppm, dw} = 0.011 + 0.657$$

1.7% from dissolved

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Data Needs: laboratory-derived physiological parameters for fish and birds

Kinetic Trophic Transfer Factors*

$$C_{fish} = (AE)\ (IR)\ (C_{invertebrate})/ke$$

$$TTF = (AE)\ (IR)/k_e$$

$$C_{fish} = (TTF_{fish})\ (C_{invertebrate})$$

$$C_{bird} = (TTF_{bird})\ (C_{invertebrate})$$

*simplified

Data Needs: field-derived Trophic Transfer Factors

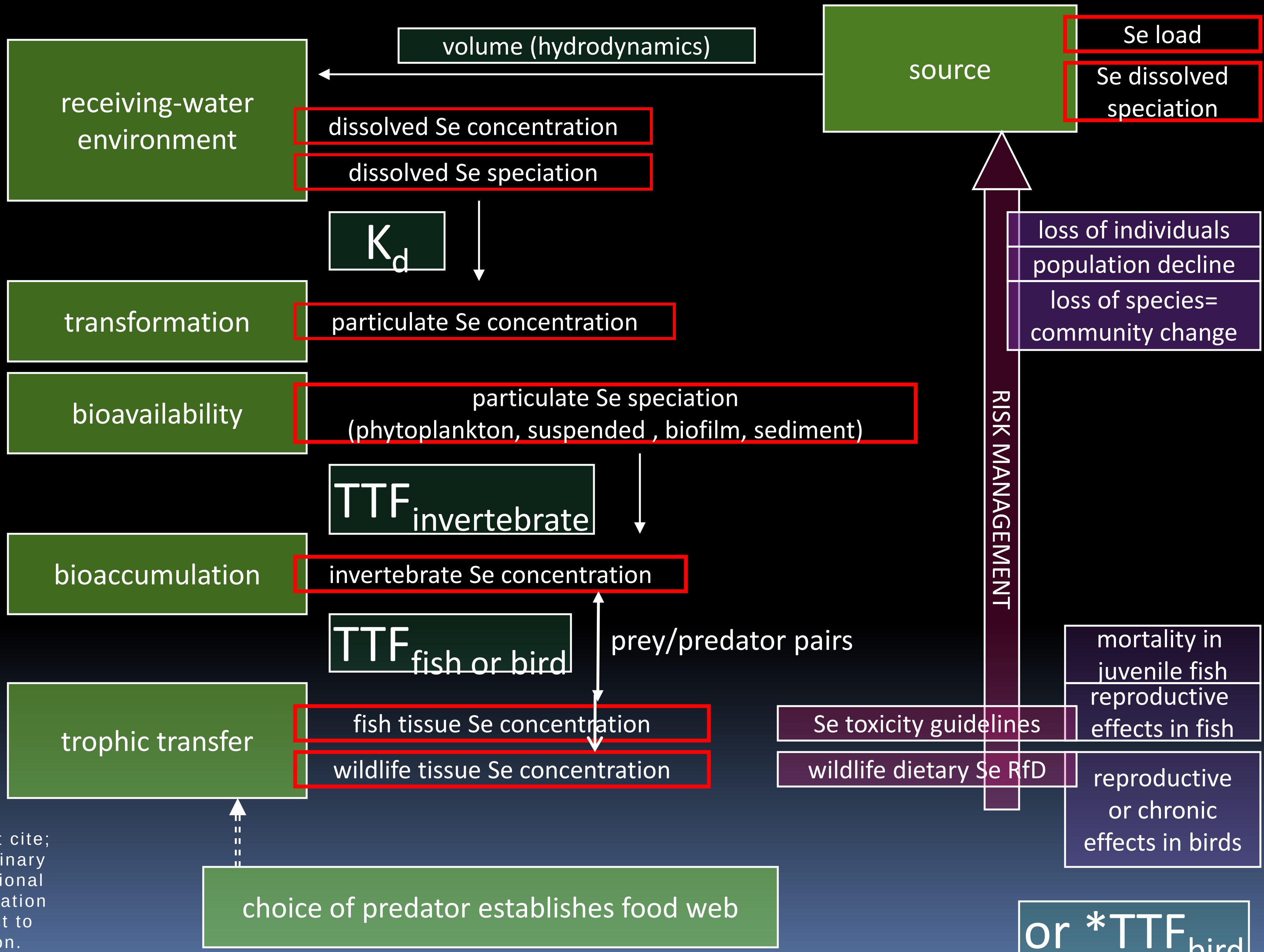
Temporally matched data sets across media (water, suspended, invertebrate, fish, and bird)

$TTF_{invertebrate} = C_{invertebrate}/C_{particulate}$

$TTF_{fish} = C_{fish}/C_{invertebrate}$

$TTF_{bird} = C_{bird}/C_{invertebrate}$

Ecosystem-Scale Selenium Model (Biodynamic)



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Translation to water-column concentration

$$C_{invertebrate} = (TTF_{invertebrate})\ (C_{particulate})$$

If $C_{particulate} = (K_d)\ (C_{water})$

dietary criterion

$$C_{water} = (C_{invertebrate})/(TTF_{invertebrate})\ K_d$$

fish tissue criterion

$$C_{water} = (C_{fish})/(TTF_{fish})\ (TTF_{invertebrate})\ K_d$$

wildlife criterion

$$C_{water} = (C_{bird})/(TTF_{bird})\ (TTF_{invertebrate})\ K_d$$

Steps in Methodology

- Choose toxicity guideline for fish in watershed
- Choose fish species to be protected
- Choose species-specific TTF_{fish} (**range 0.6 to 1.7**) or use default TTF_{fish} of 1.1
- Identify appropriate food web(s) for selected fish species based on species-specific diet
- Choose $TTF_{invertebrate}$ for invertebrates in selected food web(s) or use default $TTF_{invertebrate}$ for class of invertebrate

$TTF_{invertebrate}$ =

amphipod = 0.6	aquatic insects = 2.8
mysid = 1.2	clam-freshwater = 2.7
copepod = 1.4	clam-marine = 4 to 8
crayfish = 1.6	mussel = 6.0
daphnia = 1.9	

Methodology continued

Choose K_d based on source of Se and receiving water conditions or use a generalized default K_d of 1000 or a K_d indicative of hydrologic type and speciation

K_d for estuary= 3000-40,000

(San Francisco, Newport, and Xiamen Bays, Salton Sea)

K_d for pond = 1200-4500

(Belews, Hyco, Mud Reservoirs; Salton Sea; Great Salt Lake; lower Great Lakes)

K_d for streams & rivers = 110-600 (San Joaquin, Mud, Alamo, New, Whitewater, Fording, Elk, Luscar River/Creek)

K_d for streams = 1690 in Idaho (Angus, Crow, Sage)

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FISH: site-specific and species specific
(if 6.0 ppm Se dry weight whole-body guideline)

Se load**

Se allowed in water

Belews Lake	bluegill TTF = 1.1 →	5.4 ppm Se aquatic insect TTF = 2.8 →	1.9 ppm Se particulate* Kd = 3000 →	0.63 ppb water →	1.7 lbs Se load
river (main stream)	bluegill TTF = 1.1	5.4 ppm amphipod TTF = 0.6	9.0 ppm Kd = 150	60 ppb	163 lbs
mountaintop mining reservoir	redear sunfish TTF = 1.1	5.4 ppm *Corbicula* TTF = 4.0	1.4 ppm Kd = 1800	0.78 ppb	2.1 lbs

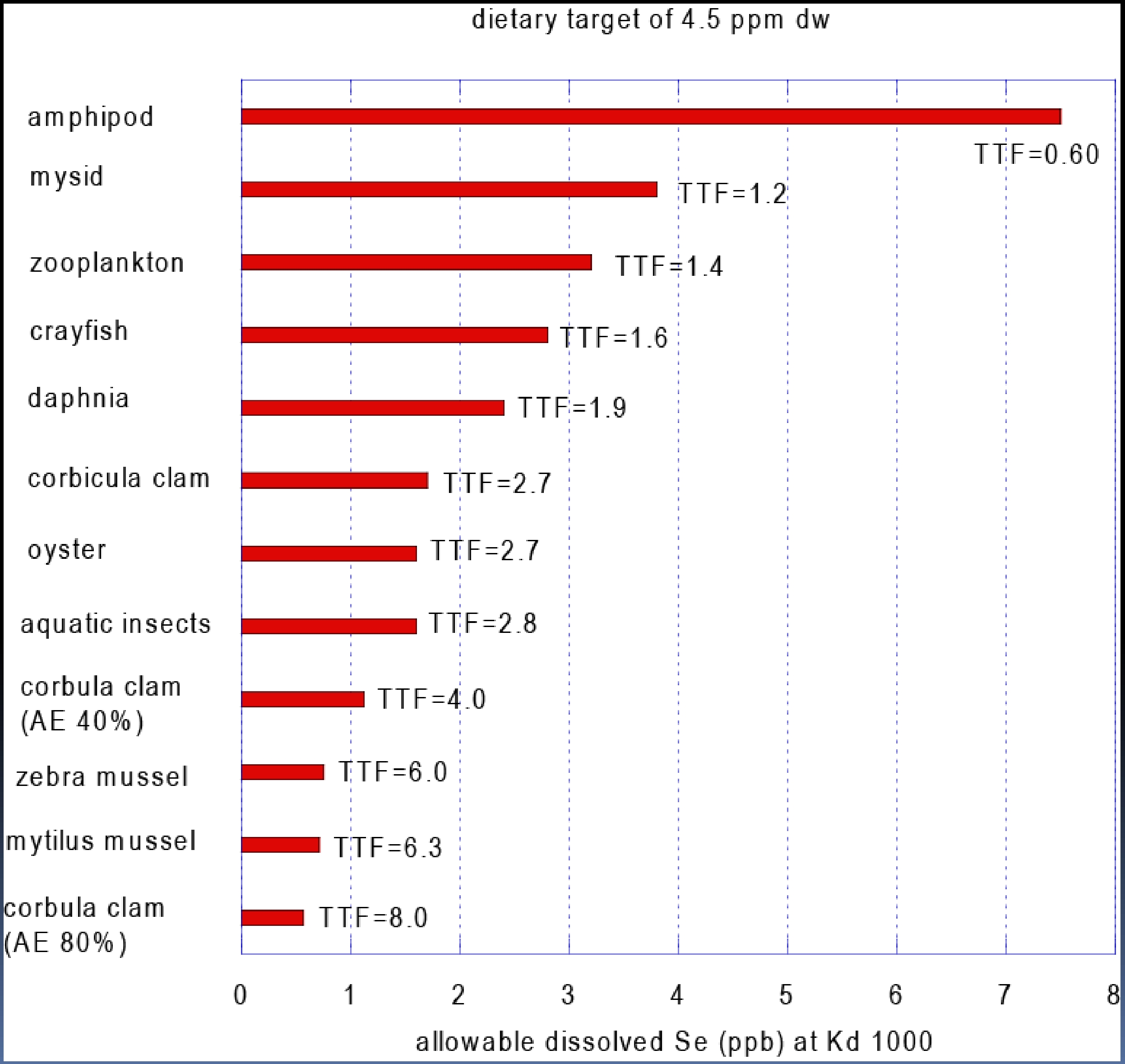
**at 1000 acre-feet

*algae, suspended material, biofilm, bed sediment

FISH: site-specific and species specific
(if 6.0 ppm Se dry weight whole-body guideline)

				allowed in water	load**
mountain streams	cutthroat trout TTF = 1.1	5.4 ppm dace TTF = 1.5 3.6 ppm aquatic insect TTF = 2.8	1.3 ppm Kd = 350 Kd = 1700	3.7 ppb 0.76 ppb	10.1 lbs 2.1 lbs
river (backwater)	largemouth bass TTF = 1.1	5.4 ppm crayfish TTF = 1.6	3.4 ppm Kd = 300	11.3 ppb	30.7 lbs
Kesterson wetland	Sacramento blackfish TTF = 1.1	5.4 ppm zooplankton TTF = 1.4	3.9 ppm Kd = 900	4.3 ppb	11.7 lbs
estuary Do not cite; preliminary provisional information subject to revision.	sturgeon TTF = 1.1	5.4 ppm *corbula* TTF = 6.2	0.87 ppm Kd = 3000	0.29 ppb	0.79 lbs

Allowable Dissolved Selenium



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USGS

Validation: data from historic and present-day watershed affected by Se

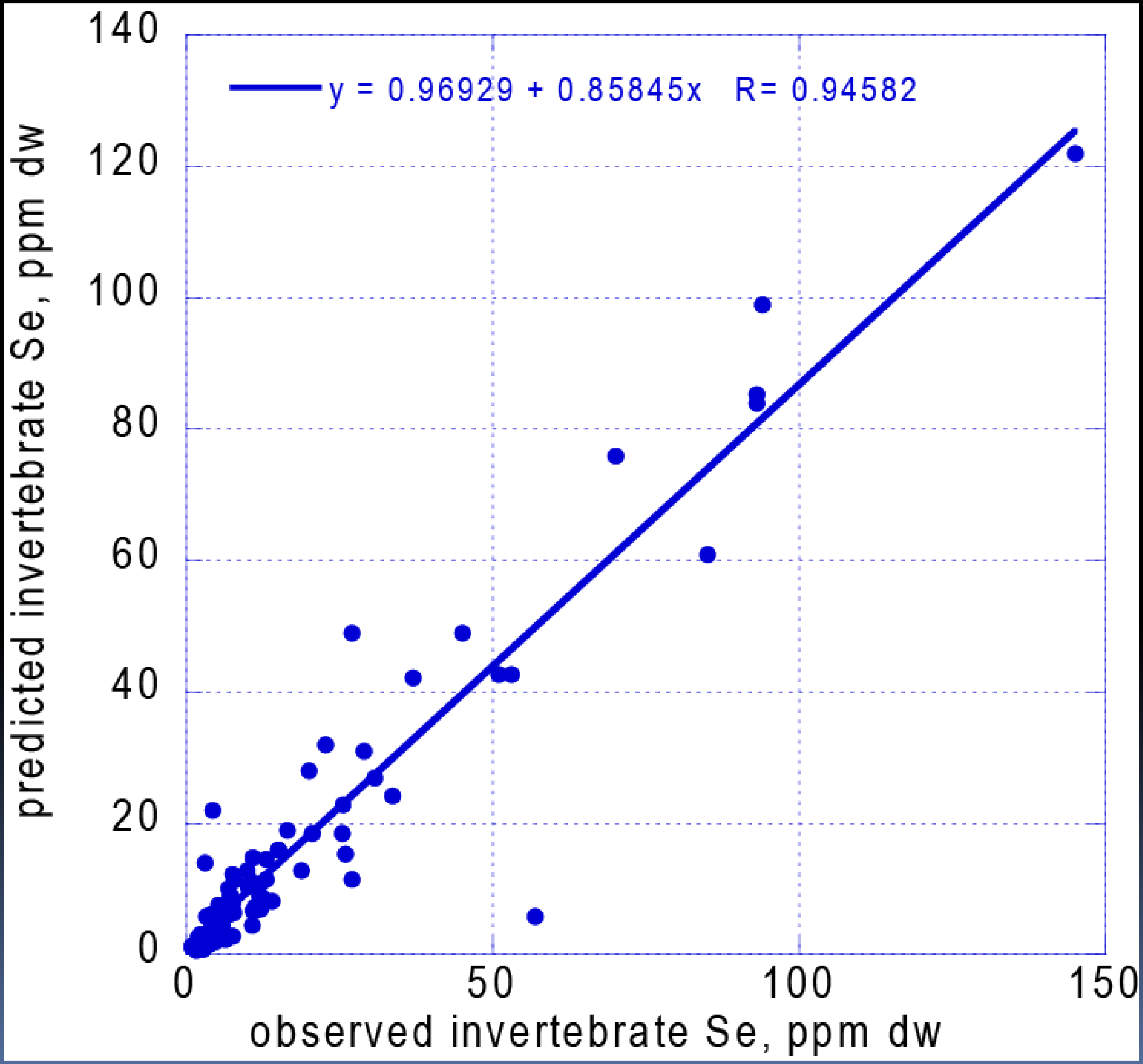
Fifty-five data sets including
Belews Lake and Hyco Reservoir, North Carolina
Kesterson Reservoir, San Joaquin River watershed, SF Bay, Newport Bay
Salton Sea, California
Great Salt Lake, Utah
Blackfoot River watershed, Idaho
Mud River watershed, West Virginia
Fording and Elk River watershed, British Columbia
McLeod River/Luscar Creek watershed, Alberta

$$C_{invertebrate} = (C_{particulate})\ (TTF_{invertebrate})$$

$$C_{fish} = (C_{particulate})\ (TTF_{invertebrate})\ (TTF_{fish})$$

$$[C_{bird} = (C_{particulate})\ (TTF_{invertebrate})\ (TTF_{bird})]$$

Predicted Invertebrate



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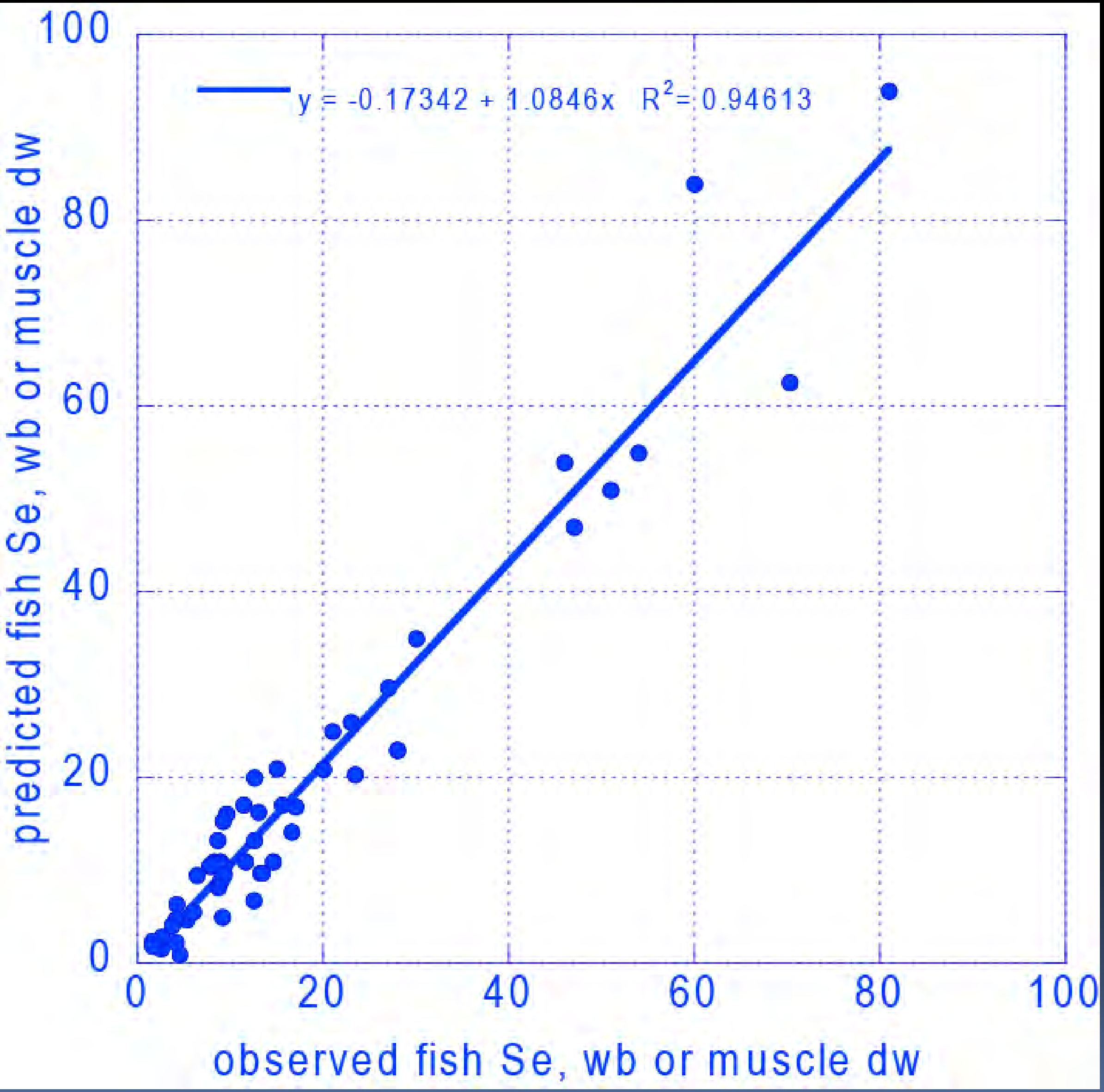
USGS

Predicted Fish



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USGS

BIRDS: site-specific and species specific (if 8.0 ppm Se dry weight egg guideline)

Kesterson wetland	stilt TTF = 1.8	4.4 ppm Se dw aquatic insect TTF = 2.8		1.6 ppm Se dw suspended material Kd = 450	3.6 Se ppb water-column if 1000 acre-feet	9.8 lbs Se load
Great Salt Lake	stilt TTF = 1.8	4.4 ppm brine fly TTF = 1.5 brine shrimp TTF = 4.2		2.9 ppm 1.0 ppm Kd = 1760	1.6 ppb 0.57 ppb	4.4 lbs 1.6
mountain stream	dipper TTF = 1.8	4.4 ppm aquatic insect TTF = 2.8		1.6 ppm Kd = 350 Kd = 1700	4.6 ppb 0.94 ppb	1.4 lbs 2.6 lbs
estuary	scaup TTF = 1.8	4.4 ppm *corbula* TTF = 6.2		0.71 ppm Kd = 3000	0.24 ppb	0.65 lbs
estuary	grebe TTF = 1.8	4.4 ppm topsmelt TTF = 1.1	4.0 ppm copepod TTF = 1.4	2.9 ppm Kd = 3000	0.97 ppb	2.6 lbs
Salton Sea	grebe TTF = 1.8	4.4 ppm topsmelt TTF = 1.1	4.0 ppm pileworms TTF = 6.0	0.67 ppm Kd = 1200	0.56 ppb	1.5 lbs

Understanding and Quantifying Processes

Critical Variables

source → environment → biodynamics → physiology → influx/efflux

load

↕

$C_{water\text{-}column}$ ↔ $C_{particulate}$ ↔ [AE, IR, k_e] $C_{invertebrate}$ ↔ [AE, IR, k_e] C_{fish} ↔ [AE, IR, k_e] C_{bird}

$K_d = \frac{C_{particulate}}{C_{water\text{-}column}}$

$TTF_{invertebrate} = \frac{C_{invertebrate}}{C_{particulate}}$

$TTF_{fish} = \frac{C_{fish}}{C_{invertebrate}}$

$TTF_{bird} = \frac{C_{bird}}{C_{invertebrate}}$