Potential Strategies and Technologies for Mitigating Stream Mercury Contamination

Mark Peterson

Environmental Sciences Division
OAK RIDGE NATIONAL LABORATORY

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UCOR, an AECOM-led partnership with Jacobs; DOE Oak Ridge Office of Environment Management (OREM)

ORNL Team:
Mark Peterson, Scott Brooks, Terry Mathews, Melanie Mayes, Ryan McManamay, Alex Johs, Katie Muller, Leroy Goñez Rodriguez, Shovon Mandal, Sujith Nair, Chris Derolph, Eric Pierce, David Watson, plus technical staff and students.

Oak Ridge Site-Specific Advisory Board (ORSSAB) Meeting
Oak Ridge, Tennessee
March 13, 2019

OAK RIDGE National Laboratory

Key Collaborations and Partnerships

- **UCOR/RSI Water Resources Restoration Program**
- **Y-12 CNS Compliance Organization**
- **Y-12 Biological Monitoring and Abatement Program**
- **DOE Office of Science**
  - Science Focus Area at ORNL
  - Joint project with U. Michigan
- **Mercury Applied Field Research Initiative (AFRI)**
- **UT/ORNL Carbon Fiber Tech Facility**
- **South River Science Team**
- **DuPont**
- **USGS**
- **Queens University**
- **James Madison University**
- **MSIPP – New Mexico State University**
- **Smithsonian Environmental Research Center**
- **U. Minnesota**
- **RT GeoSciences, Canada**
- **Flinders University, Australia**

Smithsonian Environmental
Research Center

Outline

- **The Mercury Challenge**
  - A complex contaminant in the environment
  - East Fork Poplar Creek (EFPC)
- **Approach to remediation technology development**
- **Recent project findings**
  - Soil and groundwater source control
  - Water and sediment manipulation
  - Ecological manipulation
- **Future directions**

East Fork Poplar Creek

Chemical Forms of Mercury

Elemental (Hg0)

- As metallic vapour, “liquid”, or bound in mercury containing minerals

1.2 lb

61 lbs

113 lbs

As ions [Hg(I) and Hg(II)]

- In solution or bound in ionic compounds or complexes [e.g., mercuric sulfide (HgS), mercuric chloride ($HgCl_2$)]

Cinnabar

Organic mercury (e.g., CH_3Hg, methyl mercury)

- Gaseous or dissolved organic compounds
- Primarily formed by microorganisms
- Highly bioaccumulative
- Neurological and reproductive effects
- Primary risks to humans and wildlife through eating fish

Parks et al. 2013.The genetic basis for bacterial mercury methylation. Science. 339 (6125), 1332-1335.

Global Mercury Challenges

-Measured in Arctic snow 3700 ng/L (East Fork Poplar Creek 300-400 ng/L)

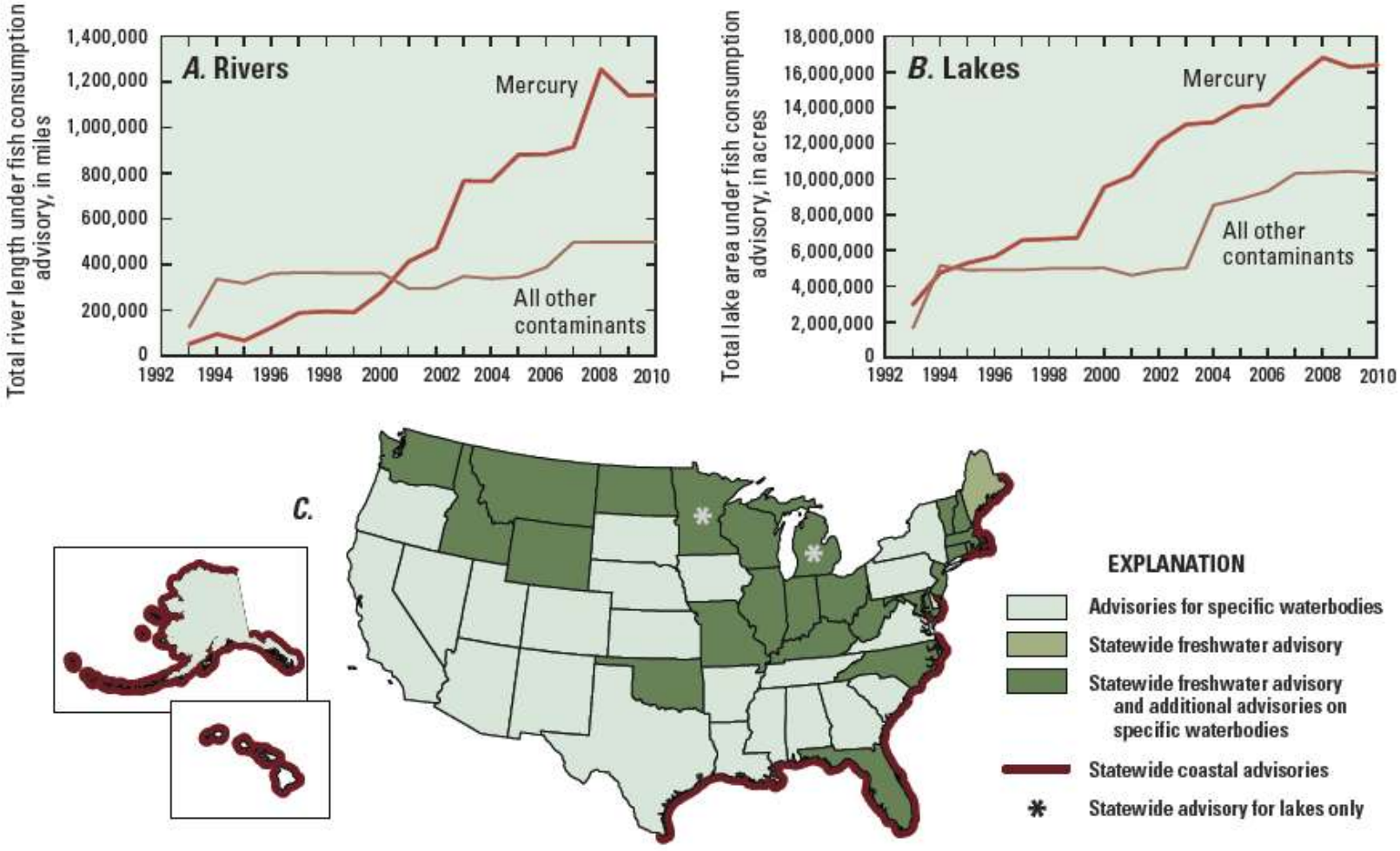
- **Transported globally primarily from coal combustion, mining, waste incineration sources**
- **Complex chemistry and chemical/biological processes; acts differently depending on system**
- **Bioaccumulative and biomagnifies**
- **Even "pristine" sites affected**
- **Concern for human and ecological risks**
- **More rigorous regulatory limits over time**
- **Strategies and solutions difficult, but needed**

-Northern lakes: Hg low in water, high in fish

United Nations Environmental Program

Mercury contamination is widespread in US

Primary risks to humans are from eating fish

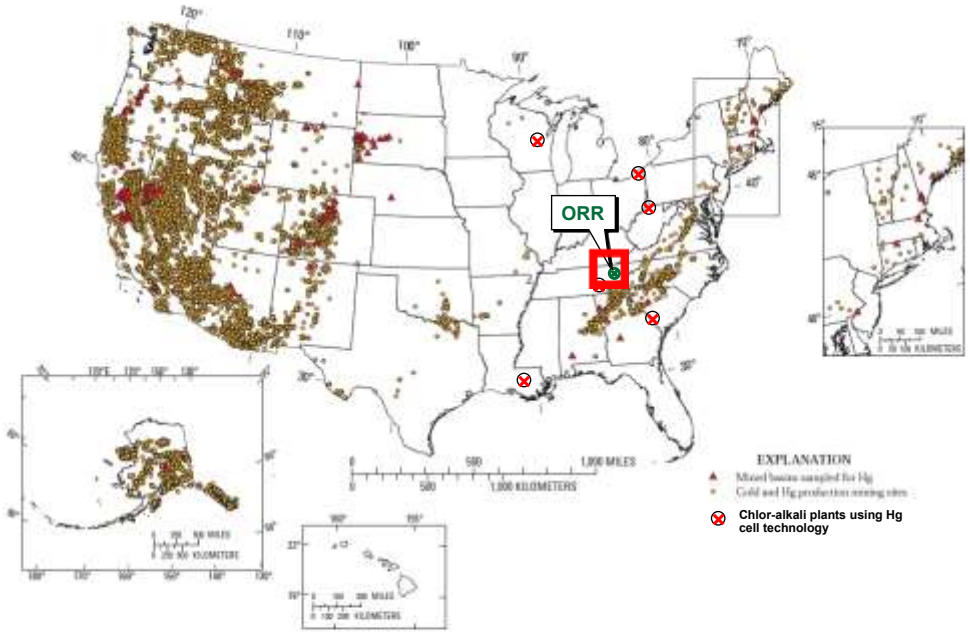


Waters that have no local industrial inputs can be affected because of **atmospheric deposition**

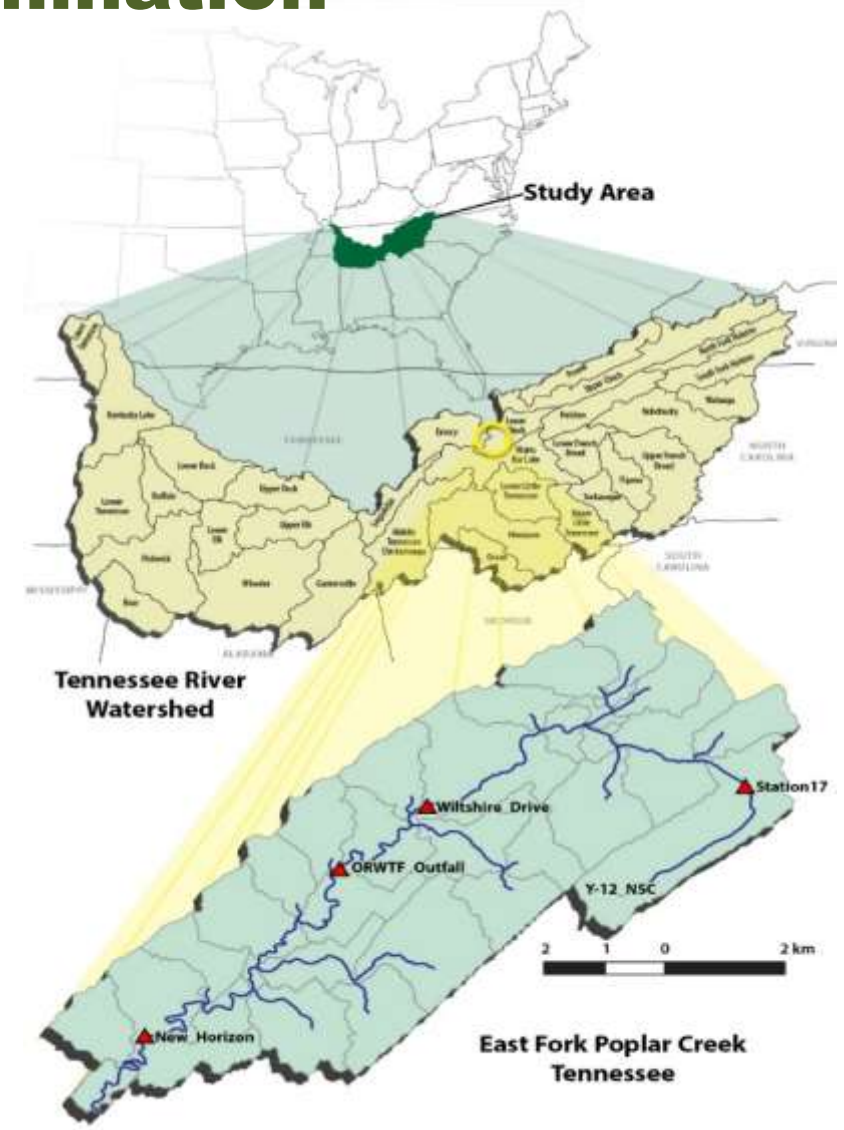
EPA: National Listing of Fish Advisories: Technical Fact Sheet 2010

Large-scale mercury use can result in severe localized contamination

Gold and Hg mining sites, chlor-alkali plants



Adapted from Scudder et al. (2009)



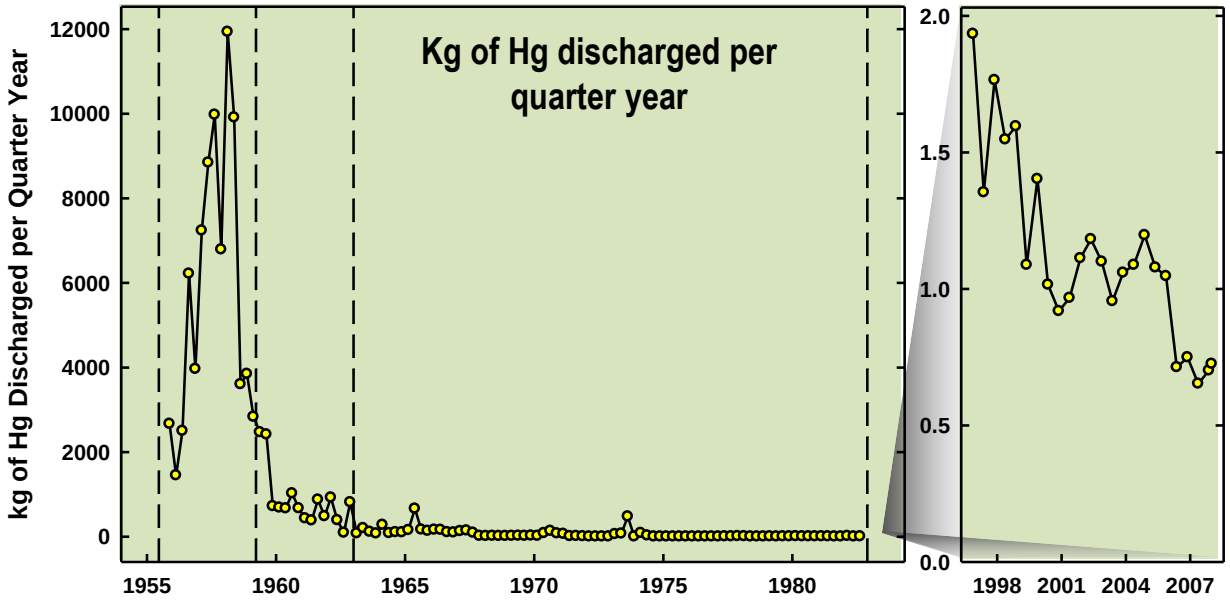
Lithium isotope separation for weapons production

Historical Mercury Releases at Y-12

- From 1950s – 1963 over 700,000 pounds of Hg suspected to have been released to the surrounding soils and stream
- ~15 miles of EFPC and 5 miles of Poplar Creek exceed water quality criteria. No fishing.

- Significantly less mercury releases over time

26 m^3 of mercury lost by volume



15-foot U-Haul

+

5X8 cargo trailer

Y-12 Remedial and Abatement Actions, 1984-2018

Sanitary and storm sewers relined (Phase I) (Y-12/ State)

Untreated discharges consolidated and eliminated

NPDES Permit/ BMAP Initiated

New Hope Pond Closed (RCRA)

Cooling water discharges dechlorinated

1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 | 1995

Central Pollution Control Facility

Lake Reality opened

Sanitary and storm sewers relined (Phase II)

Intermittent bypass of Lake Reality

Intermittent flow management

Permanent bypass Lake Reality

Big Spring Water Treatment System

Old Salvage Yard scrap removal

1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011

Flow management becomes permanent

Central and East End Mercury Treatment Systems (NPDES)

Lower EFPC floodplain remediation

Contaminated bank stabilization project completed

WEMA storm drain cleanout and relining

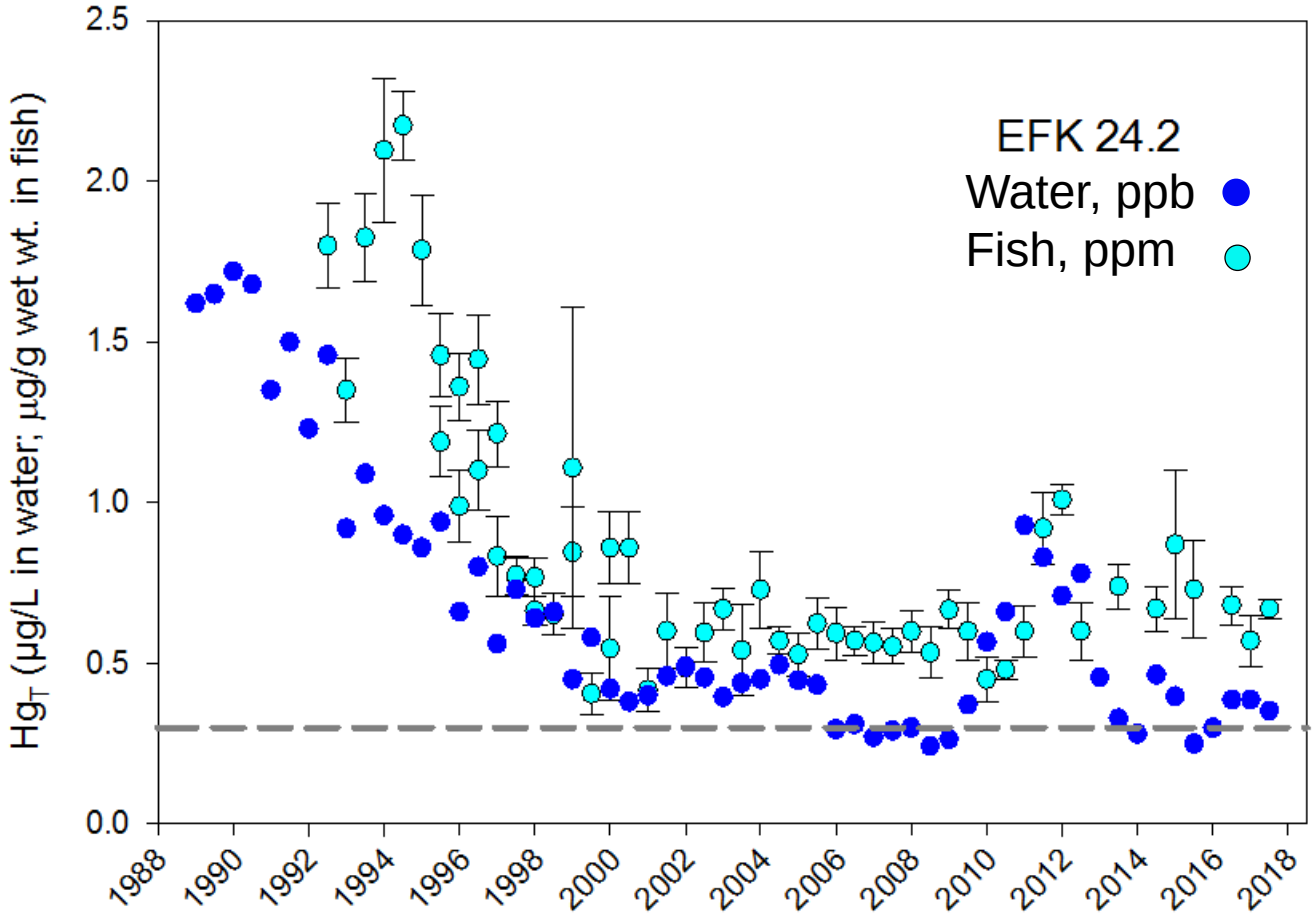
OF 200 MTF construction began

2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018

Flow management ends

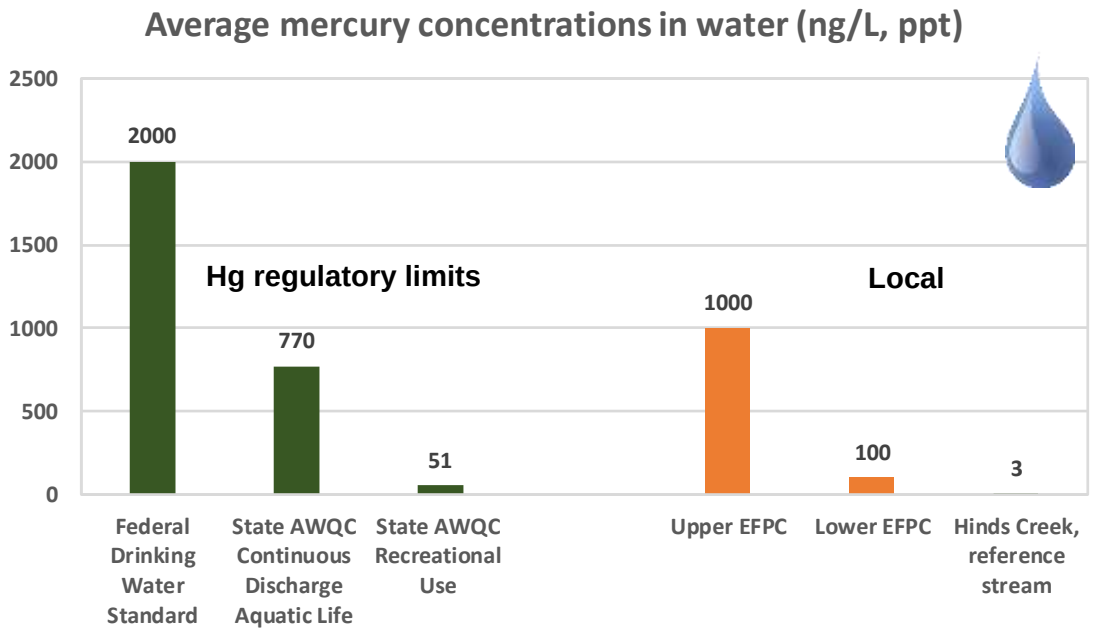
Adapted from: Loar, JM, AJ Stewart, and JG Smith. 2011. Twenty-Five Years of Ecological Recovery of East Fork Poplar Creek: Review of Environmental Problems and Remedial Actions. Environmental Management 47:6:1010-1020.

- **Significant decreases in water Hg concentrations 1989-2010**
- **Fish initially respond commensurate with water mercury concentrations, then unresponsive**

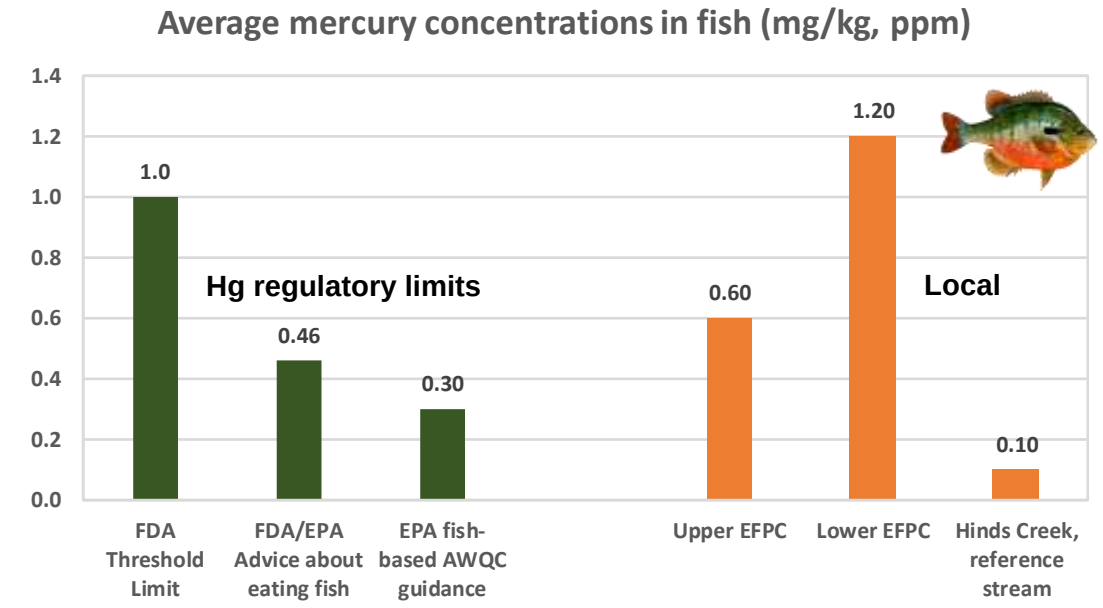


Y-12 Biological Monitoring and Abatement Program

Total Hg in water not a predictor of fish concentrations



East Fork Poplar Creek (EFPC) surface waters



East Fork Poplar Creek (EFPC) redbreast sunfish

Environmental factors affect mercury methylation and bioaccumulation

Mercury flux is only one factor controlling fish mercury concentrations

Near Source

In-stream conditions

Water chemistry
Hg speciation, pH, DOC, chlorine, sulfate, flow/flux

Subsurface interactions
Chemistry, speciation, flow paths, transport

Stream sediments/particles
Types, movement, size of zones, binding

Soil/land/riparian inputs
Seepage and overland flow, land use, % wetlands, catchments, floodplain and stream bank erosion

Microbial interactions
Methylation, demethylation, species and community factors

Sediment-associated biological
Periphyton, micro-fauna, biofilm, micro-habitat

Aquatic Food Chain
Prey availability, mercury form by species, trophic level

biological
chemical

Regulatory Endpoint

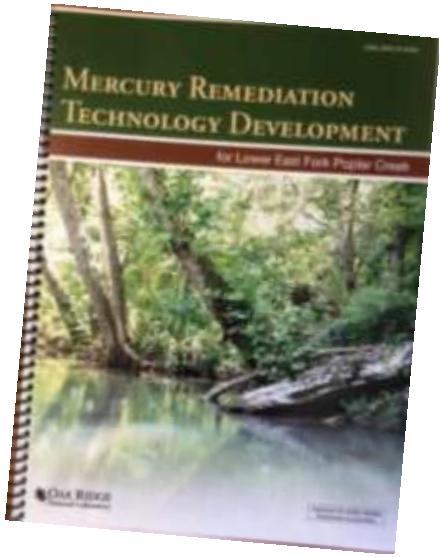
The regulatory measure of remediation success is attaining fish mercury limits

Current mercury remediation approach to East Fork Poplar Creek

- A phased adaptive management approach
- Mercury treatment actions in the near-term at the headwaters of EFPC: the **Mercury Treatment Facility (MTF)**
  - It will reduce mercury releases into creek and provide a control mechanism for mercury disturbed during demolition

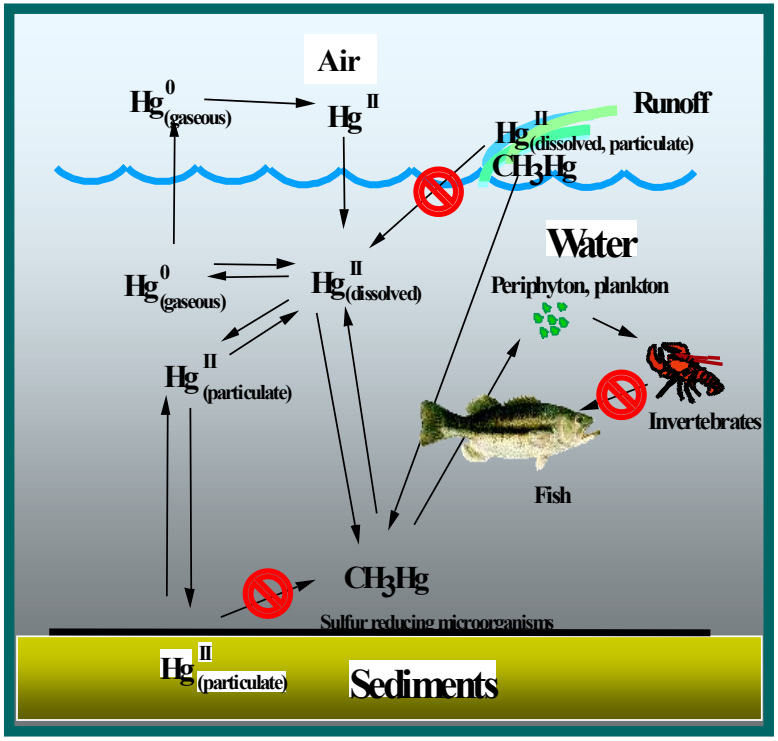
Artist rendering of Mercury Treatment Facility

- Technology Development to evaluate potential interim actions for Lower East Fork Poplar Creek in the mid-2020s



Strategy document
March 2015

The EFPC TD strategy focuses on the major factors controlling mercury in fish

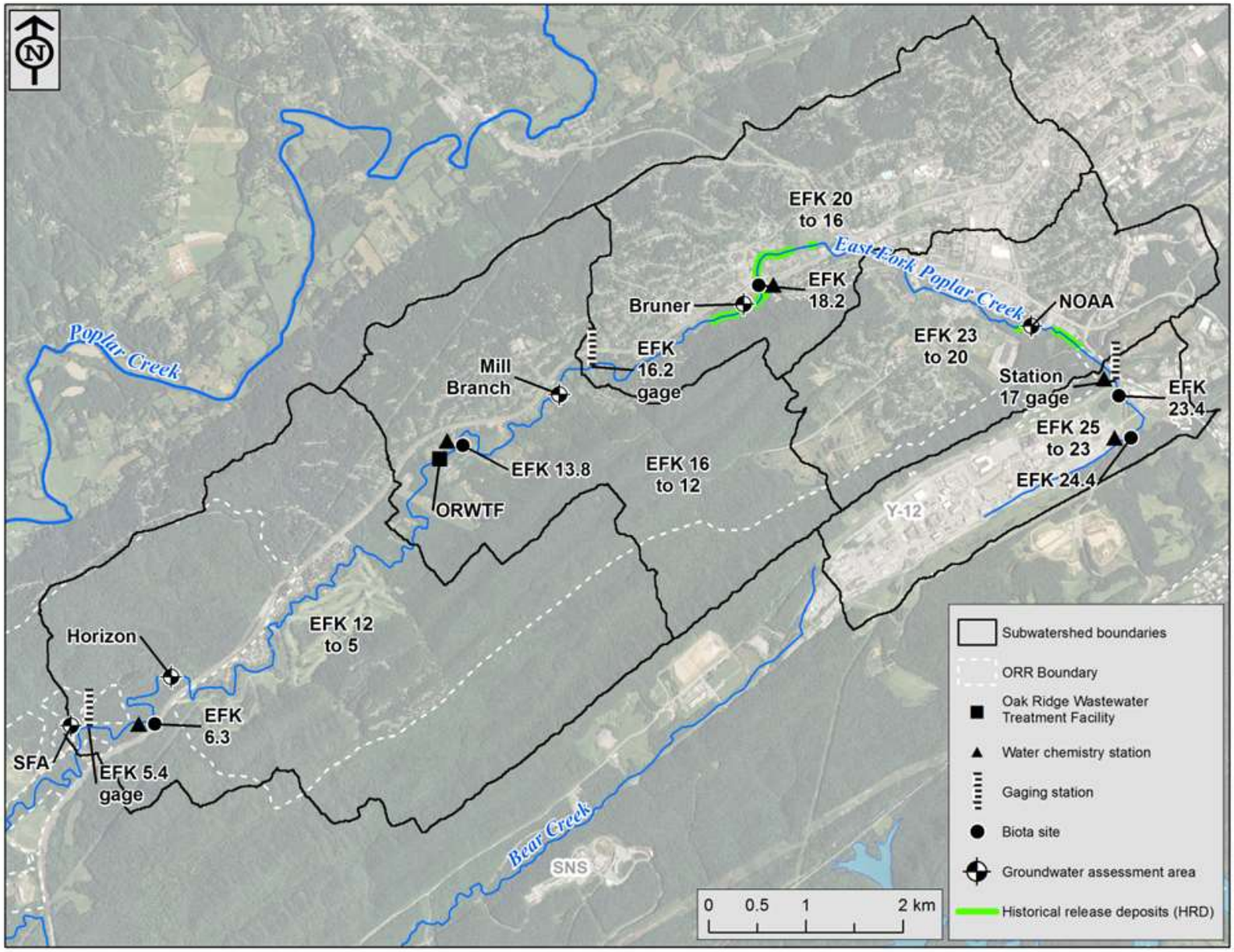


Three key factors determine the level of mercury contamination in fish—the amount of inorganic mercury available to an ecosystem, the conversion of inorganic mercury to methylmercury, and the bioaccumulation of methylmercury through the food web.

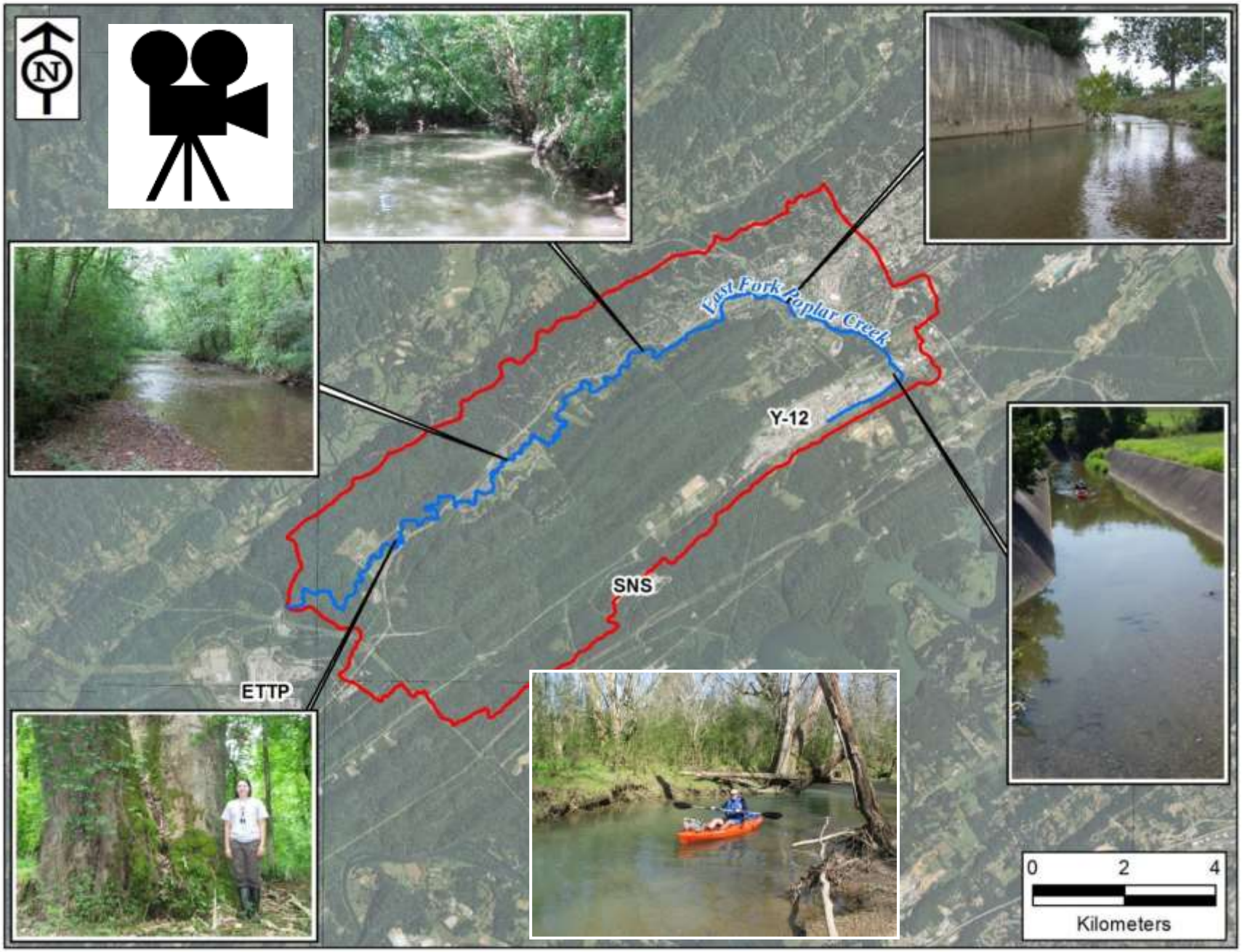
-USGS Circular 1395 (2014)

3 Main Tasks:	***Goals:***
Soil and Groundwater Source Control	Decrease mercury source inputs, **flux**
Water Chemistry and Sediment Manipulation	Decrease mercury **concentration and methylation**
Ecological Manipulation	Decrease mercury **bioaccumulation**

Primary Study Locations, EFPC



East Fork Poplar Creek Bank Soil and Sediment Survey



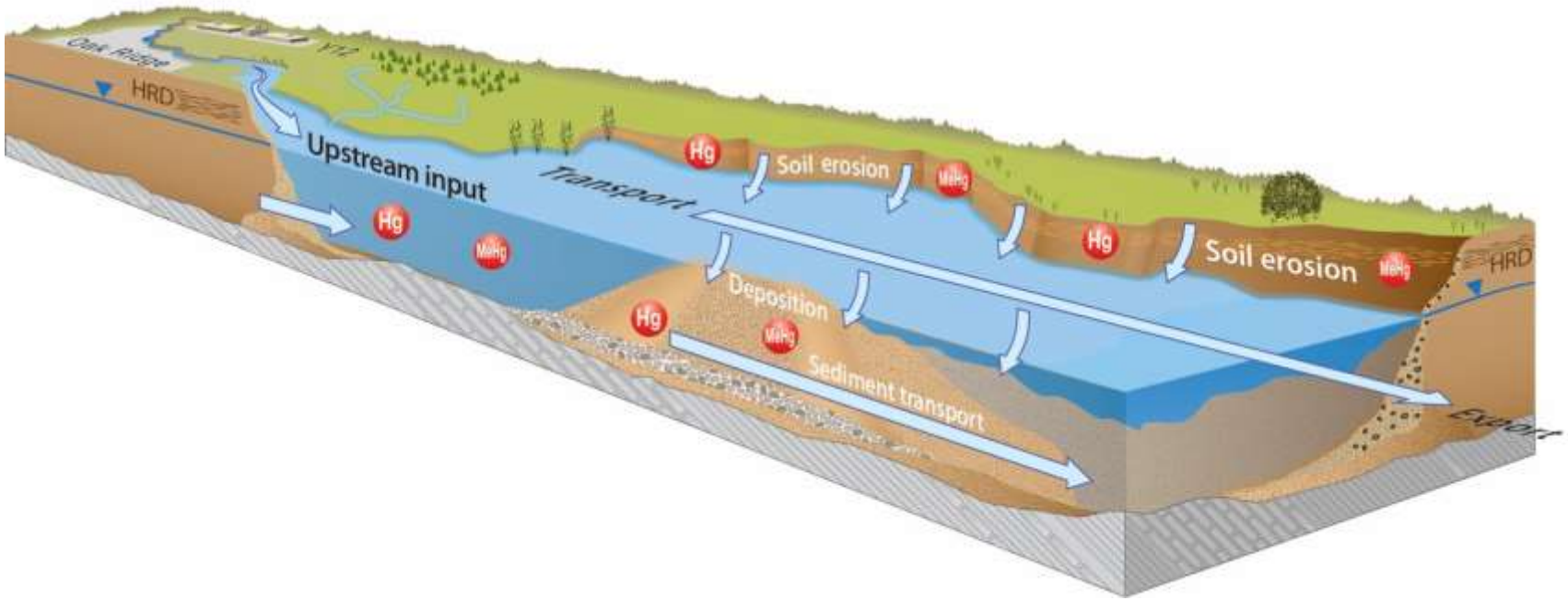
East Fork Poplar Creek Bank Soil and Sediment Survey

https://
youtu.be/6jm8jUbbiO8

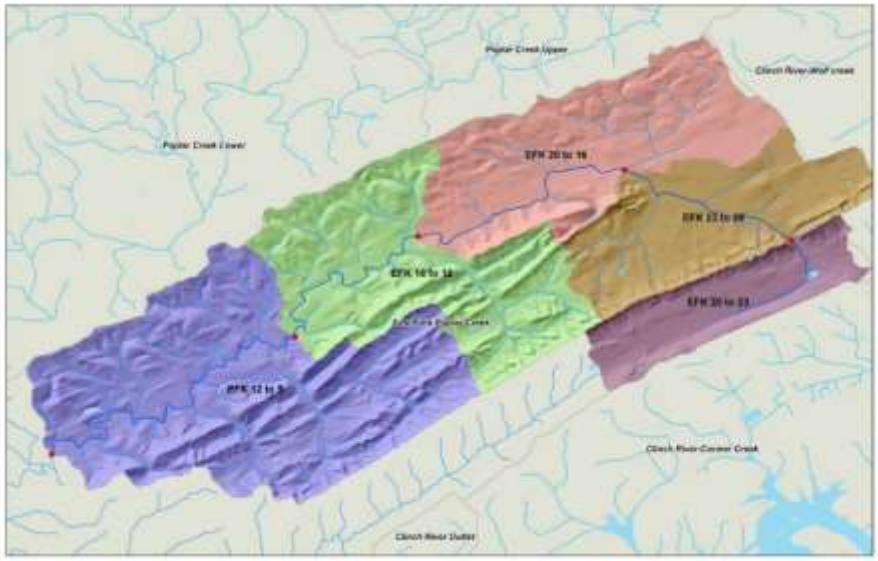
Task 1 Soil and groundwater source control

GOAL: Decrease mercury flux from stream banks including through erosion and leaching

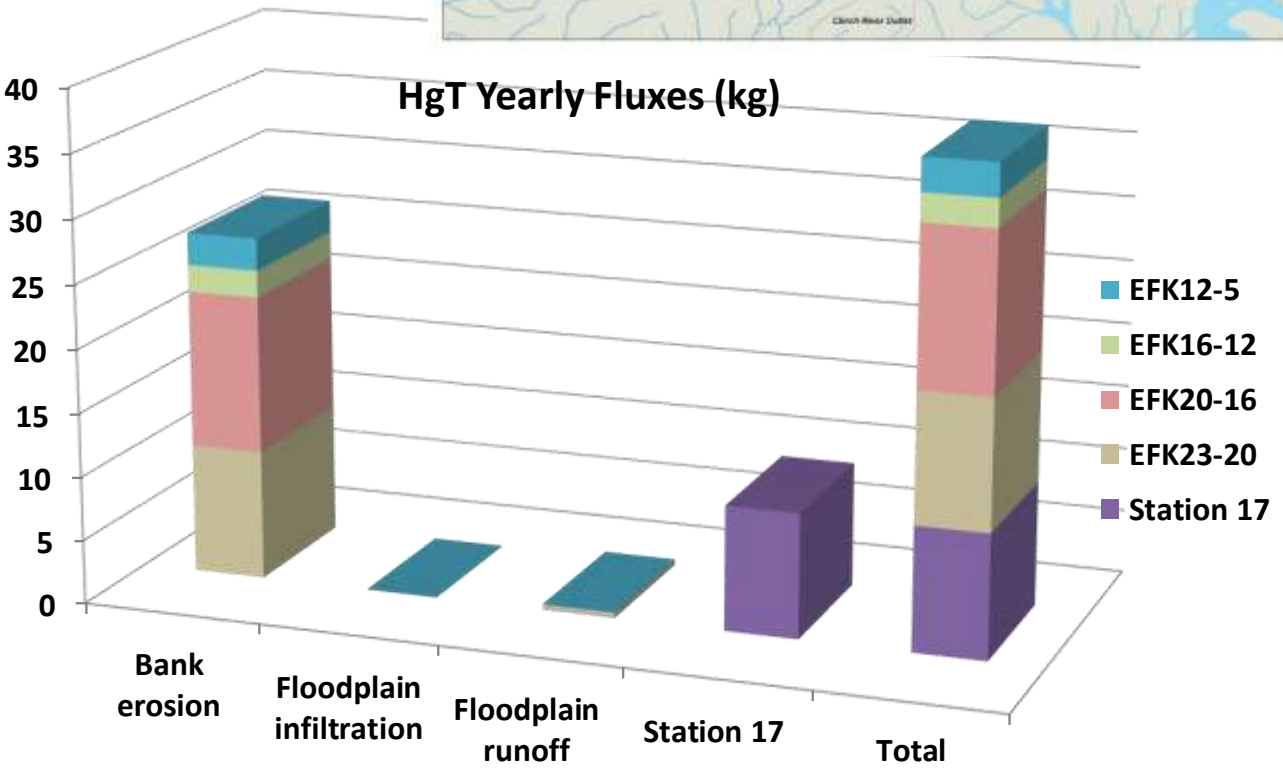
- **System studies**
  - Erosion studies
  - Mercury concentration and flux
  - Groundwater studies
  - Predictive modeling
- **Technology Development laboratory studies**
  - Characterization of the historical release deposits (HRD)
  - Sorbent studies, lab and field



Key Finding: Importance of bank soil erosion to mercury flux



- **Primary sources of HgT to EFPC**
  - Station 17
  - Bank erosion in upper two reaches of LEFPC
- **Low flux from shallow groundwater and floodplain runoff**
- **Refining estimates**

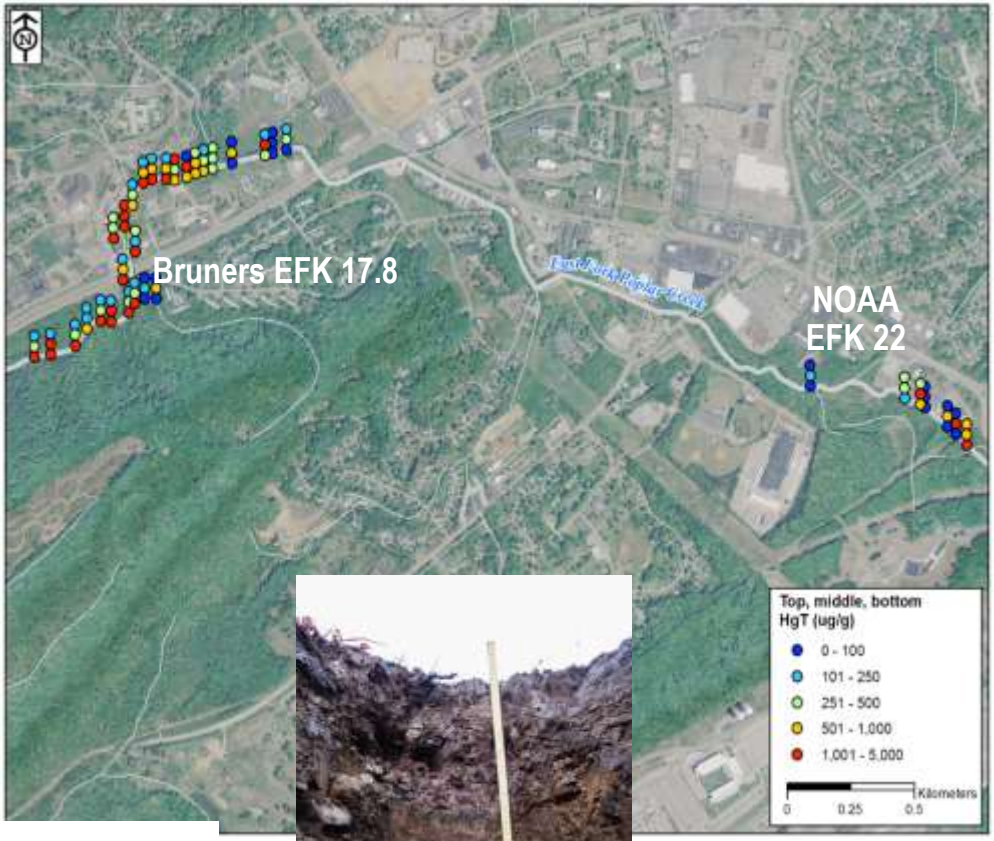


Modeled fluxes based on surveys of HgT and erosion

Historical Release Deposits (HRD) in EFPC streambank soils

- The HRD is found in an ~ 5km reach in upper EFPC
- High Hg concentration coupled with high erosion in some areas
- Outside the high Hg zones, Hg concentrations are similar in bank soils and sediments

- Thus, the case is made for the prioritization of the HRD areas for technology development



Journal of Soils and Sediments
https://doi.org/10.1007/s11368-018-2183-0

SEDIMENTS, SEC 1 • SEDIMENT QUALITY AND IMPACT ASSESSMENT • RESEARCH ARTICLE

Source relationships between streambank soils and streambed sediments in a mercury-contaminated stream

Johnbull O. Dickson[1,2] · Melanie A. Mayes[1] · Scott C. Brooks[1] · Tonia L. Mehlhorn[1] · Kenneth A. Lowe[1] · Jennifer K. Earles[1,3] · Leroy Goñez-Rodriguez[4] · David B. Watson[1] · Mark J. Peterson[1]

Received: 5 June 2018 / Accepted: 28 October 2018

Sorbent Studies

- Laboratory batch and column experiments on a variety of sorbents
- Effectiveness, role of DOM, role on MeHg, and cost major factors
- Sorbent coupons are being deployed in EFPC creek banks
- Currently evaluating activated carbon fiber mats as a new remediation technology
  - Integrate Hg removal with creek bank stabilization
  - Carbon fiber precursors include polyethylene (PE) or polyacrylonitrile (PAN)
  - Initial results suggest excellent Hg removal efficiency

Samples provided by Amit Naskar (ORNL, Chemical Sciences Division)

Bank stabilization, South River, Virginia

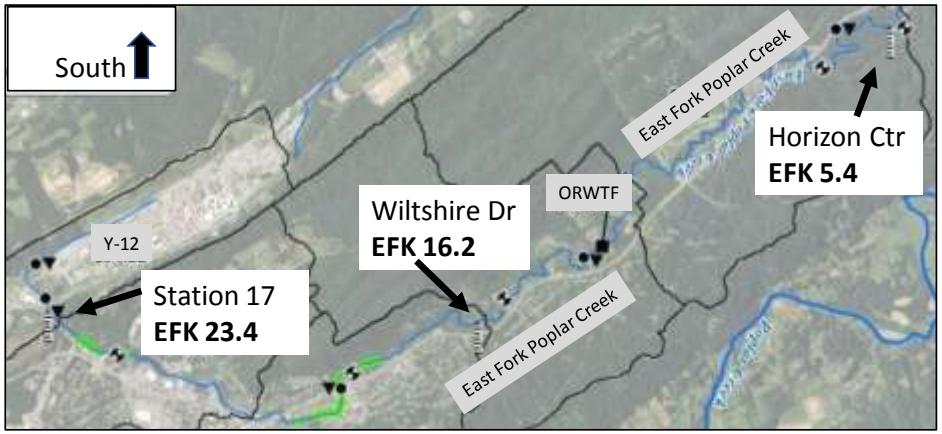
Task 2. Water chemistry and sediment manipulation

GOAL: Decrease mercury concentration and methylation, by disrupting: Hg transport and loading, aqueous partitioning, methylation, and exposure/ bioaccumulation

- **System studies**
  - New gauging stations established
  - Better spatial and temporal resolution of concentration and flux
  - Sediment source investigation

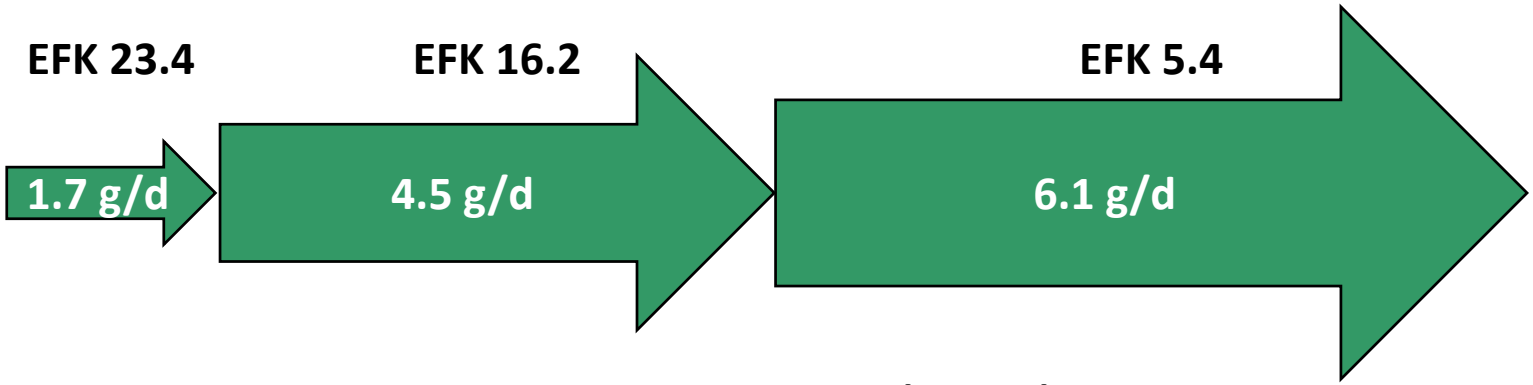
- **Technology Development**
  - Ascorbic acid addition
  - Sorbent studies

Base flow Hg flux

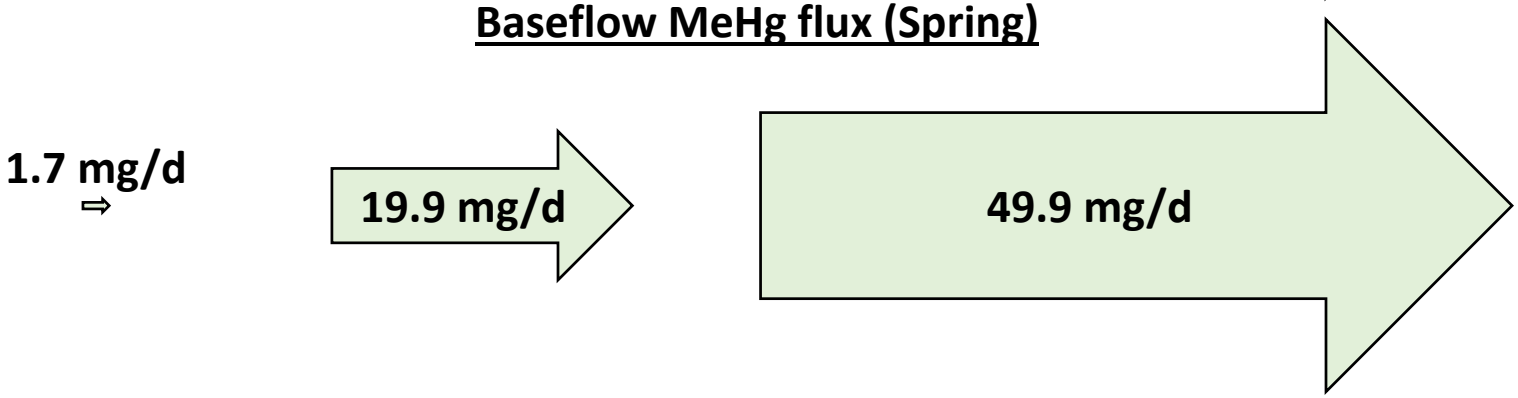


- ~75% of HgT from upper 7 km of stream
- ~60% of MeHgT from lower 11 km
- Y-12 only 28% of HgT; 3% of MeHgT

Baseflow total Hg flux



Baseflow MeHg flux (Spring)

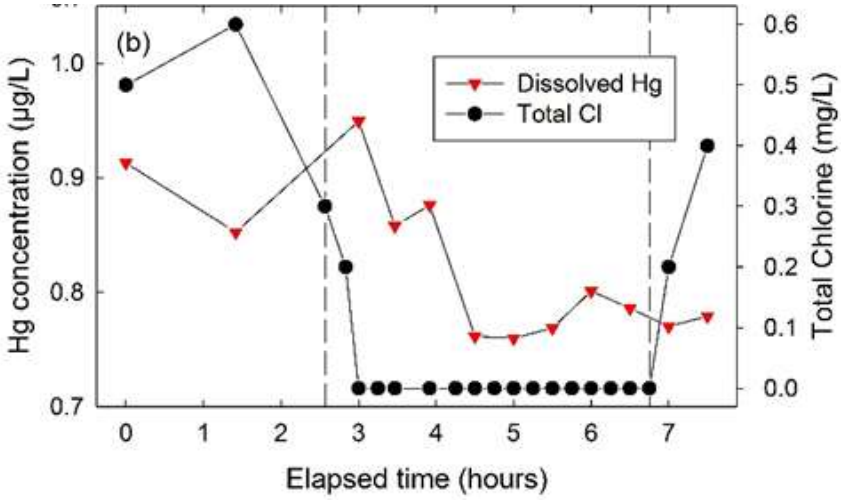


Additional Findings

- **Sediment study and report**
  - Sediment Hg decreased 67% since 1984
- **Higher particulate Hg and MeHg at night (bioturbation?)**

- **Effect of sorbents on methylation study**

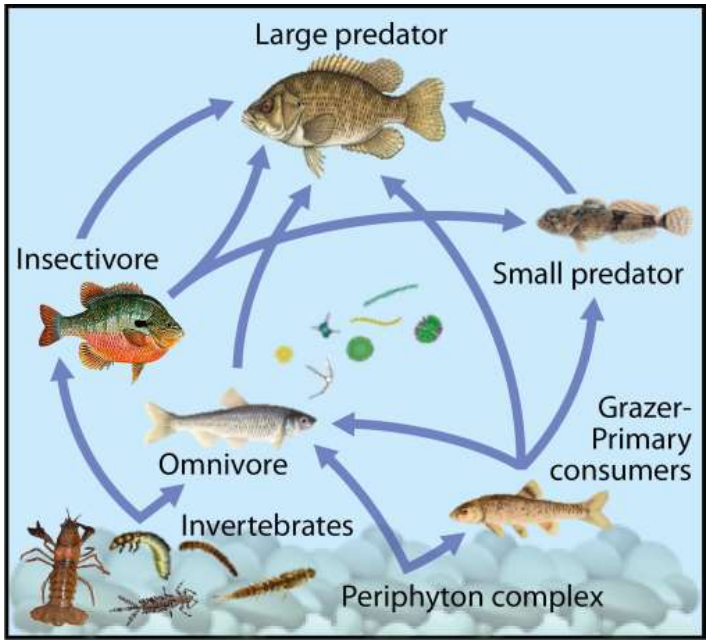
- **Alternative dechlorination chemicals lab tests and 2 field trials**
- **20-25% decrease in Hg during ascorbic acid test of Y-12 storm drains**



Task 3. Ecological Manipulation

GOAL: Reduce methylmercury concentrations in fish

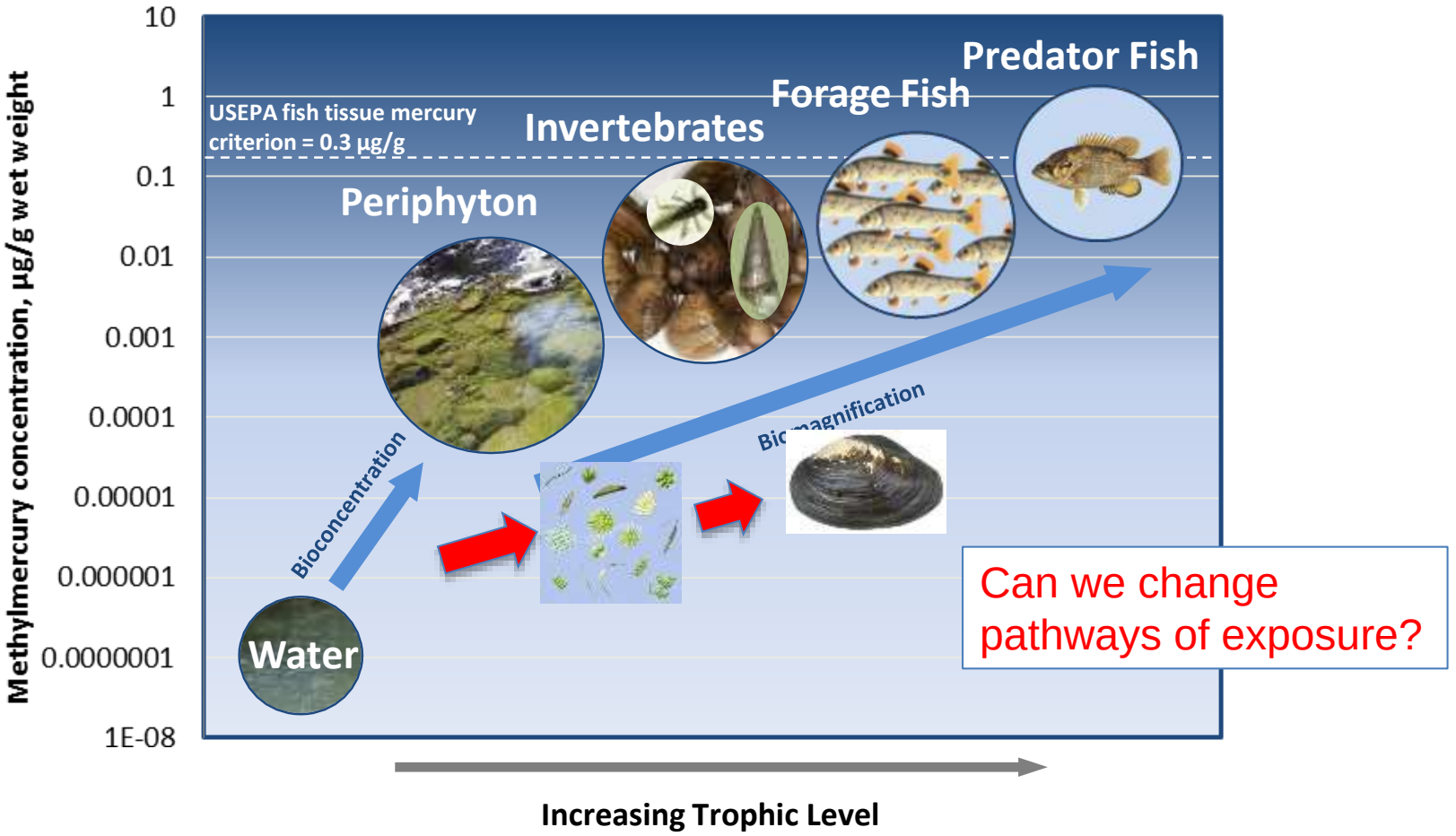
- **System studies**
  - Evaluate Hg and MeHg inventories in food web
  - Understand role of population/community dynamics on mercury bioaccumulation
  - Understanding role of periphyton dynamics on mercury bioaccumulation in fish



- **Technology Development**
  - Evaluate effect of mussel filtration on Hg

Food Chains Make a Difference on Hg Bioaccumulation

- Longer food chains can > Hg
- Each organism has different bioaccumulation potential
- Greatest biomagnification step low in the food chain



First time EFPC food chain systematically surveyed for mercury bioaccumulation

Field collections

Lab processing-Taxa

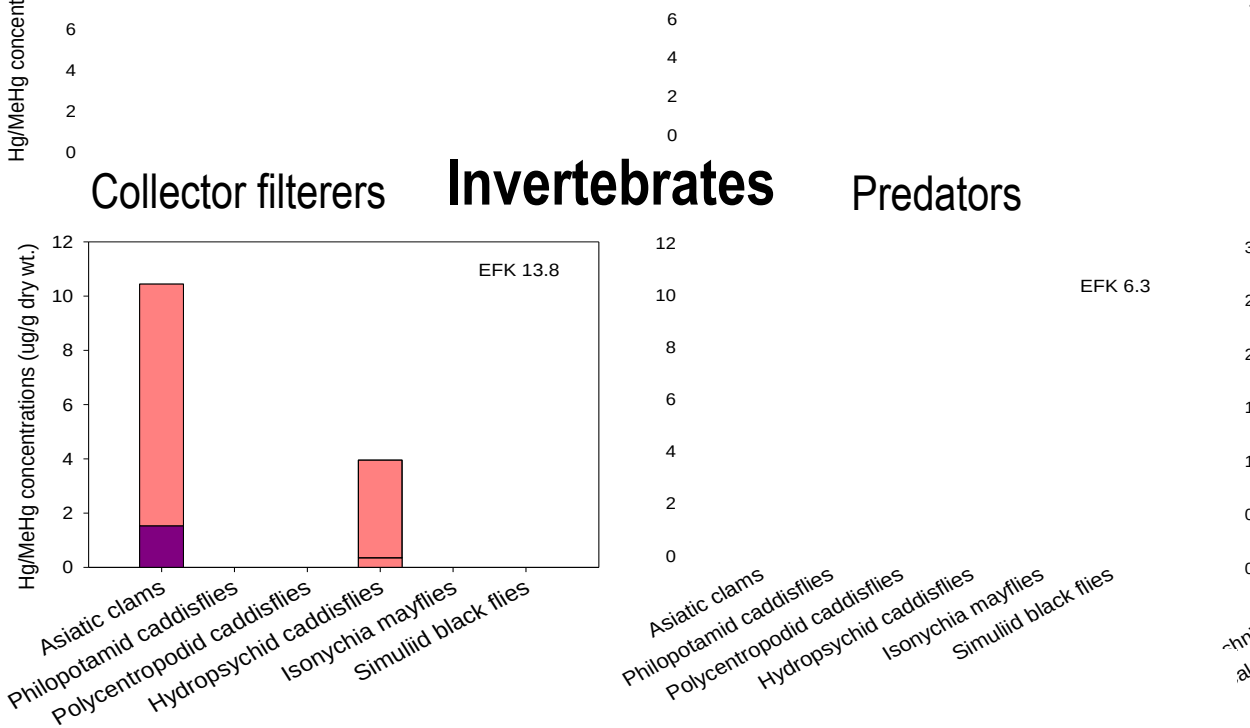
Lab processing-Size

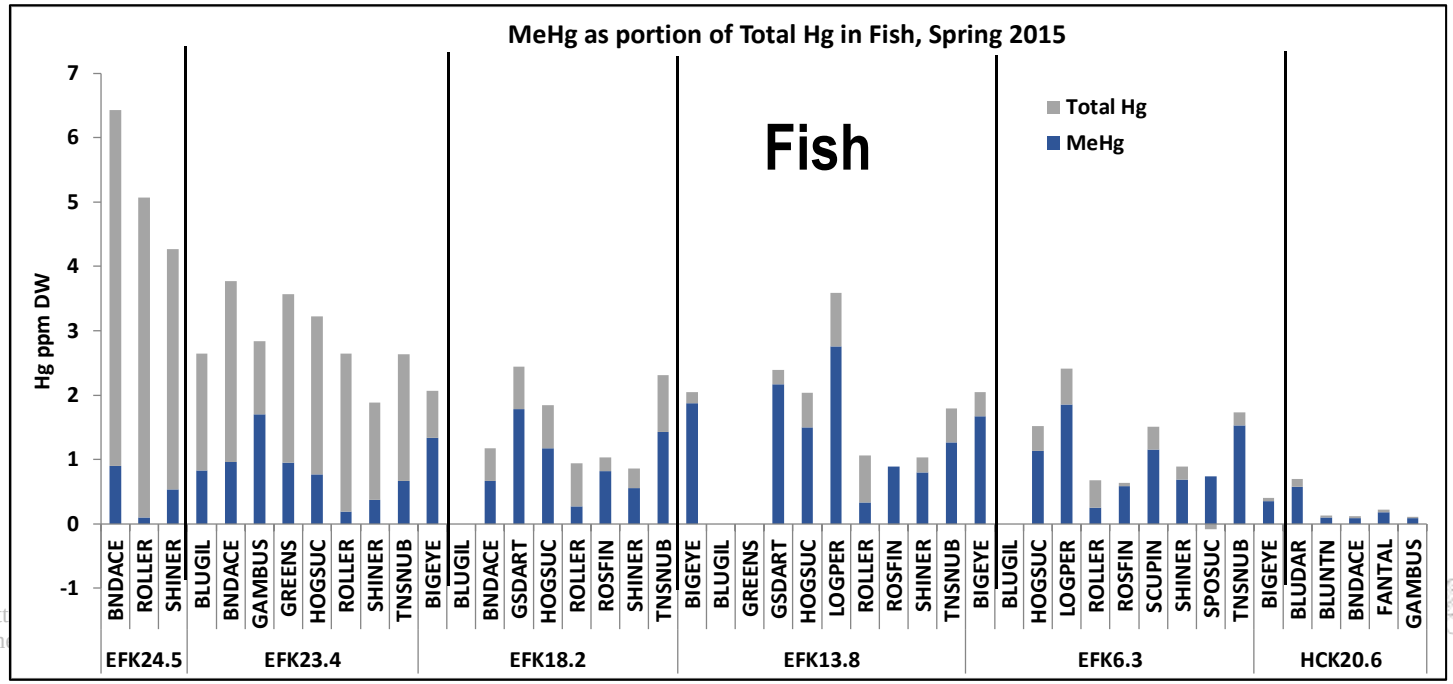
Analysis

- Mercury
- **Methylmercury**
- Del N15

Investigating Me

- Major taxa differences in MeHg uptake
- Collector filterers have a negative effect
- Higher % MeHg with distance downstream



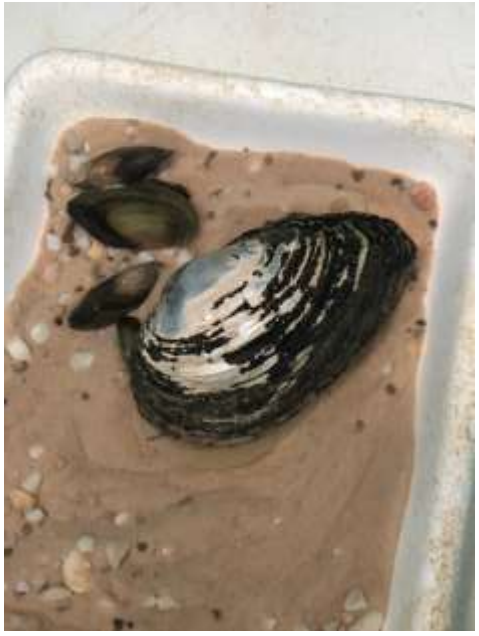


Bivalve Testing

- Mussels highly effective in removing particles from water
- Mussels low in HgT, low in MeHg
- Collaborating with TWRA's Cumberland Water Research Center to culture native mussels for testing

Paper Pondshell
Utterbackia imbecillis

Aquatic Ecology Laboratory

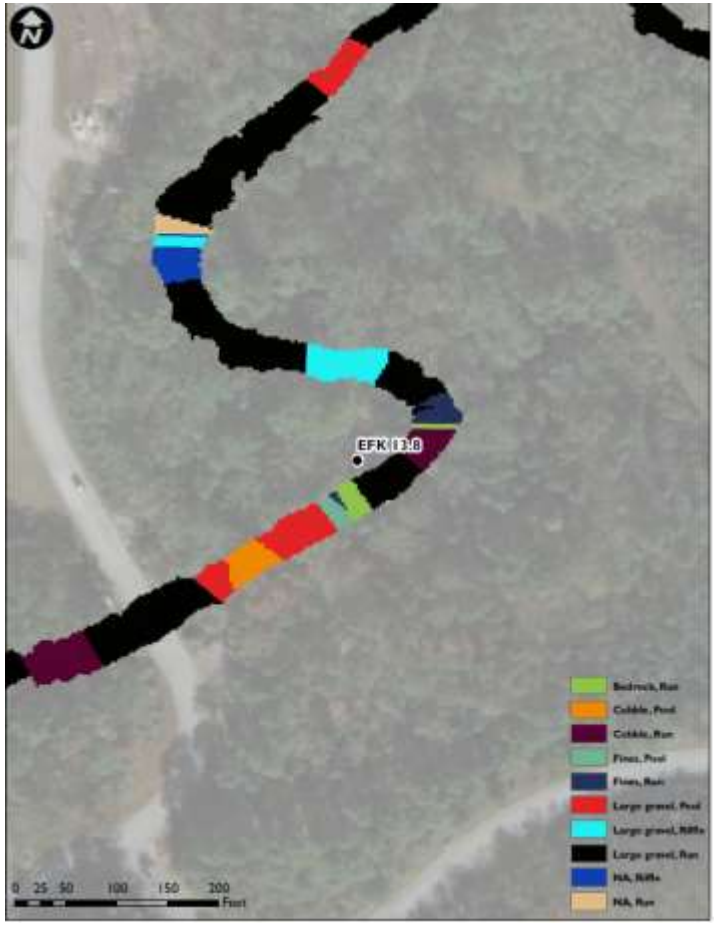


Fast motion mussel filtering

Quantifying potential for Hg filtration by bivalves in EFPC

- **Evaluating species filtration rates under different environmental conditions to examine the effects of light, temperature, and particulate load**
  - Higher temperature, higher filtration
- **Examination of substrate obtained from kayak surveys of EFPC**
- **Estimation of carrying capacity of EFPC for mussels**
- **Controlled stream mesocosm studies to evaluate Hg removal efficiency planned**

EFPC sediment characteristics



Potential future strategies for mitigating Hg in EFPC?

Decrease Hg sources

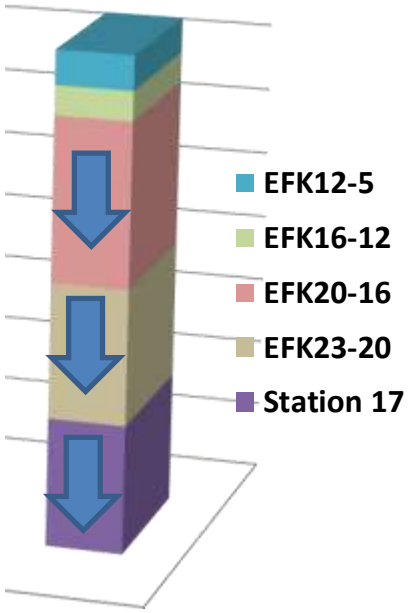
- MTF will decrease Hg flux and downstream erosion
- Develop bank stabilization and sorbent solutions for high Hg streambanks

Develop watershed scale recommendations that can impact surface water variables

- What “knobs” need to be turned to decrease Hg methylation?
- Decrease flashy flows, modify nutrients, algae, light, habitat?

Modify the food chain to decrease Hg risks while improving natural quality

- Reintroduce native mussels to decrease particle-associated Hg
- Fish management actions



high

Hg

med

low

EFPC Ecosys

Surface Hydrology

Hydraulics

Bank erosion & Sediment Trans.

Floodplain & GW Hydrology

Periphyton Biomass & Methylation

Fish & Invert Biomass, Biodynamics

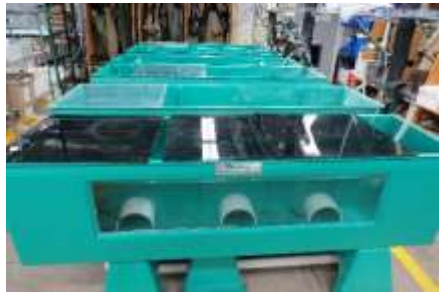
Fish & Invert Functional Roles

Future technology development

- Flow-through testing of EFPC water planned

Aquatic Ecology Laboratory

- Projected start: FY2020
- Need to advance the scale of testing beyond field studies and bench scale
- Unique facility to develop mercury remediation technologies



SSAB: Look forward to your visit!