Willamette Mercury TMDL

TMDL Technical Approach

Willamette Mercury TMDL Advisory Committee Meeting
February 15, 2018

DEQ

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

TETRA TECH

complex world | CLEAR SOLUTIONS™

Willamette Mercury TMDL Advisory Committee Meeting

February 15, 2018

OVERVIEW OF TECHNICAL APPROACH

Context and Constraints

- ► Court Decision
  - Specifies certain things that must be done and a schedule
- ► Contract
  - Tetra Tech Region 10 TMDL Support Contract end in March, will be rebid
- ► Funding
  - EPA has limited funding through March; unclear what may be available thereafter

Technical Work Objectives

- ► Produce complete package by end of March
- ► Meet requirements of Court Decision
- ► Document all analyses per QAPP
- ► Lay framework for further refinement if resources allow

TETRA TECH

SECTION I: USEPA QA/R-5 GROUP A, PROJECT MANAGEMENT

I.A TITLE AND APPROVAL SHEET

Modeling Quality Assurance Project Plan

for

Mercury TMDL Development for Willamette River Basin (Oregon)

Contract EP-C-12-055
Task Order 22

Prepared for:

USEPA, Region 10
1200 Sixth Avenue, Suite 900
Seattle, WA 98101

Prepared by:

Tetra Tech, Inc.
PO Box 14409
One Park Drive, Suite 200
Research Triangle Park, NC 27709

December 26, 2017

QAPP 491, Draft Revision 2

This quality assurance project plan (QAPP) has been prepared according to guidance provided in the following documents to ensure that environmental and related data collected, compiled, and/or generated for this project are complete, accurate, and of the type, quantity, and quality required for their intended use:

- *EPA Requirements for Quality Assurance Project Plans* (EPA QA/R-5, EPA/240/B-01/003, U.S. Environmental Protection Agency, Office of Environmental Information, Washington DC, March 2001 [Reissued May 2006])
- *EPA Office of Water Quality Management Plan*. (EPA/821/R-09/001, U.S. Environmental Protection Agency, Office of Water, Washington DC, February 2009)
- *Guidance for Quality Assurance Project Plans for Water Quality Modeling Projects* (EPA 910-R-16-007, U.S. Environmental Protection Agency, Region 10, Office of Environmental Review and Assessment, Seattle, WA, December 2016)

Court Requirements

- ► Submit revised TMDL by 4 April 2019
  - Technical work needs to be done by early Fall 2018 to allow sufficient time for public notice and review
- ► Incorporate revised Oregon fish tissue criterion for protection of human health
- ► Revise existing TMDL to “incorporate all the new data related to mercury that has been gathered since the first TMDL”

Court Requirements (continued)

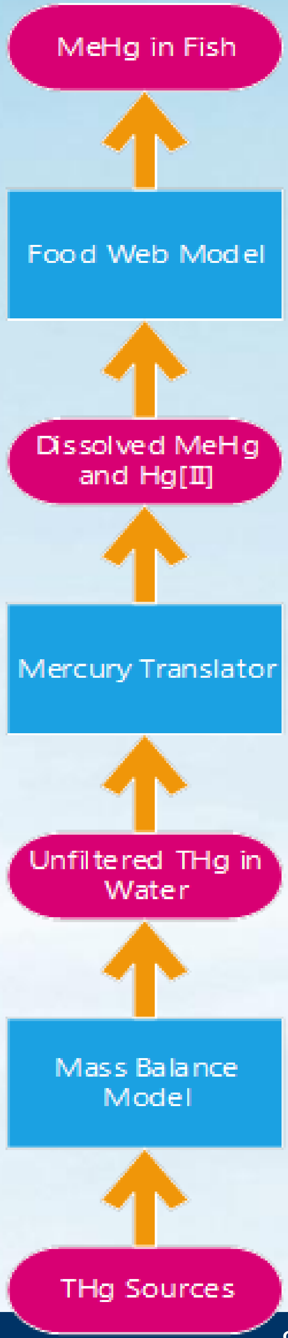
- Analyze "factors affecting mercury pollution, including potential multiple sources, bioaccumulation patterns, and changes in the types of mercury being released and transformed in the entire complex river system"
- Incorporate maximum daily load targets (TM**D**L)
- Assign wasteload allocations (WLAs) to point sources

How do we accomplish this, given schedule and budget constraints?

- Work with the 2006 TMDL analysis framework and components, but update and improve them where possible
- Design analyses to support further refinement if future work is funded

The 2006 TMDL Linkage Analysis

- ► Link sources of total mercury (THg) to methylmercury (MeHg) in fish
- ► Three components:
  - **Mass Balance Model**: Link THg sources in the watershed to instream concentrations
  - **Mercury Translator**: Link THg concentrations to MeHg and Hg[II] exposure concentrations
  - **Food Web Mode**l: Link exposure concentrations of MeHg to fish tissue



TMDL Approach: Simplified Reality!

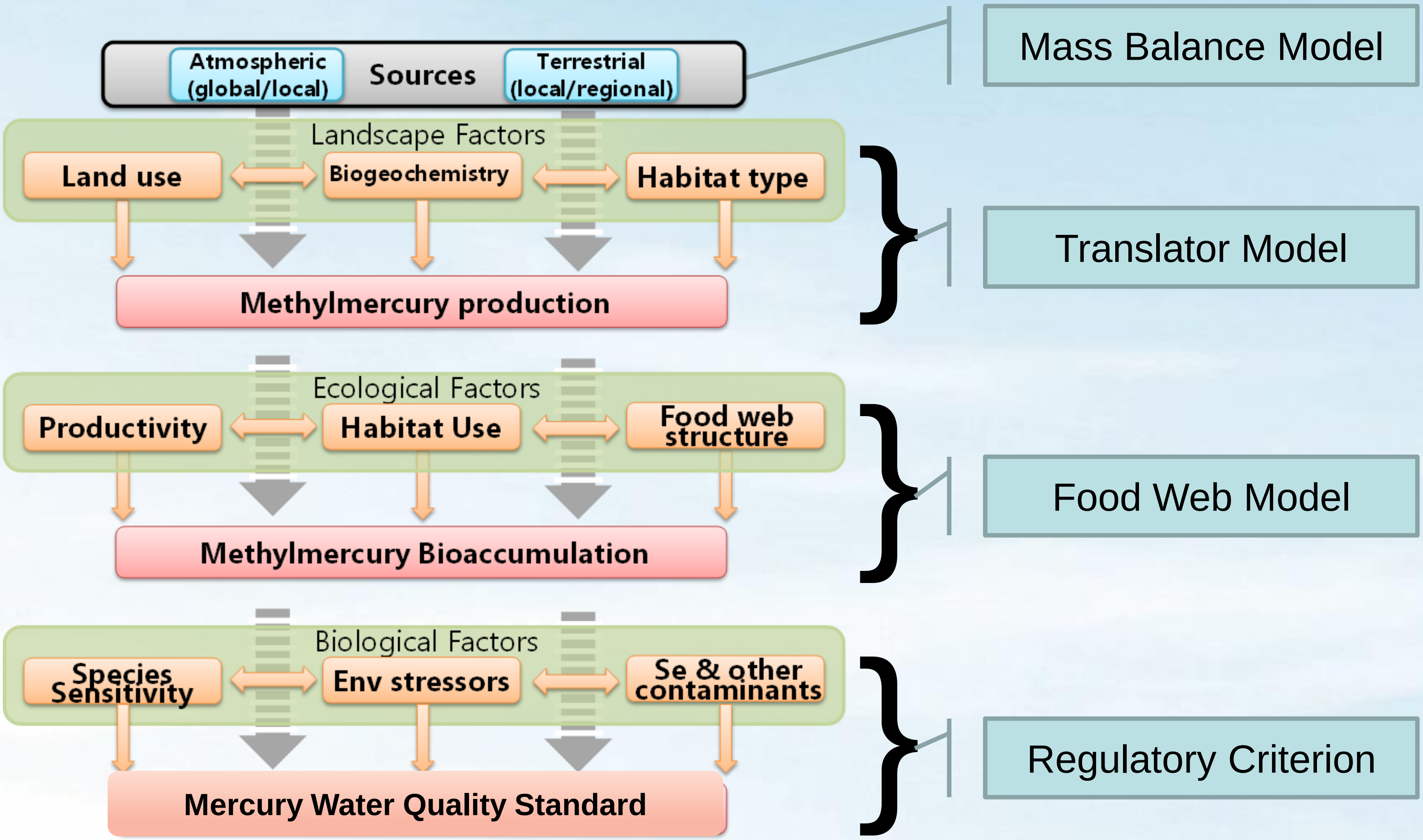


Figure adapted from: Eagles-Smith, C.A., et al. 2016. "Mercury in western North America: A synthesis of environmental contamination, fluxes, bioaccumulation, and risk to fish and wildlife." *Science of the Total Environment* 568: 1213-1226

MeHg Production

- MeHg is the form that bioaccumulates; most Hg in environment is in inorganic forms (Hg[II] and elemental Hg_0)
- Methylation is a byproduct of bacterial reduction of sulfate under low oxygen conditions in soils, sediment, or lake bottom water
- Depends in non-linear ways on temperature, carbon, sulfur, and reduction/oxidation conditions – for much of which we have limited data in WRB

MeHg Production (continued)

- ► Many attempts have been made to model methylation on a process basis at a watershed scale, but these have shown limited success at detailed prediction of MeHg production, which depends on complex site-specific details
- ❖ *Therefore*: use of empirical local relationships between MeHg and THg (the Translator Model) is an appropriate method for TMDL development

Willamette Mercury TMDL Advisory Committee Meeting

February 15, 2018

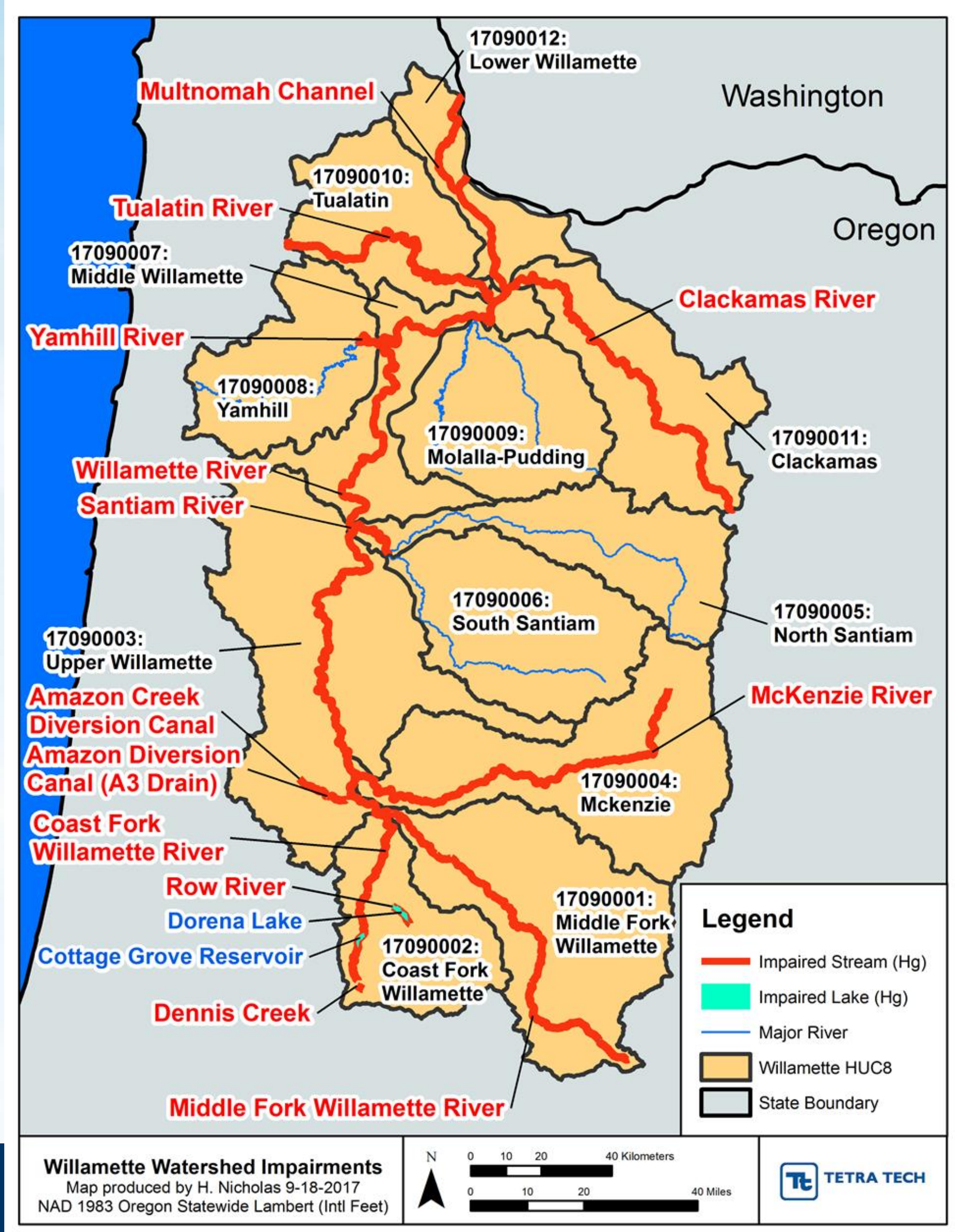
DATA SUMMARY

Data

- Plentiful new monitoring over multiple years since 2006 TMDL
- 2006 TMDL relied in large part on one year of MeHg sampling in 2002-2003
- But, mercury cycling is highly complex, and the watershed occupies 11,500 mi^2 so data will remain a concern
- Start with impairment listings, based on fish tissue concentrations

Waterbody Segments Impaired for Mercury in WRB

- ► 37 stream and 2 lake segments (2012 Integrated Report)
  - All to be addressed in revised TMDL
- ► 2006 TMDL addressed 8 segments (mainstem, Coast Fork, and two reservoirs)

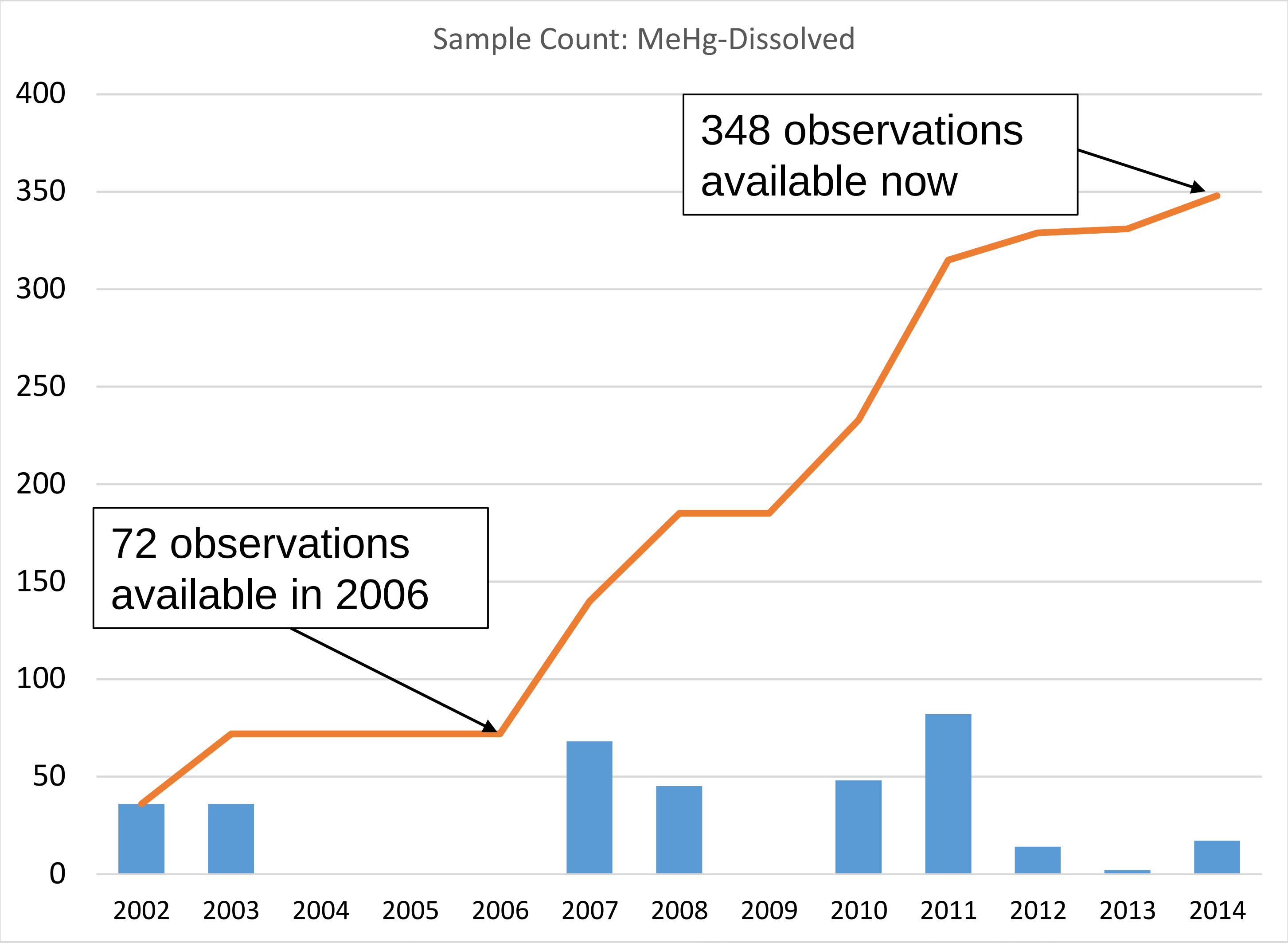


TETRA TECH

Data Sources and Types

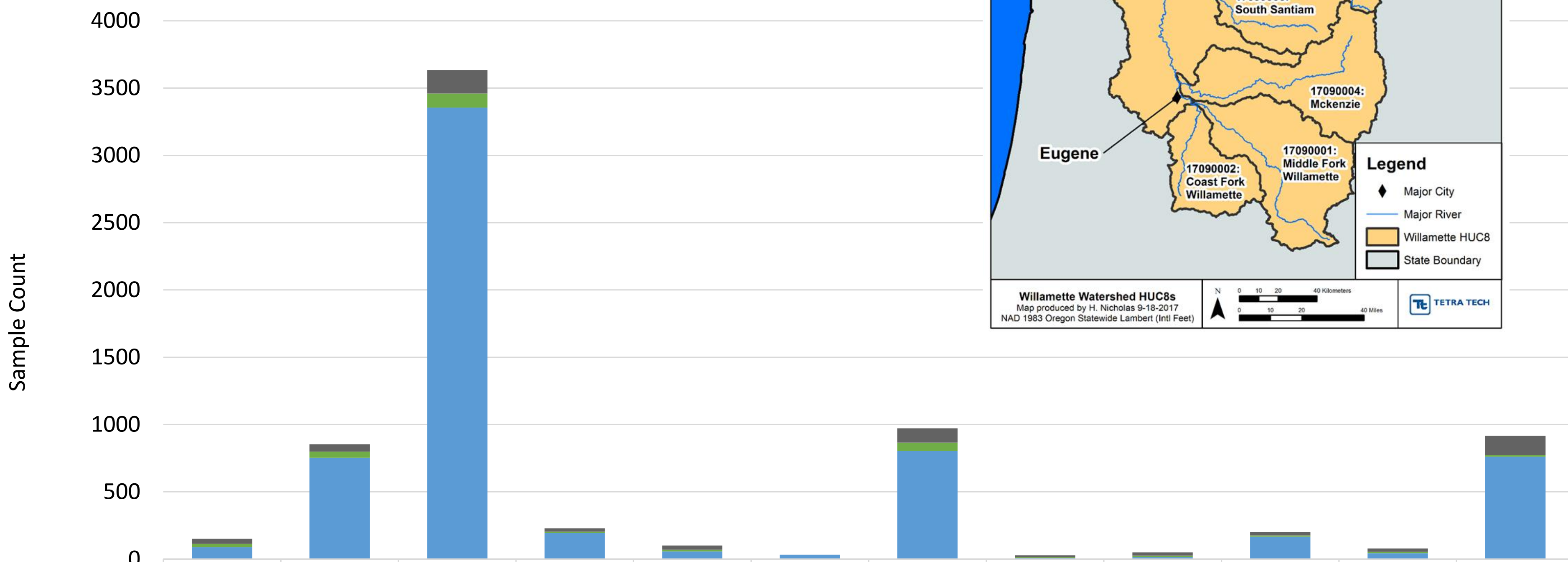
- ► Ambient monitoring by ODEQ and USGS
- ► Special studies (e.g., Cottage Grove Reservoir, Portland Harbor Superfund)
- ► Regional studies (Western North America Mercury Study)
- ► 2006 TMDL relied on MeHg, THg, and fish data from 2002-2003, plus older THg and fish data
- ► Current update: Use data from 2002 to present due to improvements in sampling and analytical methods

Temporal Distribution



Data Availability by HUC8

(Data currently in hand with confirmed location identification)



	Middle Fork Willamette 17090001	Coast Fork Willamette 17090002	Upper Willamette 17090003	Mckenzie 17090004	North Santiam 17090005	South Santiam 17090006	Middle Willamette 17090007	Yamhill 17090008	Molalla-Pudding 17090009	Tualatin 17090010	Clackamas 17090011	Lower Willamette 17090012
Water, THg	38	54	173	25	31	0	106	15	24	24	25	142
Water, MeHg	25	45	105	9	13	0	63	5	10	9	12	13
Fish, THg	88	754	3355	195	57	32	803	8	16	167	43	761

TETRA TECH

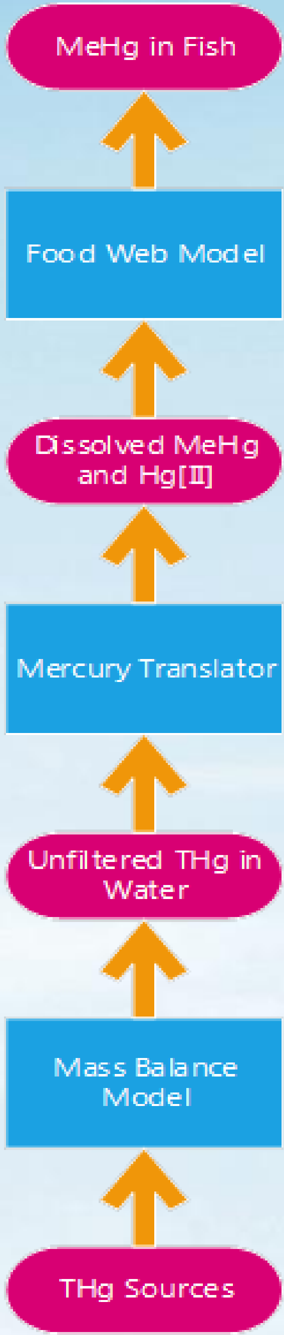
Current Data Gaps

- Limited Hg data in some HUC8s (e.g., South Santiam)
- Limited data on Hg in 9 of 11 major reservoirs in the watershed
- Largely lacking cofactor data on sulfur cycle, redox, and other factors that drive methylation
- Limited information on how food web structure varies across the watershed
- *The level of data is acceptable for TMDL development*

Willamette Mercury TMDL Advisory Committee Meeting

February 15, 2018

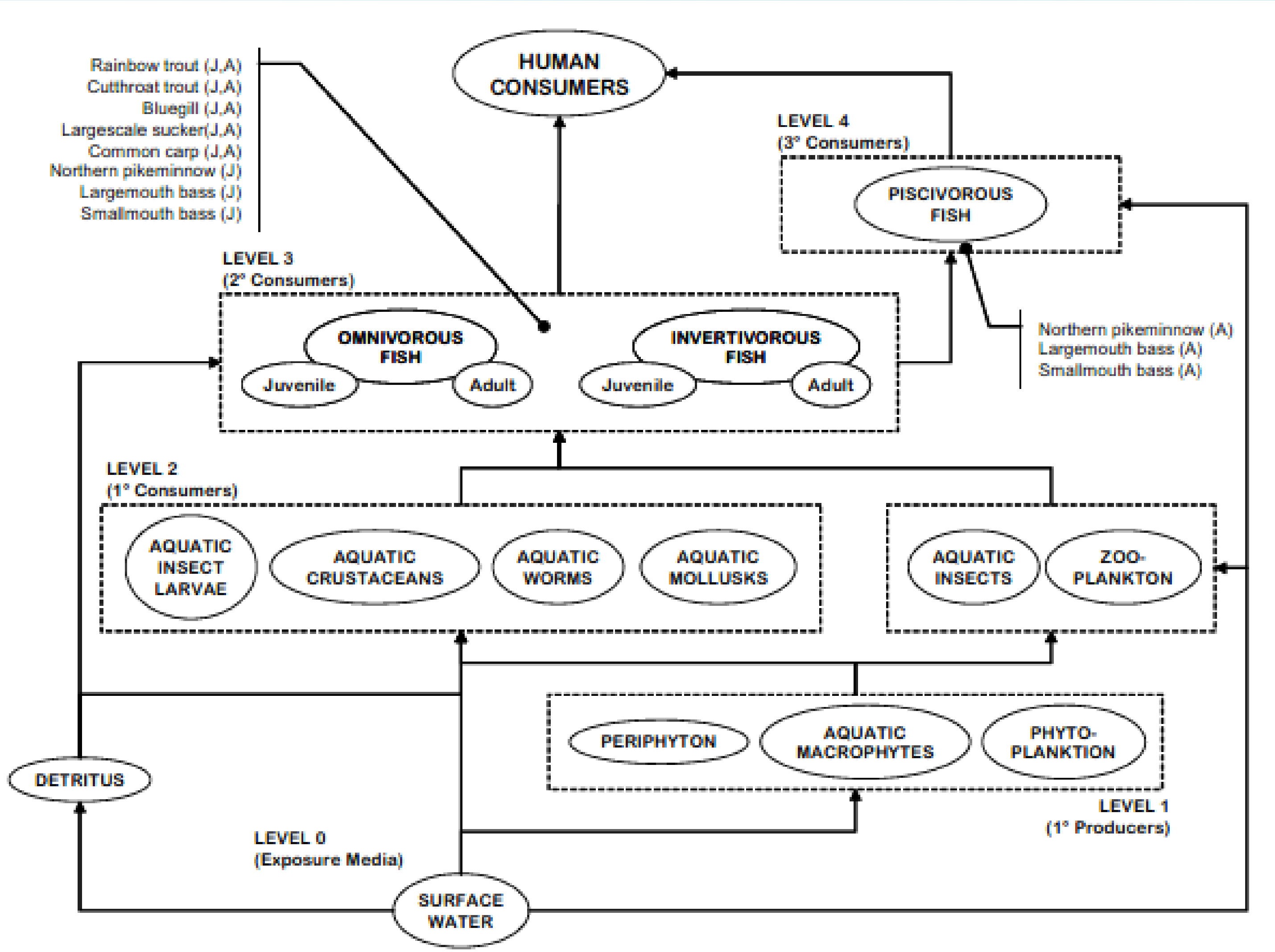
FOOD WEB MODEL



Food Web Model (FWM)

- *Purpose of the Model*: Determine exposure concentrations (MeHg, Hg[II]) that are consistent with achieving fish tissue targets in each species of interest
- Probabilistic ("Monte Carlo") model that draws thousands of samples from the distributions of input variables to build up a cumulative distribution function of the response
- Describes accumulation of mercury through complex food web relationships ("who eats what")
- Originally developed in Crystal Ball software; Tetra Tech successfully converted to R statistical programming language

Feeding Relationships in the FWM



Food Web Model

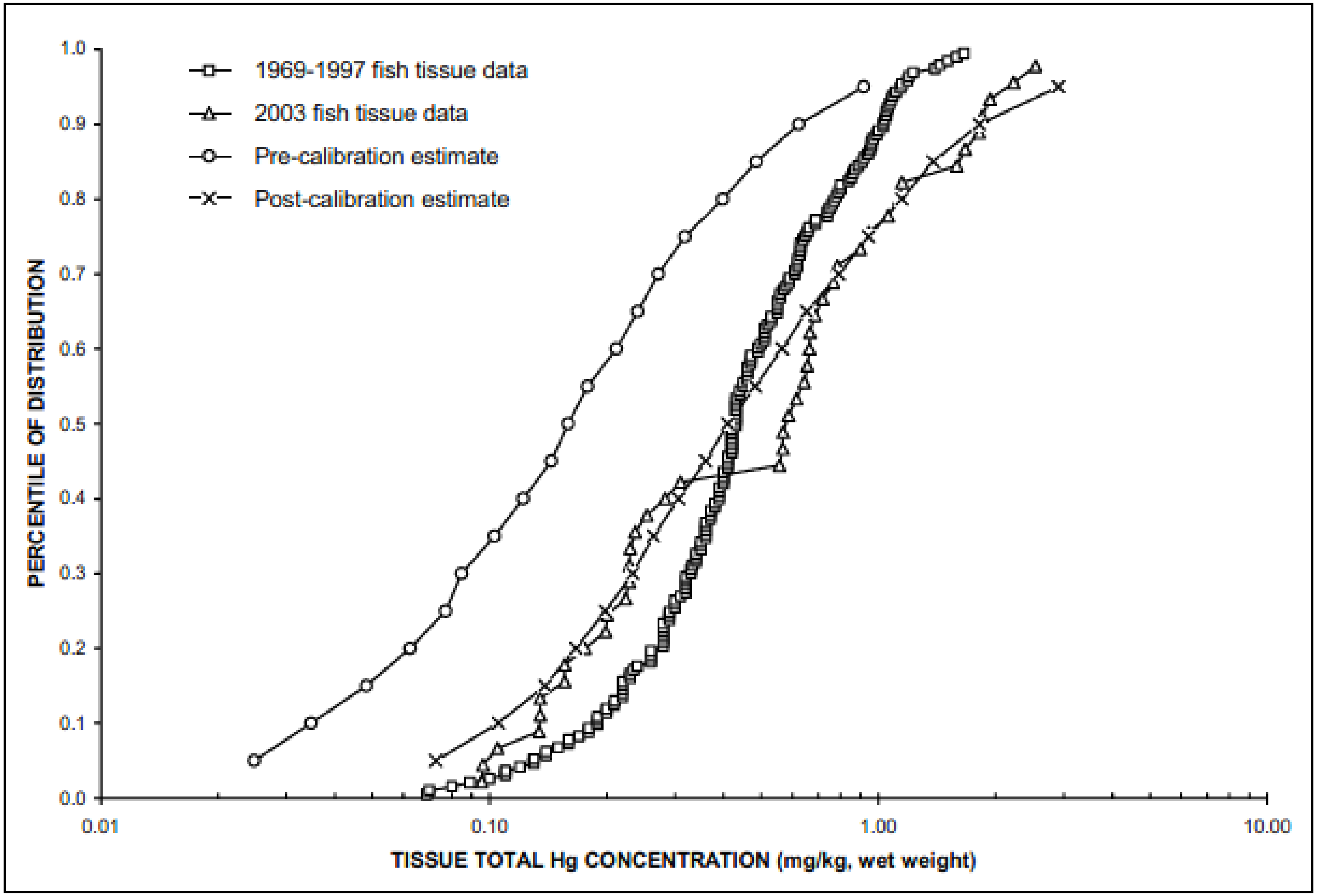
- Uses MeHg and Hg[II] exposure and tissue data from all parts of the WRB
- MeHg:THg and Hg[II]:THg ratios established separately by Mercury Translator Model
- Calculate distribution of biomagnification factors (BMFs) for TL4 and TL3 fish: Northern Pikeminnow, Largemouth Bass, Smallmouth Bass, Rainbow Trout, Carp, Largescale Sucker, Bluegill, Cutthroat Trout

Who Eats What…

Table 5. Matrix of predator-prey interactions included in the model.

pred →												NPM		LMB		SMB		LSS		CAR		RBT		CTT		BLU	
prey ↓		DET	AQP	PHY	PER	ZOO	AQL	AQC	AQI	AQM	AQW	J	A	J	A	J	A	J	A	J	A	J	A	J	A	J	A
DET						●	●	●	●		●							●	●		●					●	●
AQP							●	●	●									●	●		●					●	●
PHY						●				●								●	●	●	●				●	●	●
PER							●	●			●							●	●	●	●					●	●
ZOO							●	●	●	●		●		●		●		●	●	●	●	●		●	●	●	●
AQL									●			●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
AQC													●	●	●		●		●		●		●			●	●
AQI												●	●	●	●	●	●		●		●	●	●	●	●	●	●
AQM									●										●		●					●	●
AQW														●		●			●		●		●		●	●	●
NPM	J												●	●	●	●	●						●		●		●
	A														●		●										
LMB	J											●	●		●	●	●						●		●		●
	A												●				●										
SMB	J											●	●	●	●		●						●		●		●
	A												●		●												
LSS	J											●	●	●	●	●	●						●		●		●
	A												●		●		●										
CAR	J											●	●	●	●	●	●						●		●		●
	A												●		●		●										
RBT	J											●	●	●	●	●	●						●		●		●
	A												●		●		●										
CTT	J											●	●	●	●	●	●						●		●		●
	A												●		●		●										
BLU	J											●	●	●	●	●	●						●		●		●
	A												●		●		●										

2006 FWM: Calibration for Largemouth Bass



TETRA TECH

2006 FWM: Biomagnification Factors: Use to Calculate Acceptable MeHg/hg[II] Exposure Concentrations for Each Species

Table 8. Comparison of model estimated biomagnification factors for eight species of Willamette River fish and U.S. EPA national bioaccumulation factors for mercury.

Fish Species	Model Estimates (L/kg) [a]			
	5^{th}-%tile	50^{th}-%tile	Mean	95^{th}-%tile
TROPHIC LEVEL 4 SPECIES				
Northern pikeminnow	2.20×10^{6}	1.02×10^{7}	1.67×10^{7}	4.83×10^{7}
Largemouth bass	1.60×10^{6}	7.70×10^{6}	1.39×10^{7}	4.34×10^{7}
Smallmouth bass	4.36×10^{5}	3.67×10^{6}	8.10×10^{6}	3.03×10^{7}
U.S. EPA direct estimate bioaccumulation factor for trophic level 4 species [4, Tables D-8 and -19]	3.26×10^{5}	6.81×10^{6}	1.11×10^{7}	1.42×10^{7}
TROPHIC LEVEL 3 SPECIES				
Rainbow trout	4.15×10^{5}	2.20×10^{6}	4.03×10^{6}	1.32×10^{7}
Carp	8.56×10^{5}	4.09×10^{6}	6.92×10^{6}	2.19×10^{7}
Largescale sucker	7.23×10^{5}	3.46×10^{6}	6.04×10^{6}	1.95×10^{7}
Bluegill	5.41×10^{5}	2.61×10^{6}	3.87×10^{6}	1.14×10^{7}
Cutthroat trout	3.39×10^{5}	1.54×10^{5}	2.60×10^{6}	7.92×10^{6}
U.S. EPA direct estimate bioaccumulation factor for trophic level 3 species [4, Tables D-7 and -18]	4.61×10^{5}	1.58×10^{6}	2.09×10^{6}	5.41×10^{6}

FWM Model Sensitivity Analysis

- ► Key factors contributing to variance in fish Hg:
  1. Diet specification
  2. MeHg elimination rate coefficients
  3. MeHg assimilation efficiency
  4. Adult body length (surrogate for weight/age)
- ► Items 2 and 3 were focus of previous calibration
- ► Plentiful new data to specify 4 and better fit 2 and 3
- ► Are there newer studies for item (1)?

FWM Refinement (Future Work?)

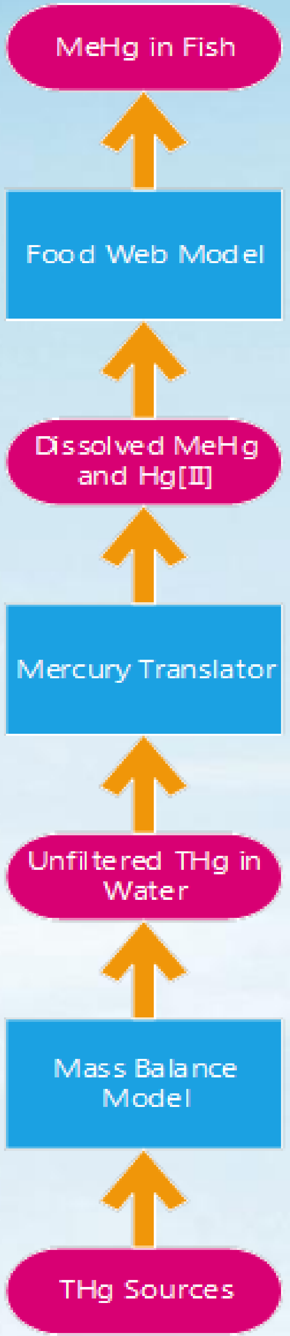
- Current Work: Single FWM represents entire WRB
  - Meets requirements of Court decision
- Desirable: Separate FWMs for different ecoregions
  - Different fish species prevalence
  - Different food web structure
  - Significant differences in temperature that affect growth, MeHg elimination, etc.
- 2006 TMDL recommended 4 zones
  - Considerable research, local expert consultation needed to specify model structure – not consistent with March schedule
  - Note: Can look at spatial differences in MeHg:THg translator even without separate FWMs

Questions?, Discussion …then lunch

Willamette Mercury TMDL Advisory Committee Meeting

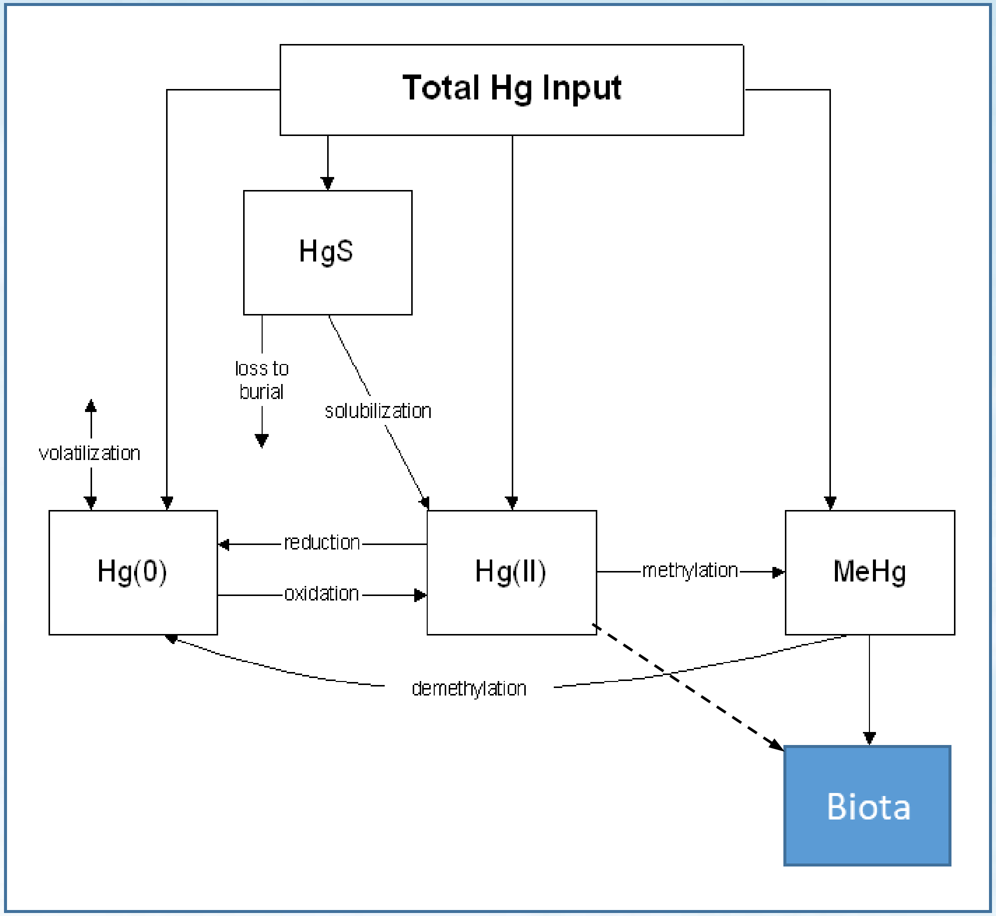
February 15, 2018

MERCURY TRANSLATOR MODEL



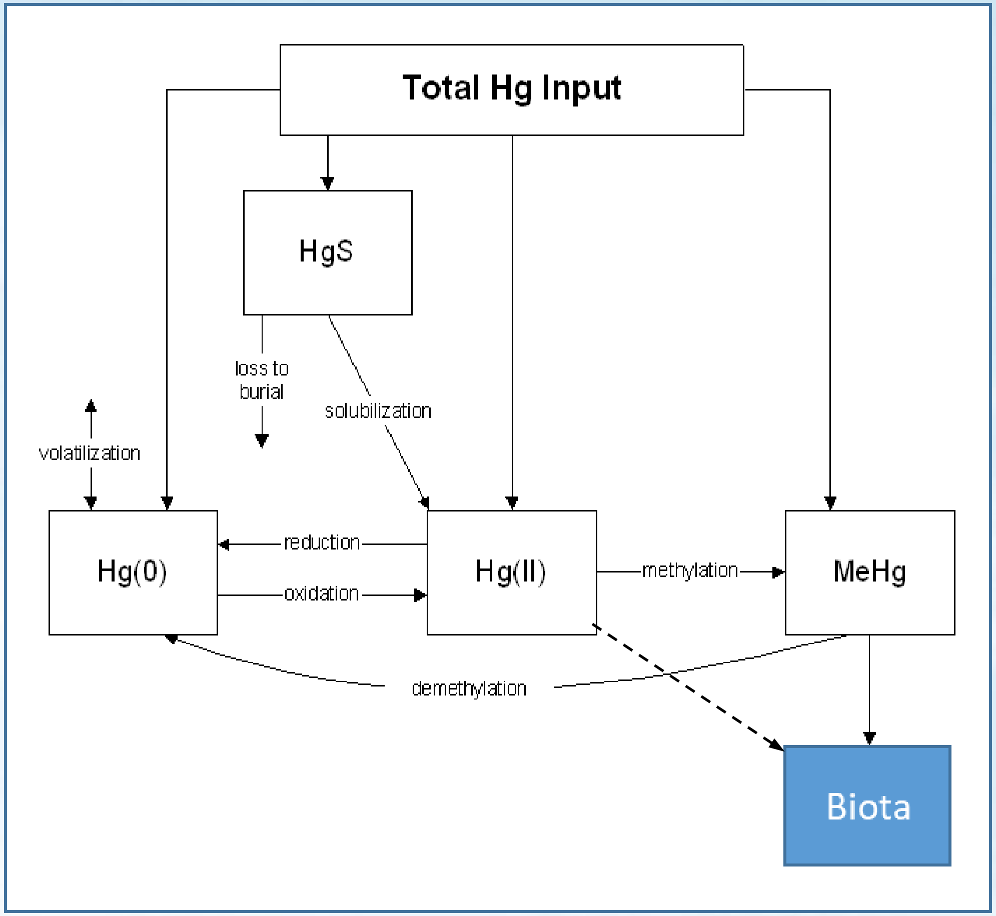
Mercury Translator Model: Relating Total Hg Input to Biotic Exposure Concentrations

- Bioaccumulation driven primarily by dissolved MeHg
- MeHg is reactive: Created by bacterial methylation, de-methylated by bacteria and light
- MeHg created from dissolved inorganic Hg[II], but this fraction is also not constant



Dissolved and Total, Methyl and Inorganic Mercury

- MeHg is mostly created in the environment, not directly loaded
- Chemical differences between effluent sources and receiving water are expected to result in changes in the dissolved and particle-bound fractions



Mercury Translator Model (Ω)

- *Purpose*: Convert dissolved MeHg [dMeHg] target exposure concentrations from FWM to corresponding THg concentration targets in water
- Translator is an empirical approximation of the complex relationships that determine Hg solubility and methylation
- Ω = ratio of dMeHg to THg over an appropriate spatial and temporal scale

Refining the Translator

- Large amounts of paired data now available
- Examine extent to which data support and suggest different translator relationships in different parts of the watershed and/or for different seasons
- Document results to EPA and ODEQ and, if warranted, calculate different Translator relationships for different locations or seasons

Mercury Translator Model - Details

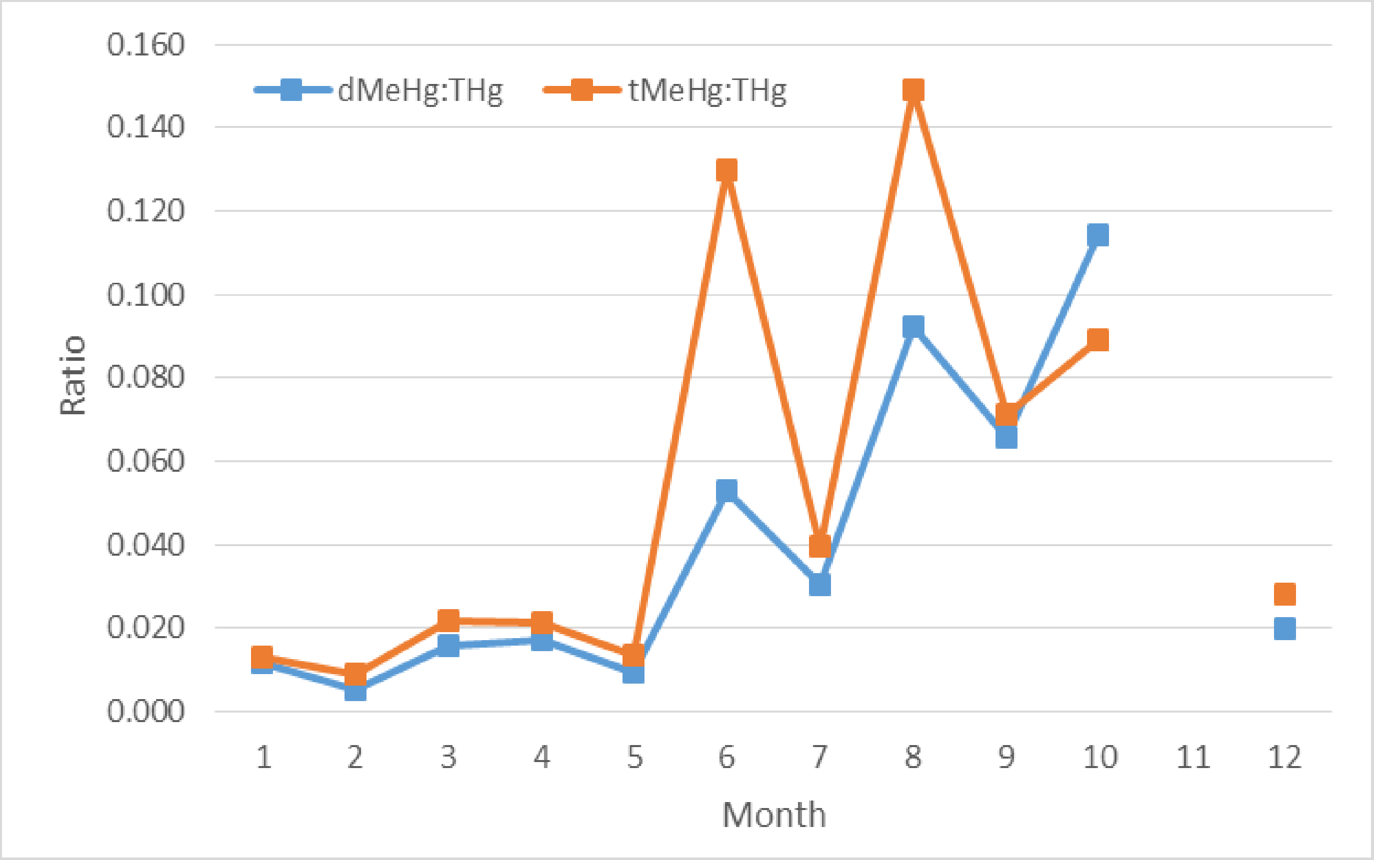
- Expect Ω may vary according to local biochemical conditions
- We don't expect constant ratio in paired-in-time data due to delays between THg delivery and methylation
- Need to account for presence of non-detects (Helsel, *Nondetects and Data Analysis*; R "NADA" package)

Analyte	**Non-detects**	**Estimated Values**
dMeHg	53.4%	11.0%
THg	4.1%	2.8%

Seasonal Variation in Ω

- 2006 TMDL recommended examining seasonal variation
- THg concentrations tend to be highest in winter-spring runoff
- dMeHg:THg ratios tend to be highest in summer and fall when THg on average is lower
- Potential adjustment: Calculate Ω on a seasonal basis, integrate to obtain annual target for THg load to achieve the MeHg exposure target

MeHg:THg Ratios, Seasonal Differences



Average ratio by month, uncensored data only

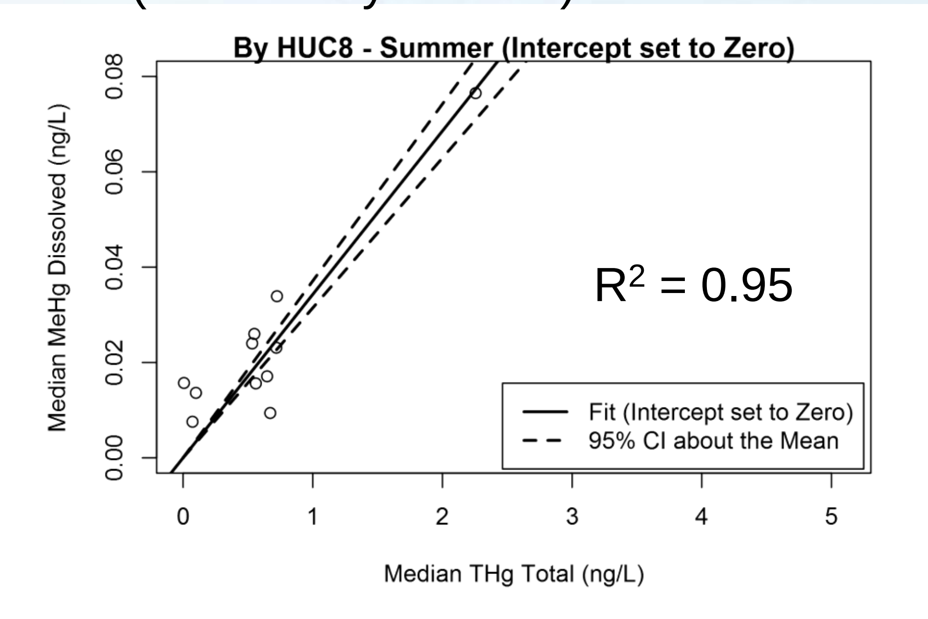
Spatial and Temporal Aggregation

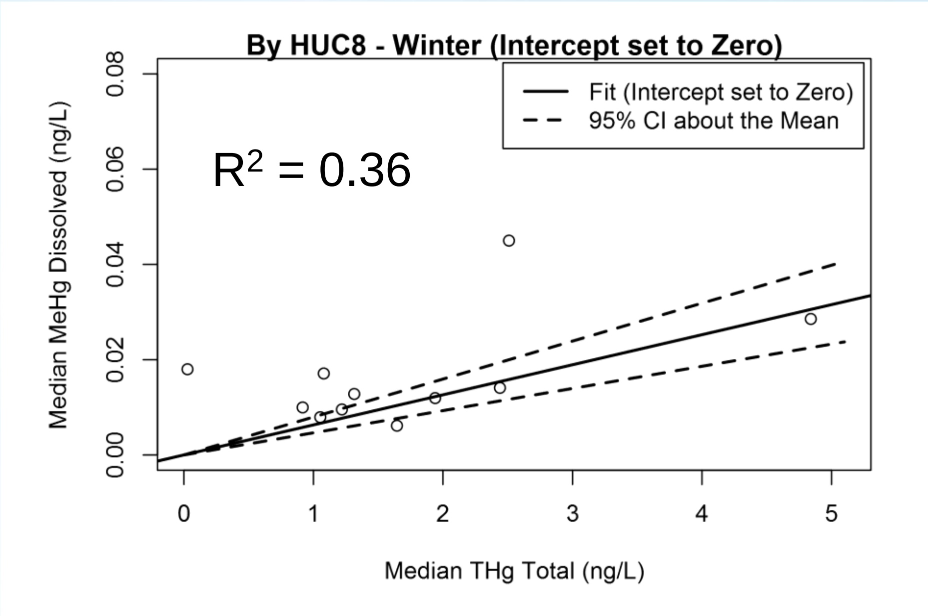
- THg varies by HUC8, but ratio of dMeHg to THg is relatively constant across all HUC8s
- Compare
  - Direct estimate of ratio from paired data using Akritas-Theil-Sen non-parametric slope estimate to address censoring
  - Aggregated approach with local medians of THg and dMeHg calculated by HUC8 with robust Regression on Order Statistics (ROS) and ratio of medians combined across all HUC8s with weighted regression (based on sample size)
  - Use medians to reduce influence of anomalies and outliers

Aggregated Seasonal Approach to Mercury Translator

- ► Provides best performance
- ► Provides the answer we need (time-averaged THg concentration corresponding to steady-state dMeHg target from FWM)

(Preliminary Results)





Willamette Mercury TMDL Advisory Committee Meeting

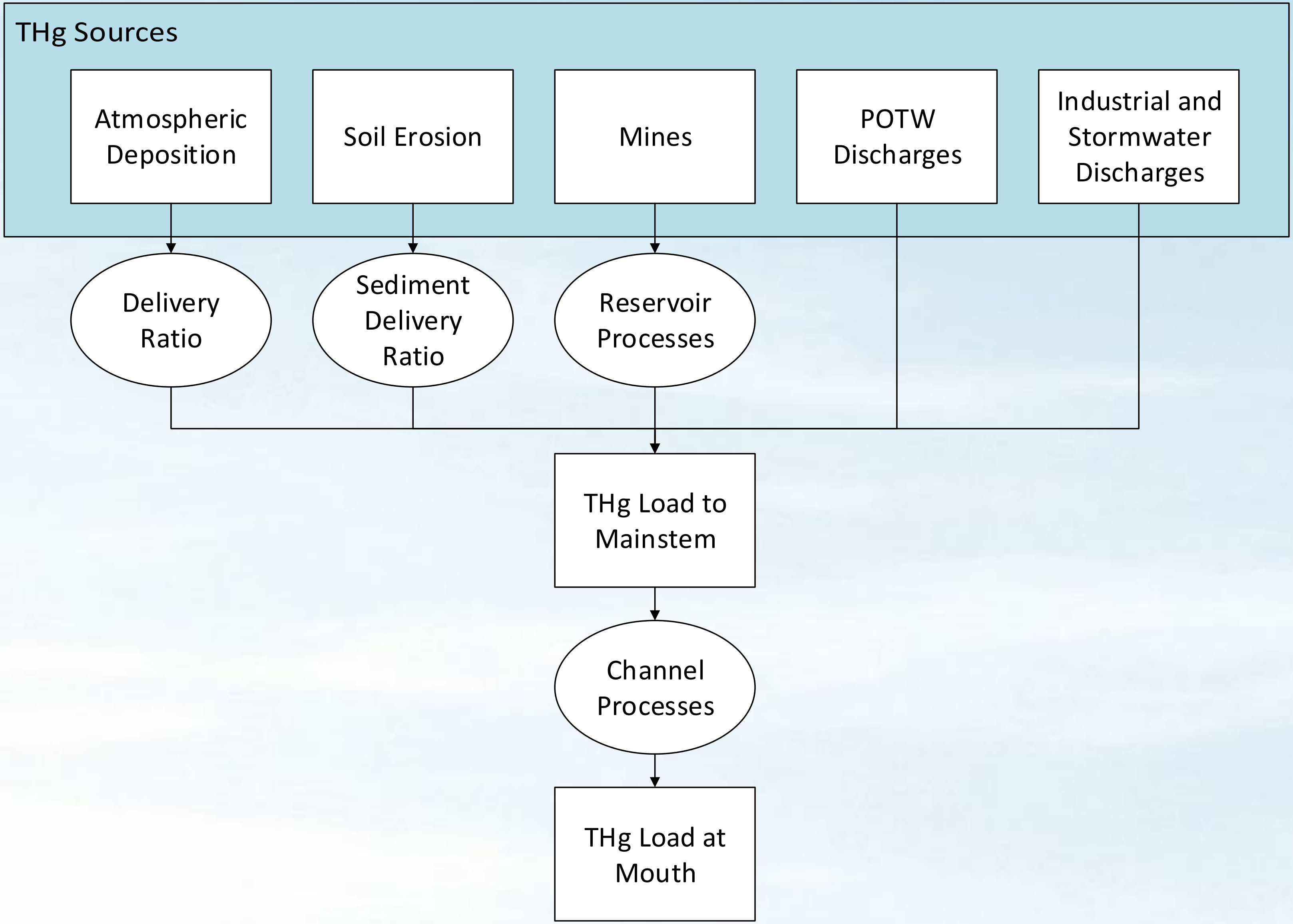
February 15, 2018

MASS BALANCE MODEL

Mass Balance Model

- *Purpose*: Connect sources of THg load throughout the watershed to ambient THg concentrations within the river network
- 2006 TMDL:
  - Estimated THg load at Portland using a non-linear rating curve relationship between THg concentration and flow, with flow based on regression against drainage area
  - Estimated THg contributions by combining source load information with assumptions about delivery ratios

Mass Balance Model, 2006 TMDL



Weaknesses in 2006 Mass Balance

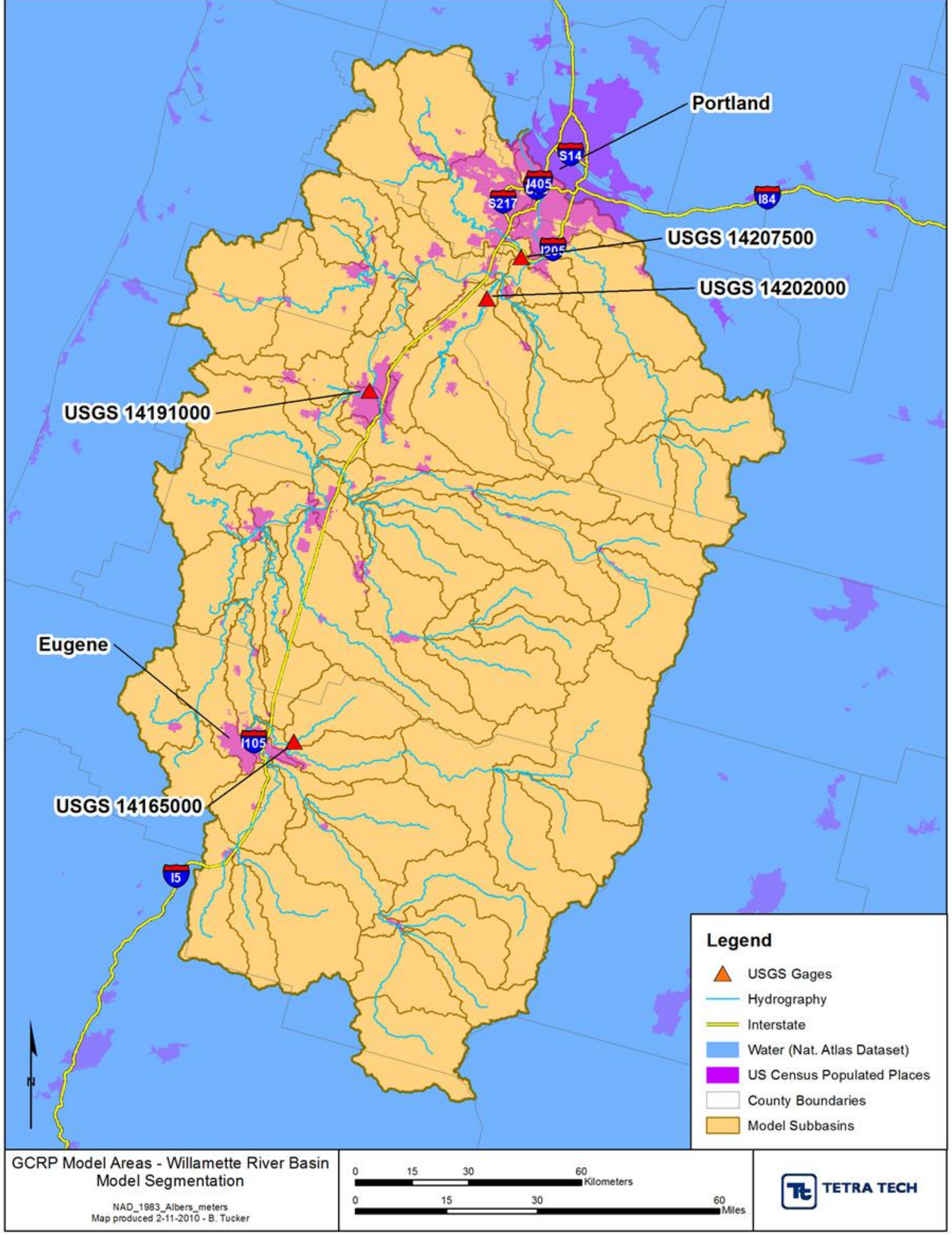
- Used USLE soil erosion, single, uniform soil THg concentration, and generic delivery ratio
- Required delivery ratio estimate for atmospheric deposition
- Channel processes used as correction factor
- Focus on load at mouth – but THg concentration predictor had R^2 of only 20%
- Best that could be done in 2006 due to lack of watershed model and limited data

Improving the Mass Balance Model

- Lots more data
- Real need is for a watershed model that predicts flow and sediment loading/transport throughout the WRM
- Schedule not consistent with developing and calibrating a new watershed model for this 11,500 mi^2 watershed
- Fortunately, we have a model available

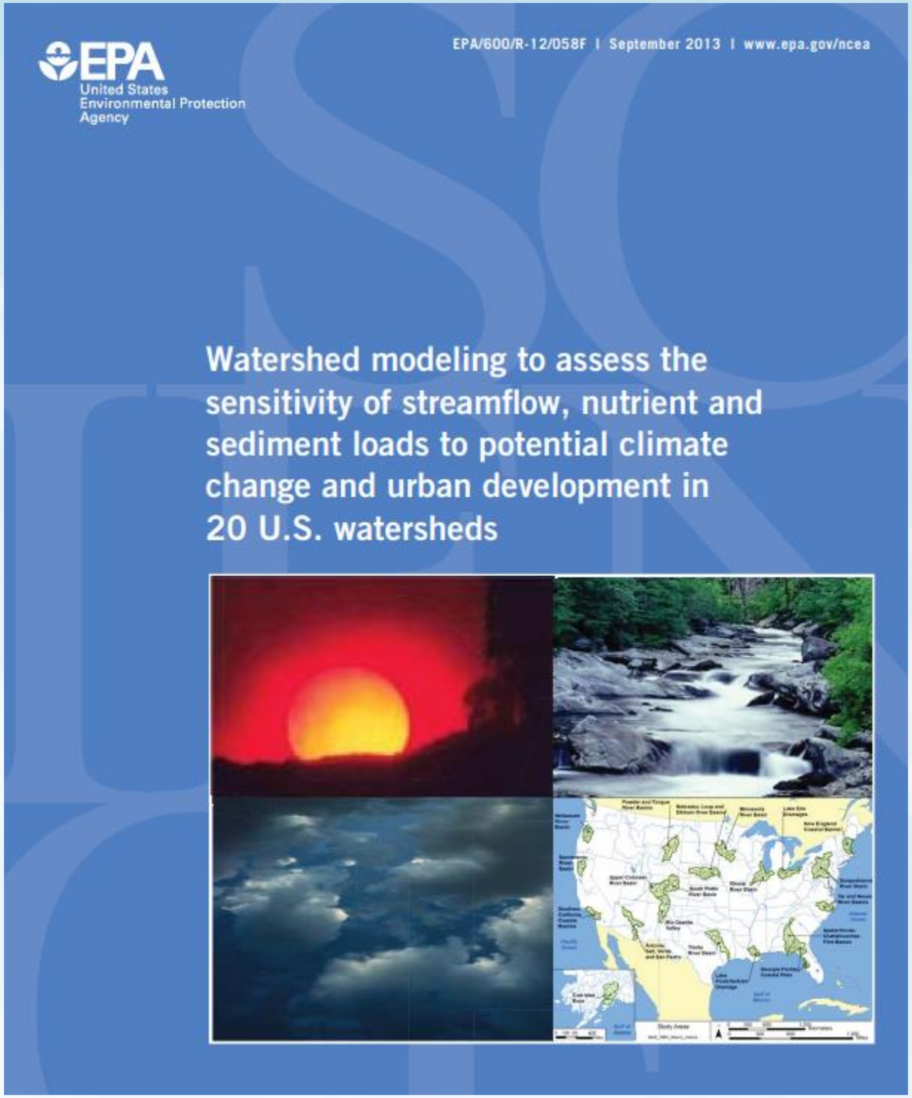
Calibrated Watershed Model

- Hydrologic Simulation Program – FORTRAN (HSPF)
- Developed by Tt and AQUA TERRA to support an EPA climate study



WRB HSPF Model

- U.S. EPA. *Watershed Modeling to Assess the Sensitivity of Streamflow, Nutrient, and Sediment Loads to Potential Climate Change and Urban Development in 20 U.S. Watersheds* (Final Report). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-12/058F, 2013.
- https://cfpub.epa.gov/ncea/global/recordisplay.cfm?deid=256912



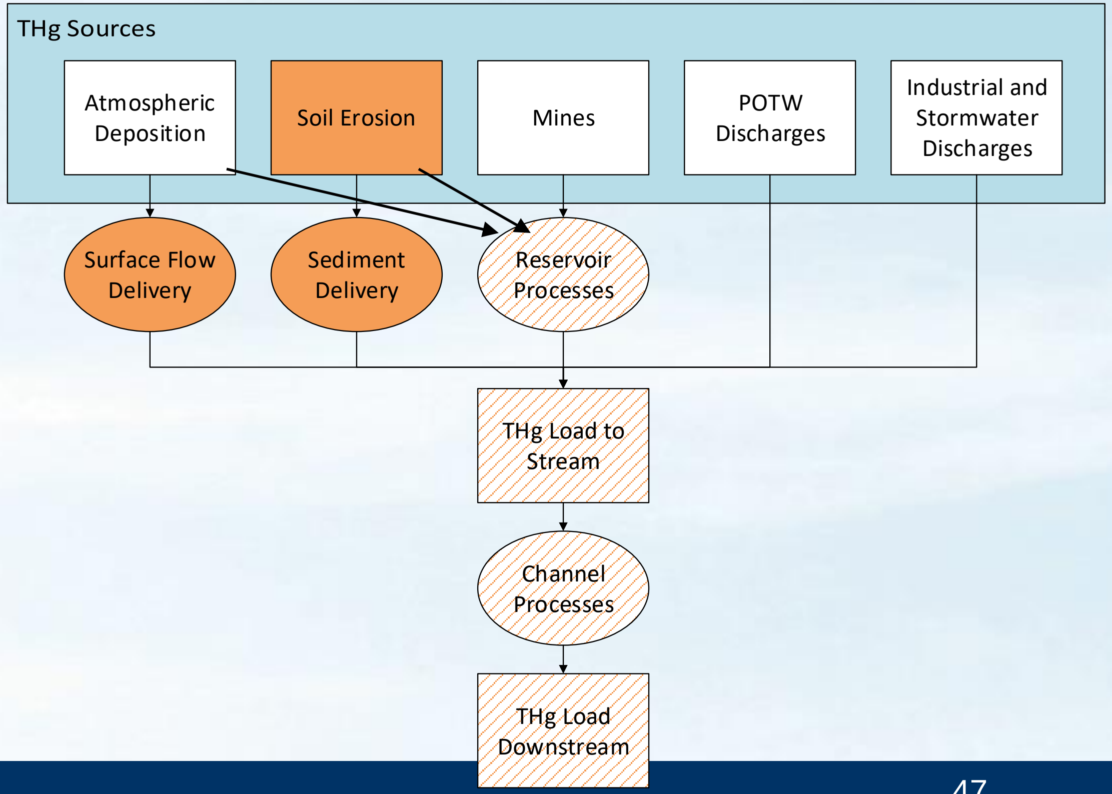
Use of the HSPF Model

- Model is developed for 1976-2005, calibrated for flow and sediment - not calibrated for mercury
- Incorporates 40 weather stations, 11 land cover types combined with soil information and imperviousness
- Appropriate uses: Long-term average results for unit area land cover
  - Surface and subsurface flow components
  - Flow contribution by watershed
  - Sediment erosion and delivery to and through stream network, including reservoir trapping

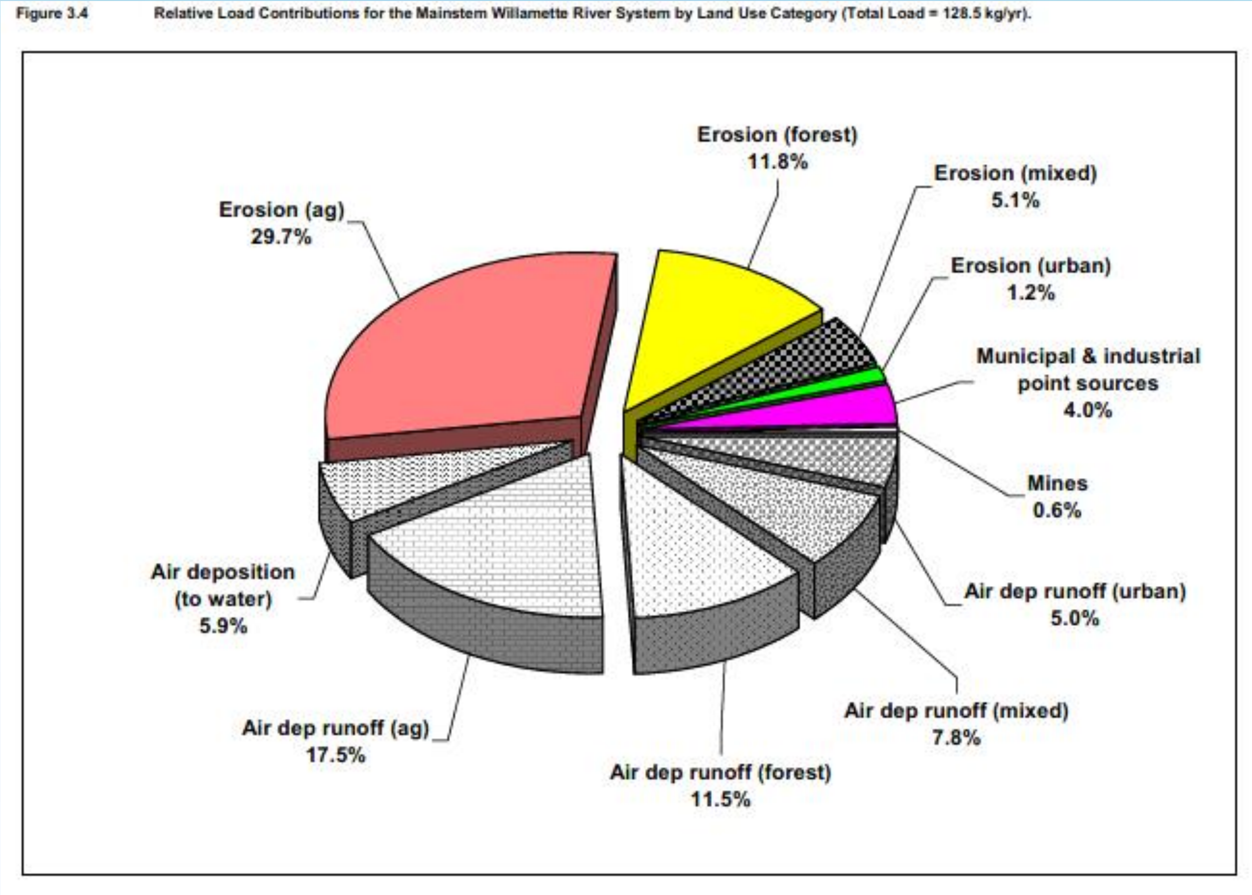
Use of the HSPF Model (Continued)

- Replaces prior guesses at delivery ratios
- Combine with newer land use information
- Point source and MS4 flows analyzed separately

Mass Balance Model Components Informed by HSPF Model



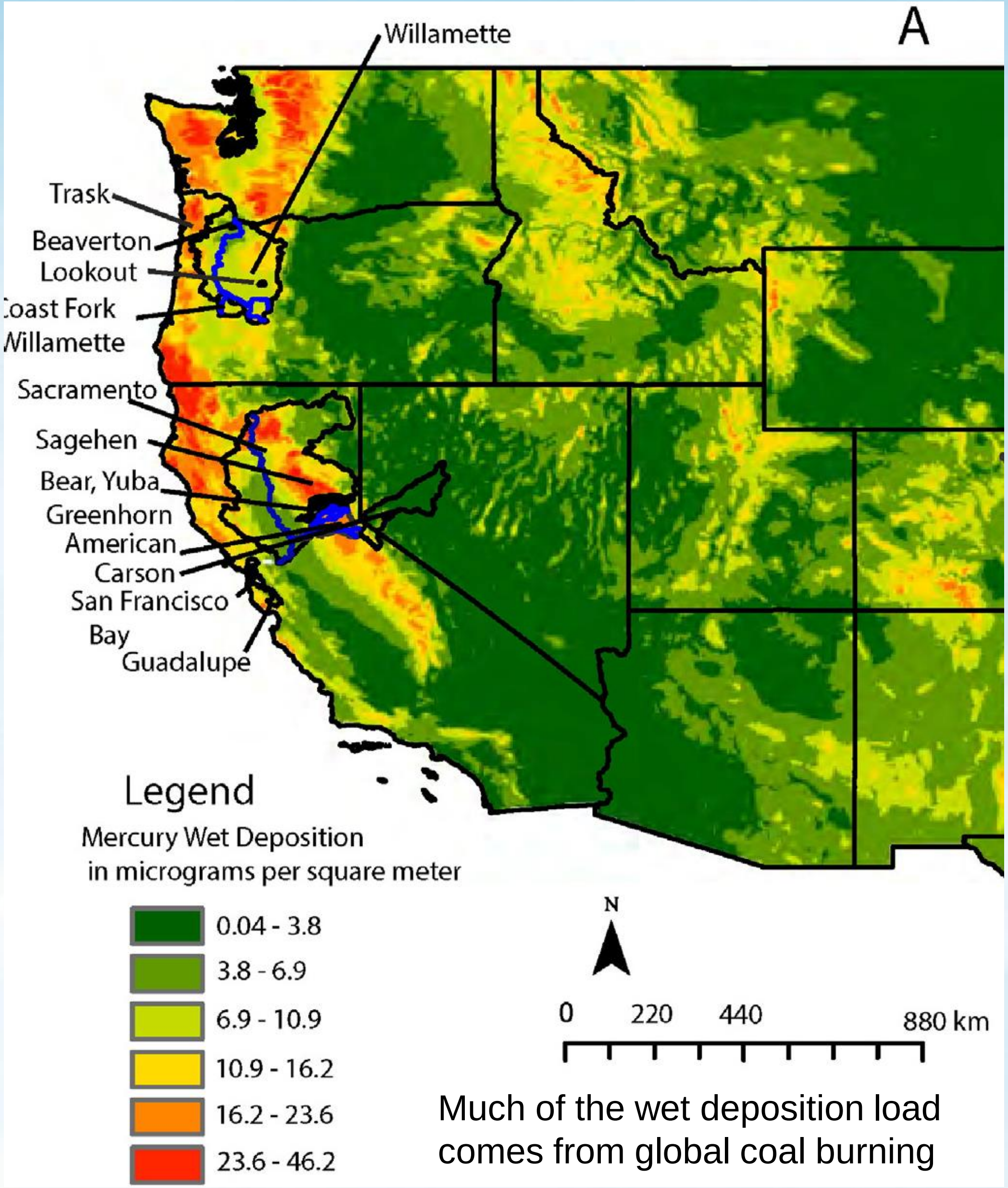
2006 TMDL:



MASS BALANCE MODEL: MERCURY SOURCES

Atmospheric Wet Deposition

- NADP data as summarized by Domagalski et al. 2016. "Comparison of mercury mass loading in streams to atmospheric deposition in watersheds of Western North America: Evidence for non-atmospheric mercury sources." *Science of the Total Environment* 568: 638-650.
- Surface runoff fraction determines delivery of wet deposition load



Much of the wet deposition load comes from global coal burning

Atmospheric Deposition to Water and Impervious Surfaces

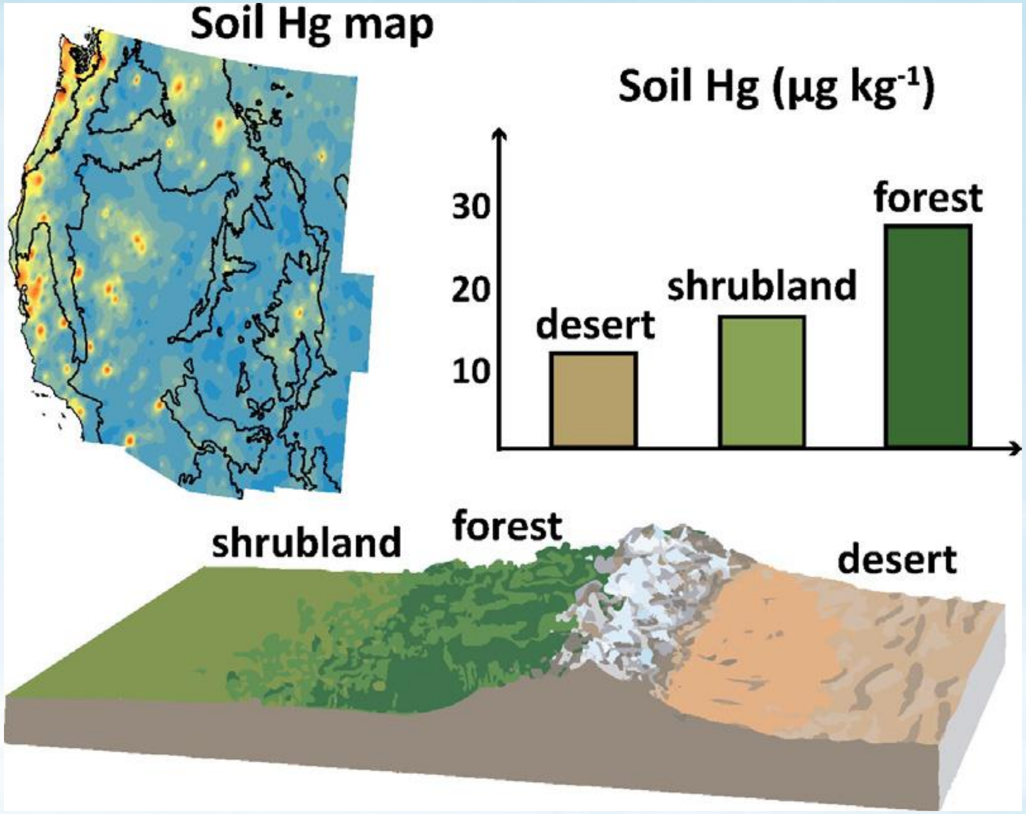
- Both wet and dry deposition to water is fully delivered to stream network
- Use estimated deposition rate grids (wet and dry) x water surface area represented in HSPF model
- Account for dry deposition to impervious surfaces using a buildup-washoff model
- Dry deposition to pervious land and wet deposition that infiltrates is already accounted for in soil matrix concentrations

Soil Matrix Sources

- Particle-associated: soil concentration x HSPF sediment erosion and delivery rate
  - Reflects land use, soil, rainfall, and slope characteristics
- Baseflow: HSPF baseflow rate x associated THg concentration (to the extent estimates are available)
- Direct runoff of Hg in wet deposition determined by deposition rate and surface runoff fraction (not tabulated with soil matrix sources)

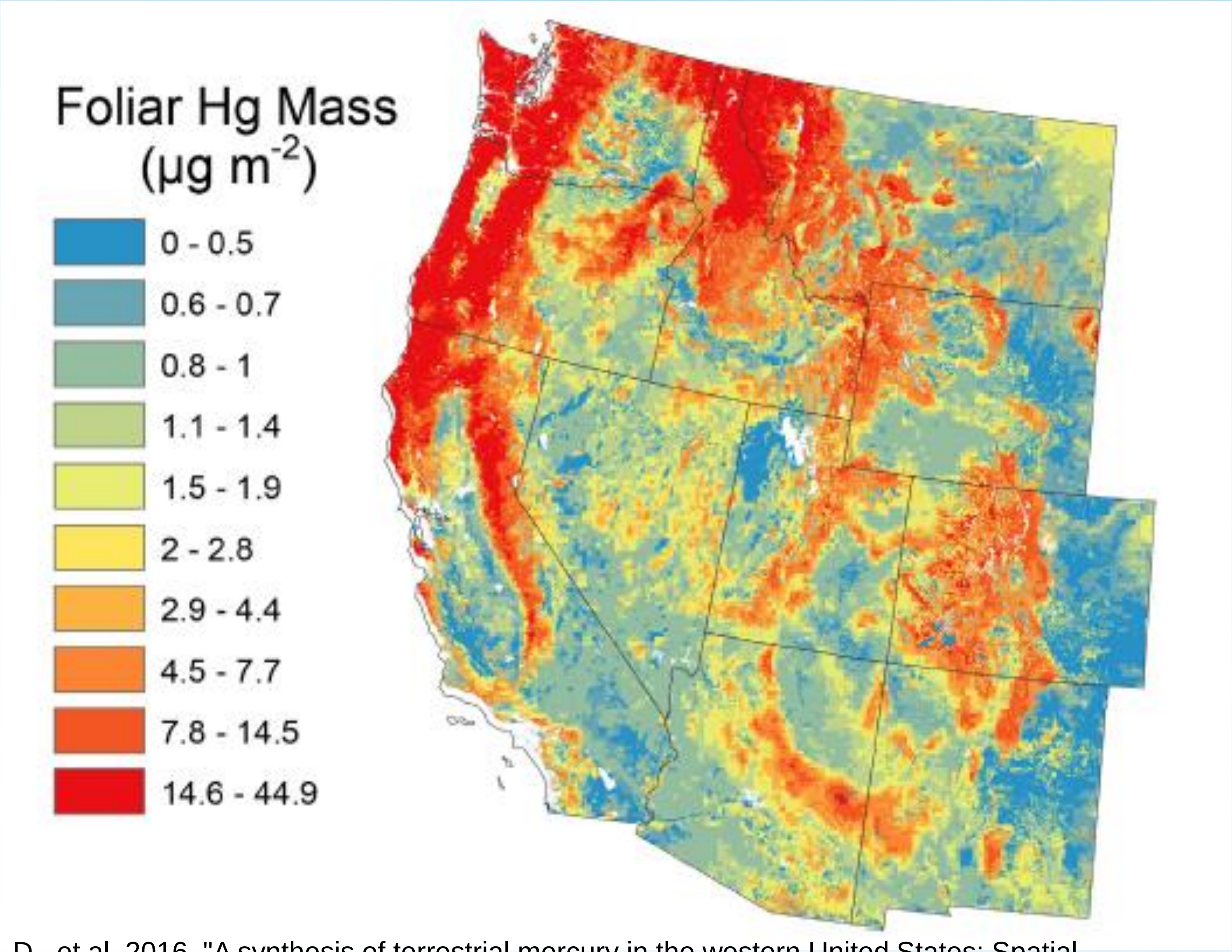
Soil Matrix Concentration

- Incorporates effect of atmospheric deposition that does not directly run off
- Smith, D.B., et al. 2013. Geochemical and Mineralogical Data for Soils of the Conterminous United States. U.S. Geological Survey Data Series 801.



Obrist, D., et al. 2016. "A synthesis of terrestrial mercury in the western United States: Spatial distribution defined by land cover and plant productivity." *Science of the Total Environment* 568: 522-535.

Leaf uptake of atmospheric mercury -> leaf fall -> soil organic litter is a major pathway for mercury load



From Obrist, D., et al. 2016. "A synthesis of terrestrial mercury in the western United States: Spatial distribution defined by land cover and plant productivity." *Science of the Total Environment* 568: 522-535.

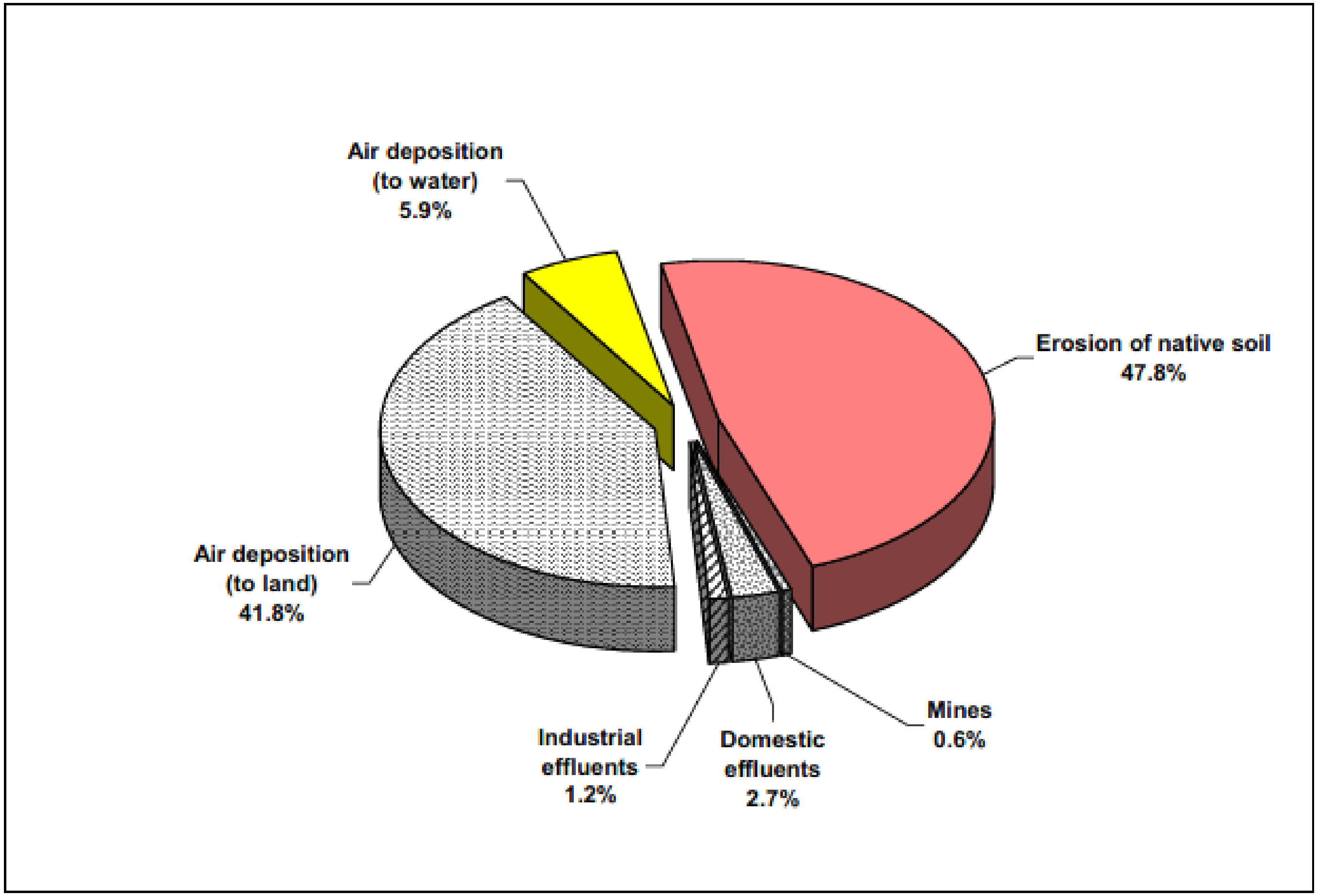
Soil Matrix Concentrations

- Incorporates net effects of land cover and land management, including canopy exchanges, forestry, irrigation, tillage, etc. that determine re-emission rates
  - We will use work of Obrist et al. and sample data from Smith et al. to specify concentrations by land cover
  - Evaluate spatial trends by land use type and incorporate if appropriate
- Note: Will not be able to address changes in soil concentrations over time in the current work

Other Sources

- 2006 TMDL: Deposition and erosion outweigh all other sources

Figure 3.3 Relative Load Contributions for the Mainstem Willamette River System by Source Category (Total Load = 128.5 kg/yr).



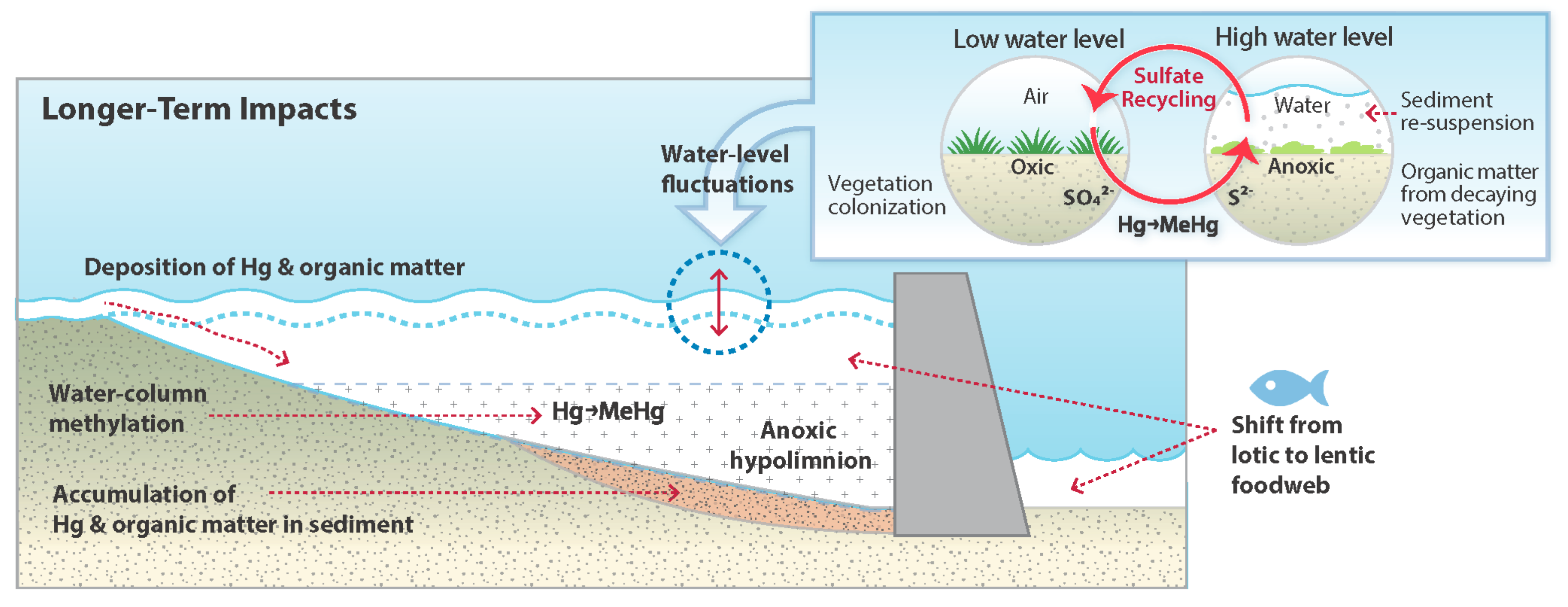
Mines

- Mostly in Coast Fork watershed
  - Hg mining at Black Butte, above Cottage Grove Reservoir
  - Gold mining in Bohemia District along Upper Row River, above Dorena Reservoir, using mercury amalgamation
  - Other mines, with limited data
- Black Butte Mine: Use results of recent Superfund investigations
- Bohemia District: Assemble data, may rely on input and output monitoring of Dorena for net impact
- Other gold and silver mines: Revisit assumption of minimal impact given current site and downstream monitoring

Reservoirs

- 11 major reservoirs
  - Mining sources dominantly above reservoirs
  - Most do not have detailed Hg studies
- Reservoirs trap sediment and associated Hg – but can provide an ideal location for creation of MeHg
- Output is mostly dissolved Hg, depends on specific characteristics of the reservoir
- Rely on empirical analysis of input – output data where available

Ongoing impacts of reservoir management
(slide: Chris Eckley)



- Lotic to lentic foodweb
- Anoxic hypolimnion: water column methylation
- Accumulation of Hg and organic matter
- Water level fluctuations: fresh organic matter; sulfate recycling

POTW Discharges

- Common source of some Hg load from various sources:
  - Dental amalgams
  - Household wastes, such as fluorescent light
  - Infiltration of atmospherically deposited Hg
- Incorporated loads from permitted POTWs based on self-monitoring of Hg
  - Update to most recent results
  - Currently need for more detailed discharge flow rates
  - Correct of bias if analytical methods with high detection limit were used

Permitted Industrial Discharges

- Some industrial sources (e.g., pulp and paper mills, auto recyclers) can be significant mercury sources
- Rely on ODEQ and EPA to
  - Retrieve flow and Hg monitoring from permitted sources with mercury discharge limits
  - Review TRI and RCRA records to identify any other potential industrial sources of significant Hg load

Stormwater Sources

- Municipal Separate Storm Sewer Systems (MS4s) and industrial facilities with exposed practices are subject to discharge permits and can be sources of mercury
  - Exposed industrial activities and associated waste
  - Atmospheric deposition
- Recent monitoring requirements for concentration
- Discharger flow rates if provided
- HSPF for other flow rates

Summary

- ► Provide technical basis to meet Court requirements by contract end in March
- ► Build on existing TMDL structure
  - Incorporating new fish tissue criterion
  - Using new data
  - Incorporating existing watershed model
- ► Lay groundwork for potential additional refinements after March, such as
  - ? localized Food Web models
  - ? projected trends in soil concentrations

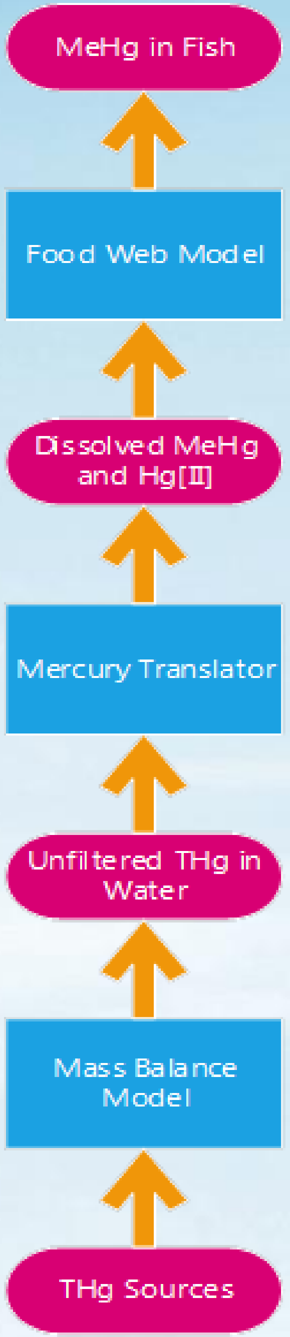
Willamette Mercury TMDL Advisory Committee Meeting

February 15, 2018

MODEL STATUS

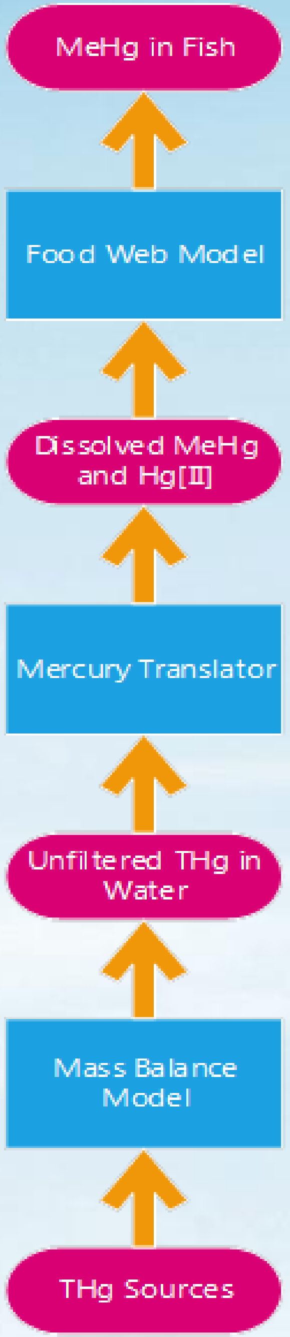
Model Status, 2/15/18

- ► Food Web Model
  - All data obtained
  - Performing final data QA checks
  - Ready to recalibrate model
- ► Mercury Translator Model
  - All data obtained and QA'd
  - Draft approach provided to ODEQ and EPA for review



Model Status, 2/15/18

- Mass Balance Model
  - HSPF model activated and extended
  - Atmospheric deposition grids obtained and processed
  - Soil concentration data processed and linked to HSPF sediment delivery
  - Available mine and reservoir data processed
  - POTW monitoring data; need final flow data
  - Industrial discharges: Waiting on data
  - MS4s: Processing data, still need to clarify sources to surface water versus infiltration
- Goal to wrap up model development by end of February



Questions?