Enhancement of *In Situ* Hydrocarbon Biodegradation through Innovative Cap Design

Presented to:

Workshop on *In Situ* Treatment Technologies for Contaminated Sediments

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Presented by:

Clay Patmont

ANCHOR ENVIRONMENTAL, L.L.C.

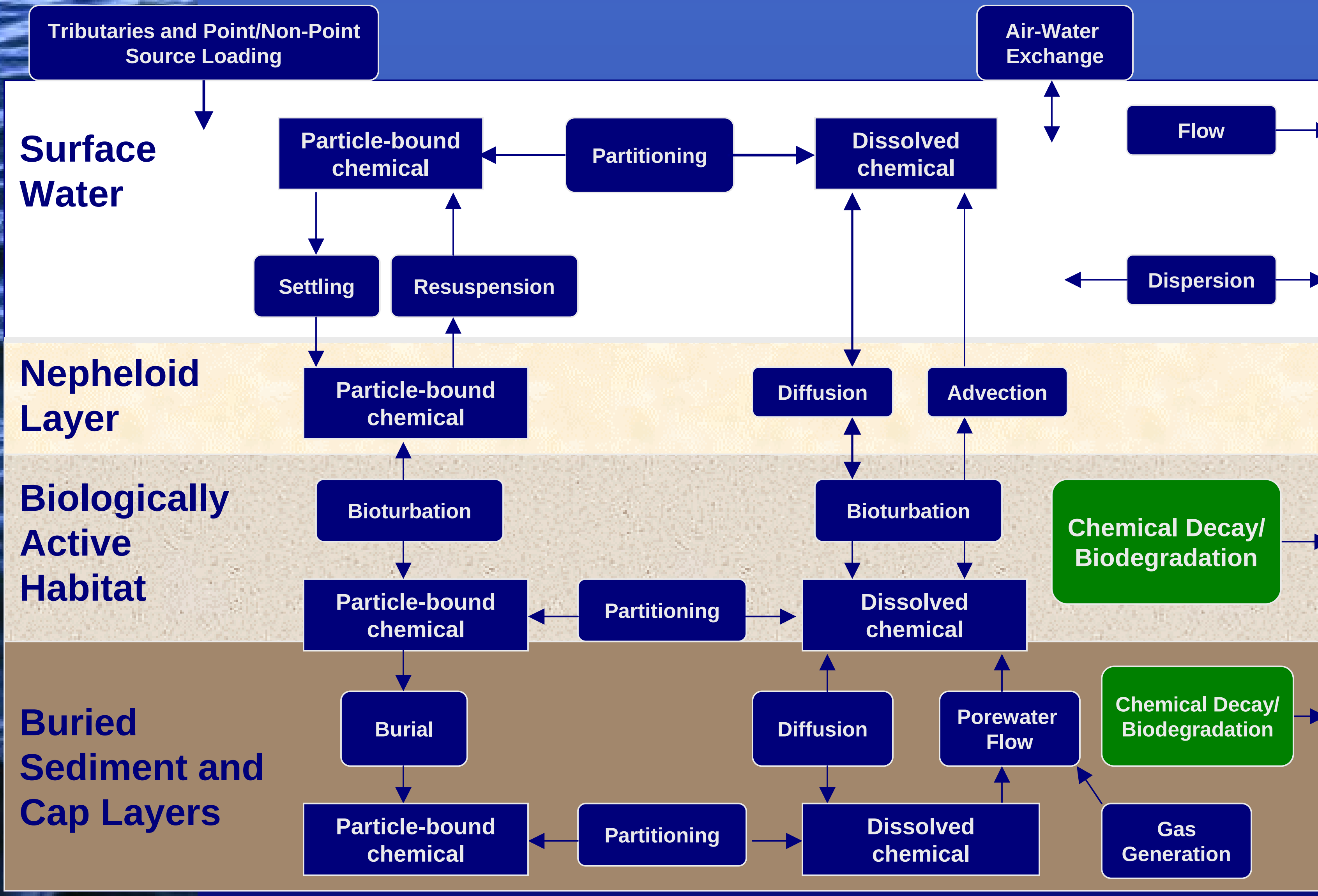
Presentation Outline

- Description - Cap Design to Accomplish:
  - Contaminant isolation below point of exposure
  - And, to the extent practicable:
    - Destruction of contaminant mass
    - Attenuation of porewater flux
- Application and Observations
  - Conceptual model development
  - Post-cap observations
  - *In situ* hydrocarbon biodegradation rates
- Future Direction

Conceptual Model Development

- Iterative process through RI/FS and design
  - Identify key points of exposure/compliance
  - Identify key fate and transport processes
- Capping alternatives/design
  - Isolation layer
  - Thin-layer (enhanced natural recovery)
  - Influence on biodegradation
  - Influence on porewater flux

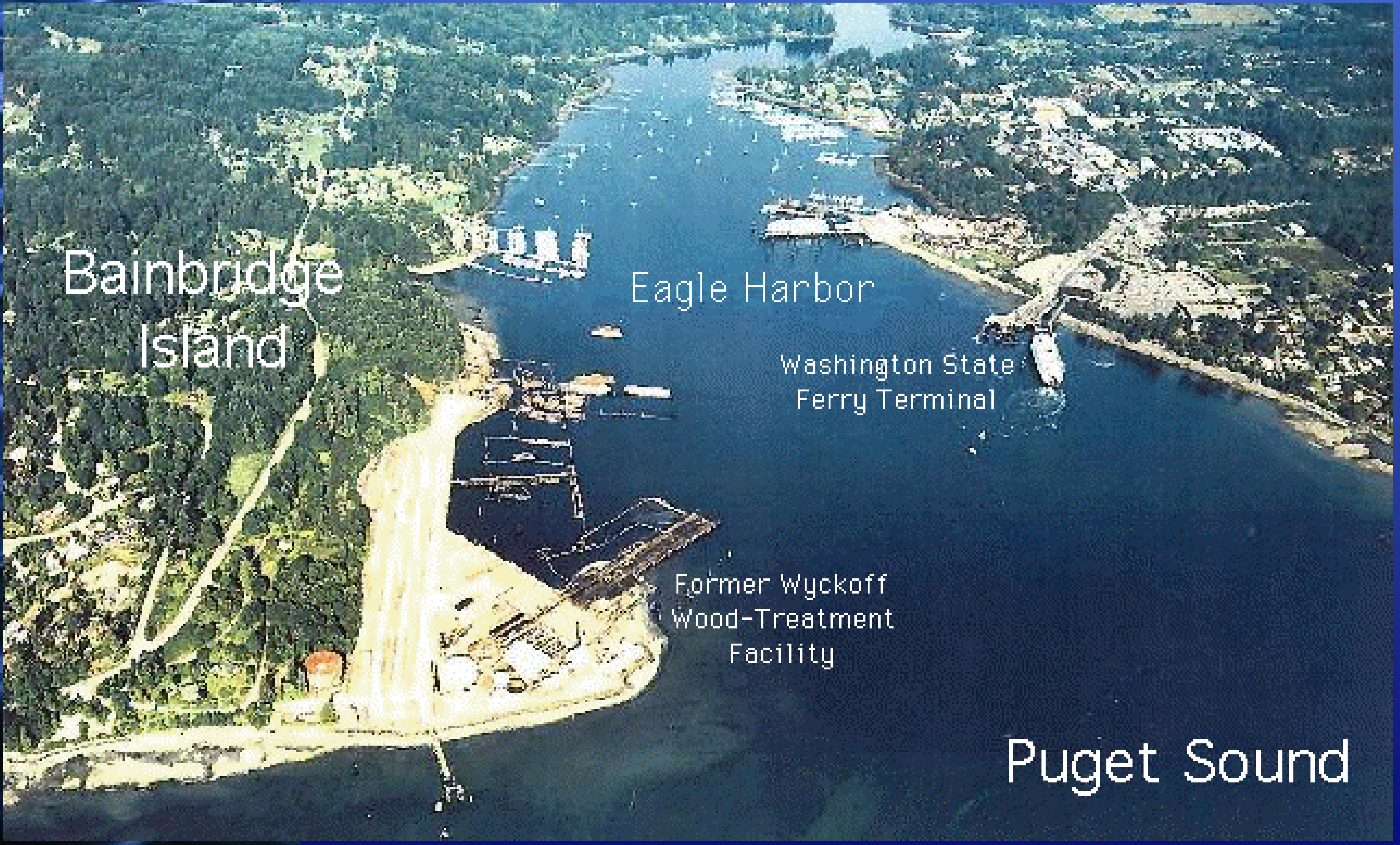
Generalized Fate & Transport Processes



Major Factors Controlling Sediment Hydrocarbon Biodegradation Rates

- Potential rate stimulants:
  - Oxygen – aerobic degradation
  - Nitrate – denitrification
  - Sulfate – sulfidegenesis
  - Nutrients and catalysts
- Potential rate depressants:
  - High (percent) hydrocarbon concentrations

Eagle Harbor Capping Site



Eagle Harbor Source Control & Cap History

Chemicals of Potential Concern → PAHs (Creosote) & Mercury

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Source Control Implementation → Major Controls Implemented in 1960s
Final Source Controls in 2000

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RI/FS and ROD → Historical Recovery Well Documented
Capping Implemented in 1994

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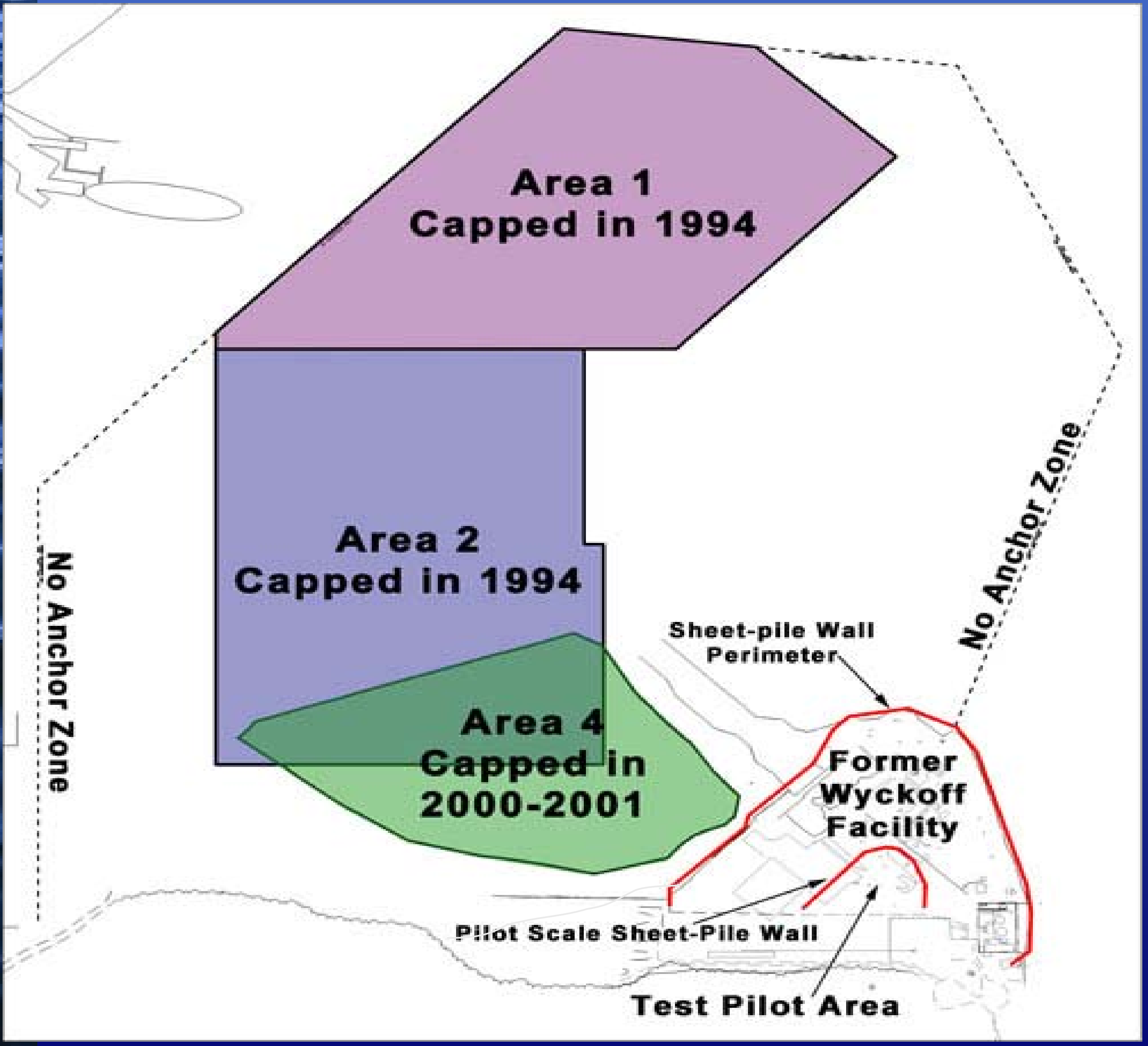
Adaptive Management

Silty Sand Cap Placement (1994)

Eagle Harbor – Adaptive Management

- Cap placed before final PAH source controls implemented (DNAPL)
- Monitoring/adaptive management
  - Cap integrity and physical stability confirmed
  - Chemical/biological performance criteria met
  - Degraded recontaminated inshore area
  - Final DNAPL source controls implemented

East Eagle Harbor Cap Layout

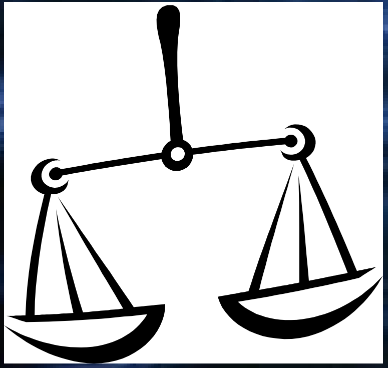


The University of Washington Marine Bioremediation Program

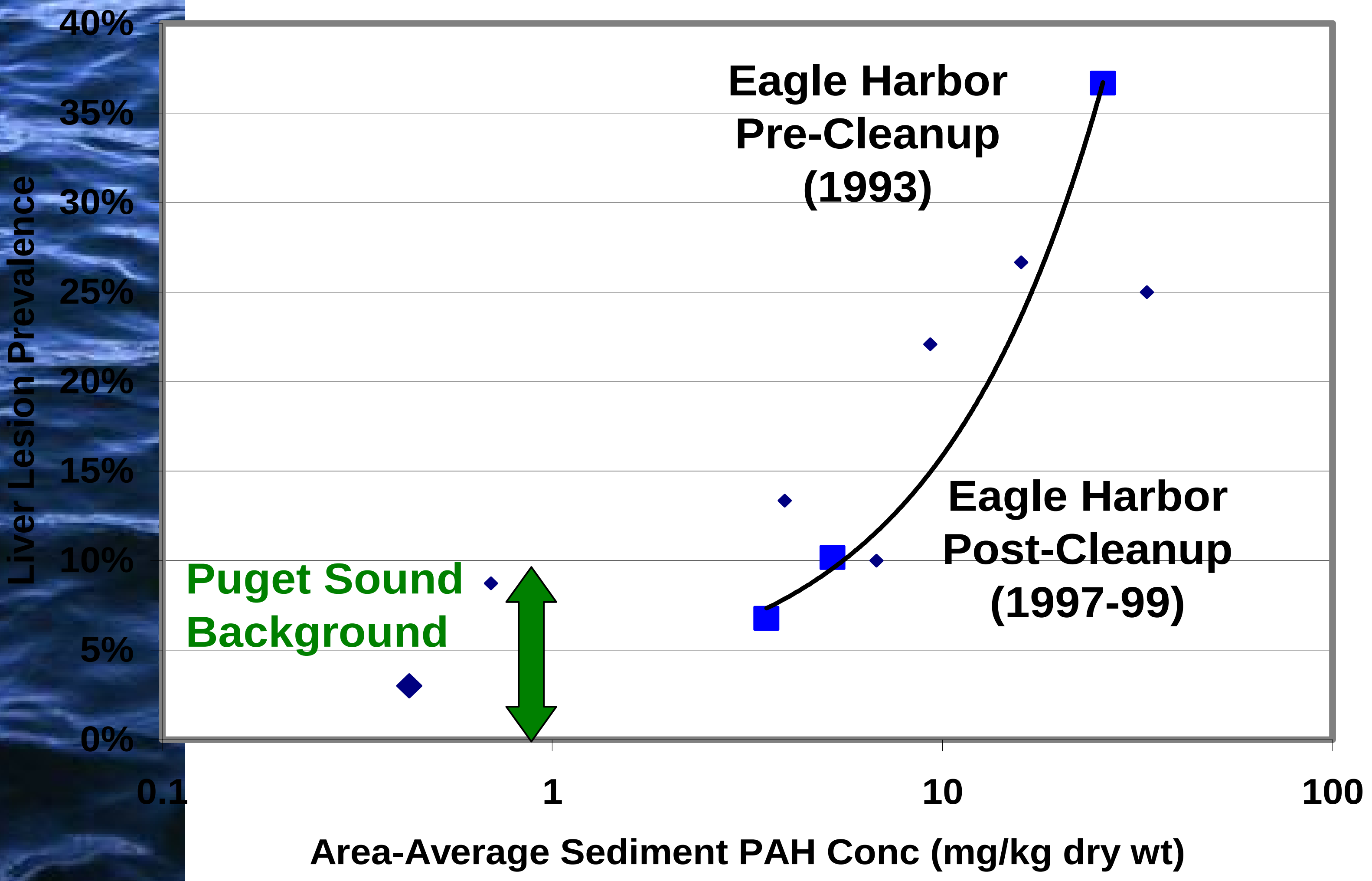
- A multidisciplinary research and training initiative investigating marine bioremediation
- Supported in the past by the US Office of Naval Research and the University of Washington Office of Research
- Jody Deming, Director
- Primary Field Site – Eagle Harbor
- Publications pending
- http://depts.washington.edu/uwmbp/

Detailed Eagle Harbor Post-Cap Biodegradation Studies

- Major findings:
  - Cap significantly depressed *in situ* PAH biodegradation rates
  - Reduced oxygen and sulfate supply
  - Nitrate amendments not effective
  - Sulfate amendments show promise
  - Complex subsurface sulfate geochemistry
- Cap-induced reduction of subsurface biodegradation rates balanced by effective exposure & risk controls



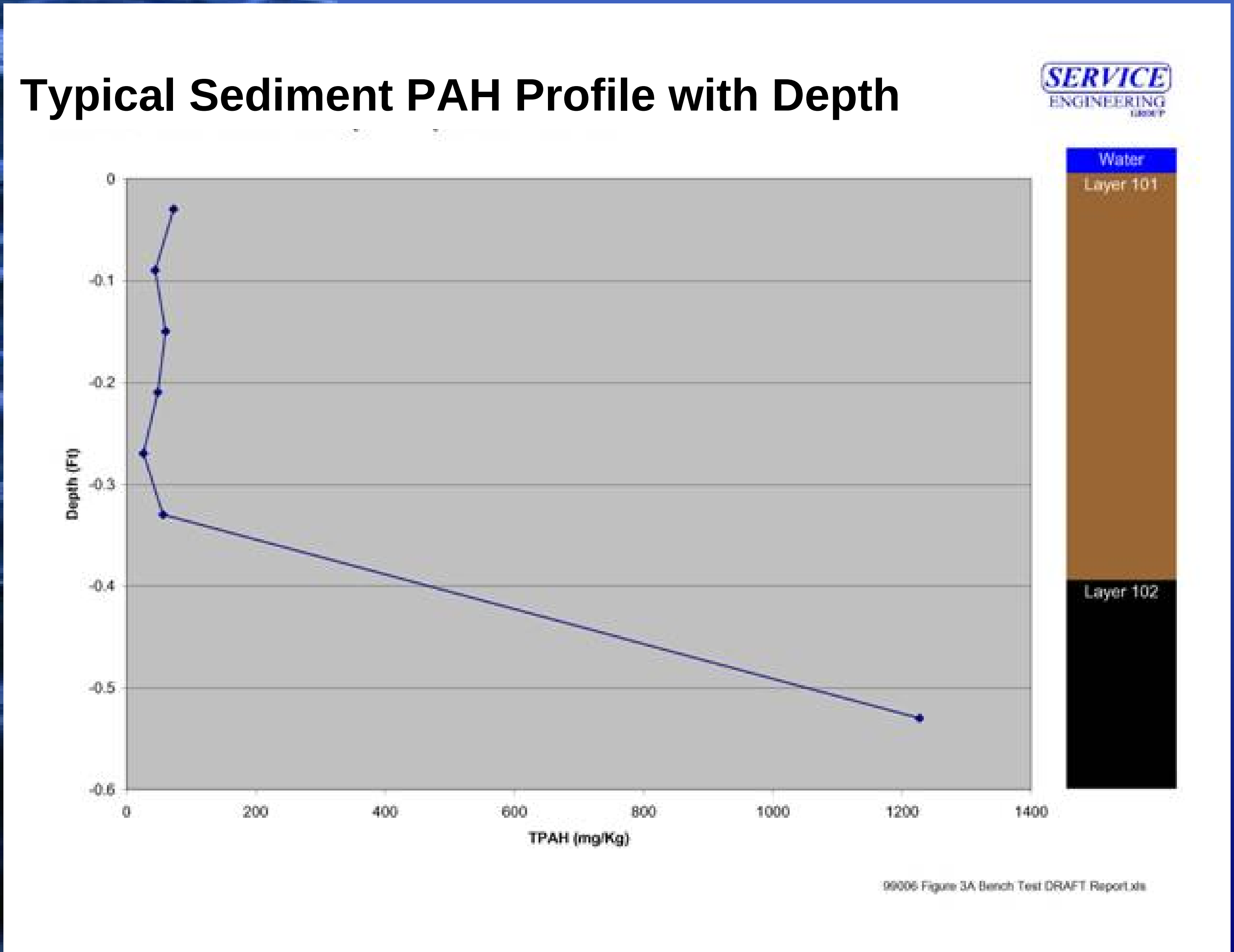
Eagle Harbor Biological Recovery: Fish Histopathology



SLRIDT (Duluth) Site Case Study

- Historic manufactured gas plant operations
- Localized sediment naphthalene accumulations from historic releases

SLRIDT (Duluth) Site Case Study



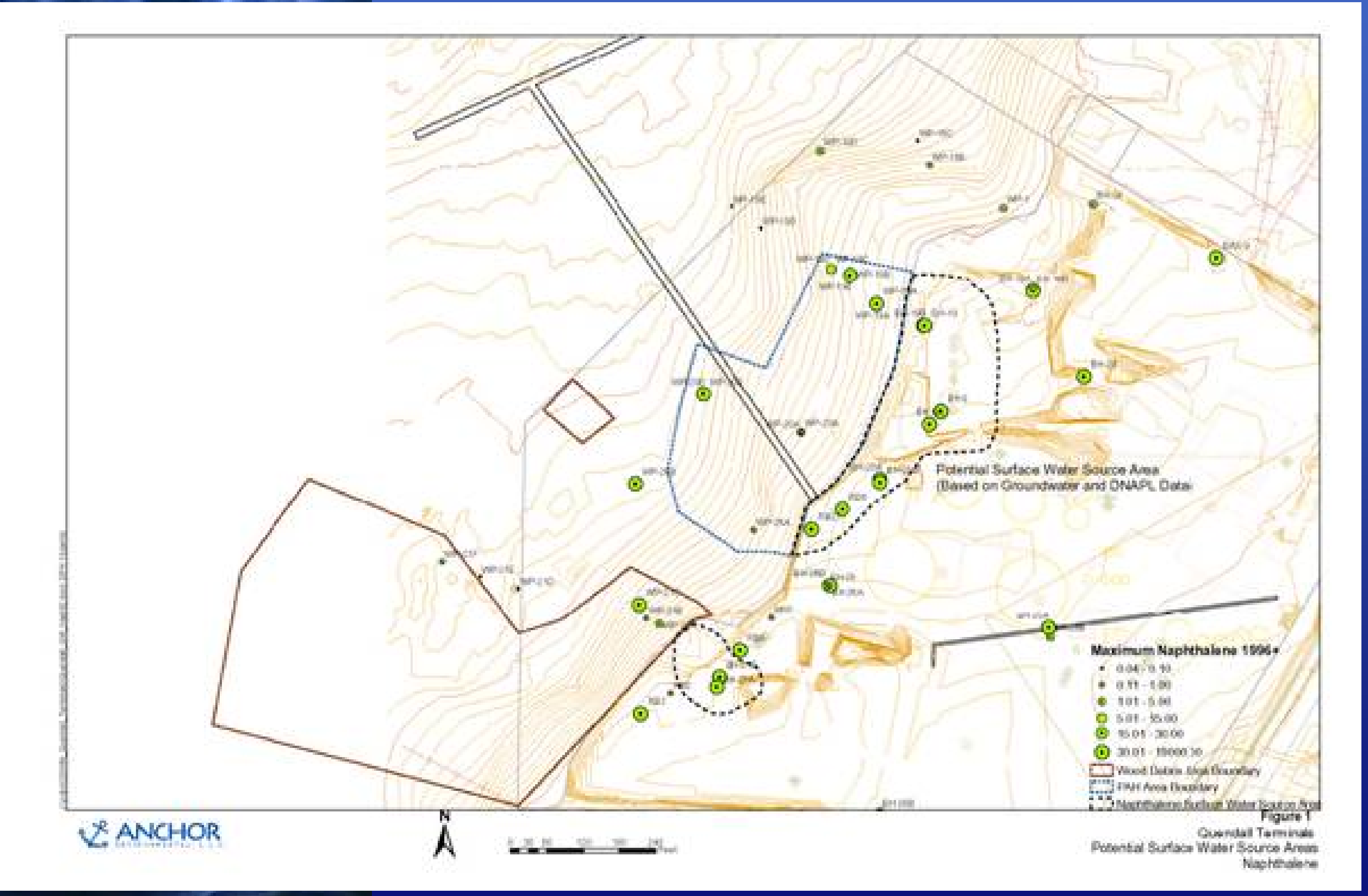
- Subsurface sediment PAH accumulations from historic releases
- Low sediment PAH conc. in mixed layer (avg. 60-fold lower than deeper seds)

Simplified Boudreau Fate/Transport Model SLRIDT (Duluth) Site

$$\frac{\partial C}{\partial t} = \frac{1}{\phi_s}\left\{\frac{\partial}{\partial x}\left(\phi_s D_B(x)\frac{\partial C}{\partial x}\right) - \frac{\partial \phi_s u C}{\partial x} - \phi_s k C^m + \phi_s \mathrm{R}e^{-\alpha x}\right\}$$

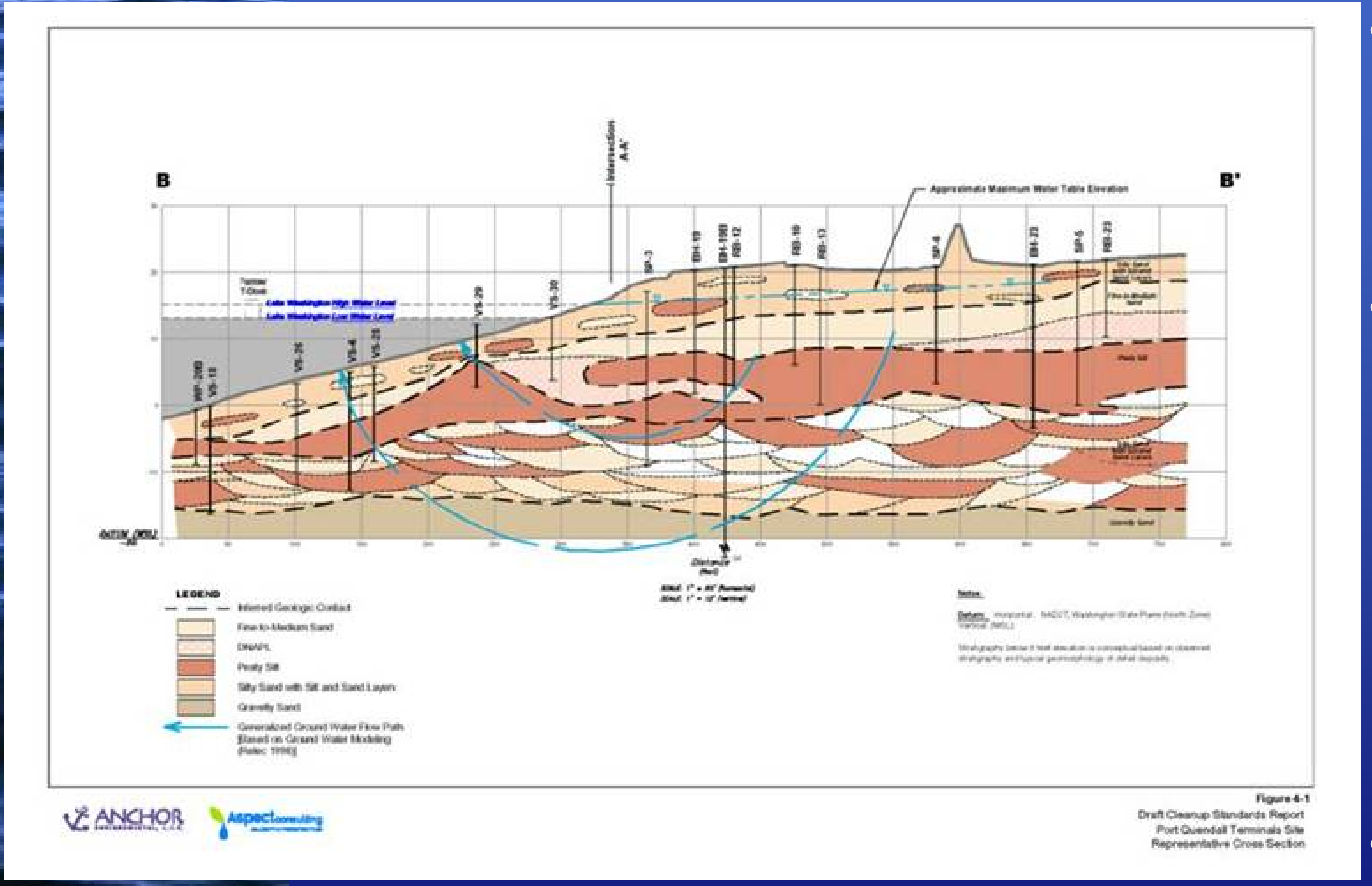
- Measured parameters:
  - Detailed sediment characterization at 5 core and flux meter locations
  - Partitioning coefficients (typical to high)
  - Seepage velocity (0.1 to 0.2 m/yr)
  - Sedimentation rate (0.1 to 0.3 cm/yr)
  - Consolidation behavior (slow)
- Calibrated steady-state parameters:
  - Hydrocarbon biodegradation rates

Quendall (Lk. Washington) Site Case Study



- Historic creosote and bulk fuel storage operations
- Nearshore releases of mobile hydrocarbons through groundwater

Quendall (Lk. Washington) Site Case Study



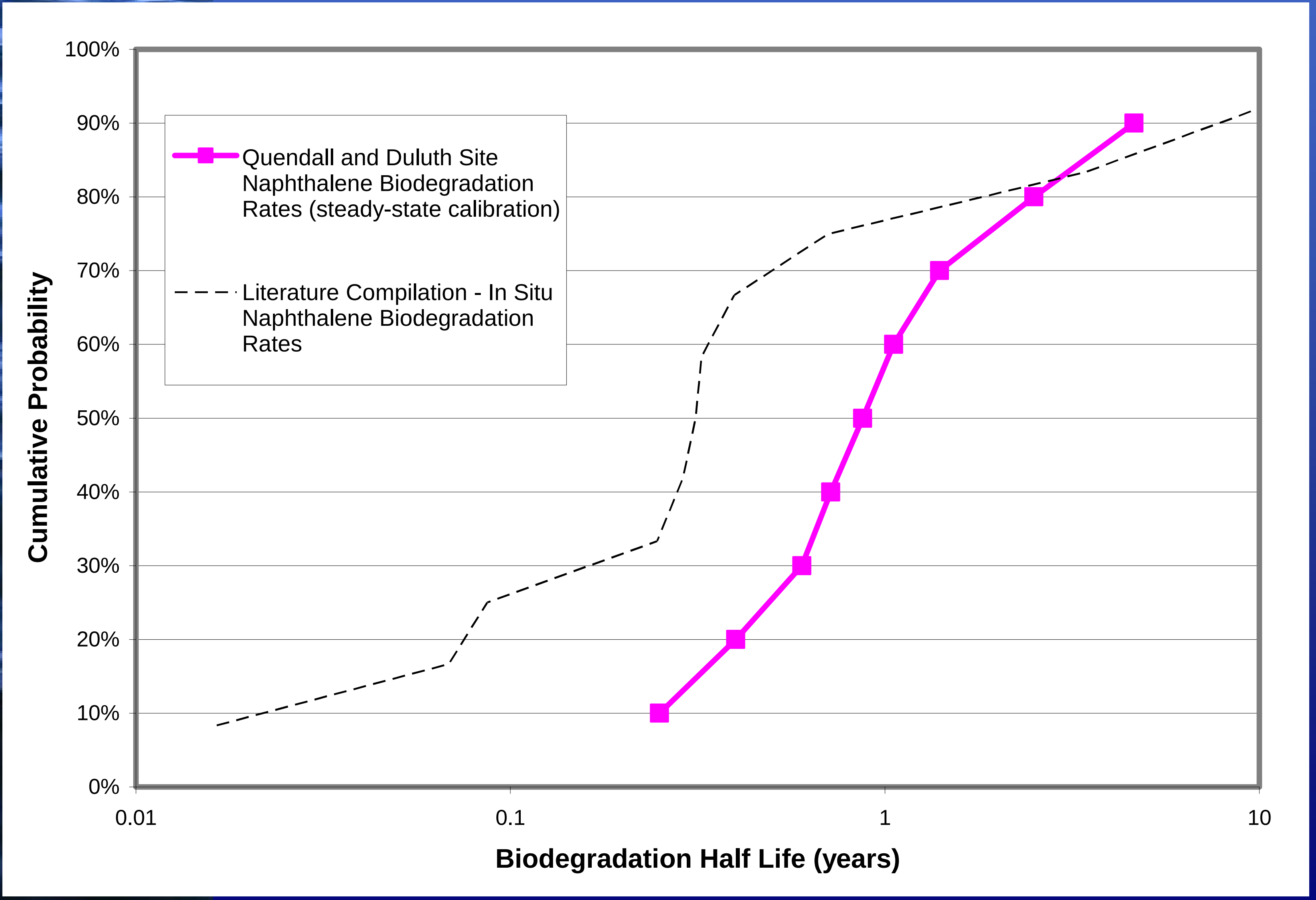
- Upland DNAPL source to groundwater
- 100 to 1,000-fold reductions in PAH concentration over last 5 feet of transport
- Steady-state

Simplified Boudreau Fate/Transport Model Quendall (Lk. Washington) Site

$$\frac{\partial C}{\partial t} = \frac{1}{\phi_s}\left\{\frac{\partial}{\partial x}\left(\phi_s D_B(x)\frac{\partial C}{\partial x}\right) - \frac{\partial \phi_s u C}{\partial x} - \phi_s k C^m + \phi_s \mathrm{R}e^{-\alpha x}\right\}$$

- Measured parameters:
  - Detailed sediment characterization at 4 core and wellpoint/flux meter locations
  - Partitioning coefficients (typical)
  - Seepage velocity (1 to 20 m/yr)
  - Sedimentation rate (0.1 to 0.4 cm/yr)
  - Consolidation behavior (slow)
- Calibrated steady-state parameters:
  - Hydrocarbon biodegradation rates

Summary of *In Situ* Near-Surface Naphthalene Biodegradation Rates



Terminal 91 CDF
Seattle, WA

Port of Seattle

>200,000 cy

Sediment

PCB Contaminated

HARTCROWSER

Terminal 91 CDF Monitoring – Chemical Attenuation Mechanisms

- 20 years of post-construction monitoring
- Coarse-grained berms and sediment caps = “HydroBioGeoChemical Filters”:
  - Metal sulfide precipitation
  - Ferrous iron oxidation/co-precipitation
  - Aerobic and sulfate-based biodegradation
  - Tidal dispersion
- Porewater and sediment protection confirmed

Summary/Future Direction

- *In situ* hydrocarbon biodegradation rates likely to be significant baseline natural recovery processes
- Opportunities to enhance/maintain hydrocarbon biodegradation rates through innovative cap design:
  - Identify rate-limiting amendments (bench-scale tests)
  - Incorporate amendments below capping layer (operational challenges; “borrow” technologies from related fields)
  - Minimize thickness and maximize grain size, esp. for O_2 and SO_4 diffusion from the overlying water column
- Target evaluation and design to specific site conditions and management questions
- Risk management balances