

# **APPENDIX A. REVIEW OF BIOACCUMULATION MODEL APPLICATIONS AT OTHER CONTAMINATED SEDIMENT SITES**

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# 1 Introduction

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This appendix provides a tabular summary of information from other sites in the United States and Canada where mechanistic bioaccumulation models have been used. Table 1 includes the following information:

- ◆ Basis of modeling (i.e., literature sources or previous models used to develop the model)
- ◆ Objectives of the modeling effort
- ◆ Target species of the modeling effort
- ◆ Chemicals included in the model
- ◆ Chemical source input media
- ◆ Whether the model was developed as a steady-state or dynamic model
- ◆ References for obtaining more information about the models

Table 1. Summary of other sites where mechanistic bioaccumulation models have been used

| Site Name<br>by Region                                           | Model Basis/Type                                                                                                                                   | Modeling Objectives                                                                                                                                                                                                                                                                    | Modeling Objective Categories |                                      |                                              |                                      | Target<br>Taxa for<br>Model | Chemicals<br>Modeled                               | Input Media                                           | Steady-state<br>vs. Dynamic | Citation                                              |
|------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------|--------------------------------------|----------------------------------------------|--------------------------------------|-----------------------------|----------------------------------------------------|-------------------------------------------------------|-----------------------------|-------------------------------------------------------|
|                                                                  |                                                                                                                                                    |                                                                                                                                                                                                                                                                                        | Develop<br>Cleanup<br>Goals   | Evaluate<br>Remedial<br>Alternatives | Understand<br>Chemical<br>Uptake in<br>Biota | Model<br>Development/<br>Methodology |                             |                                                    |                                                       |                             |                                                       |
| USEPA Region 1                                                   |                                                                                                                                                    |                                                                                                                                                                                                                                                                                        |                               |                                      |                                              |                                      |                             |                                                    |                                                       |                             |                                                       |
| GE/Housatonic River<br>(Massachusetts)                           | adapted from QEAFDCHN 1.0<br>(QEA 2001)                                                                                                            | predict future PCB concentrations, assess relative performances of remedial alternatives against baseline conditions, and estimate potential risk reductions following implementation of remedy                                                                                        |                               | ✓                                    |                                              |                                      | fish                        | total PCBs and individual congeners                | sediment, water, porewater, water column particulates | steady-state and dynamic    | USACE and USEPA (2004, 2006); Gustavson et al. (2011) |
| New Bedford Harbor<br>(Massachusetts)                            | mass balance model; previously applied by Thomann and Connolly (1984) and Connolly and Tonelli (1985)                                              | understand factors affecting the uptake of PCBs for winter flounder and lobster; model intended to provide information regarding economically important fishery                                                                                                                        |                               |                                      | ✓                                            |                                      | lobster, winter flounder    | PCBs (homologs)                                    | sediment, water                                       | steady-state                | Connolly (1991)                                       |
| USEPA Region 2                                                   |                                                                                                                                                    |                                                                                                                                                                                                                                                                                        |                               |                                      |                                              |                                      |                             |                                                    |                                                       |                             |                                                       |
| Alcoa Aggregation Site (Grasse River, New York)                  | Anchor QEA food web model                                                                                                                          | evaluate remediation options in relation to ecological and human health risk-based goals                                                                                                                                                                                               |                               | ✓                                    |                                              |                                      | appears to be fish          | PCBs                                               | unknown (model not currently public)                  | appears to be dynamic       | Anchor QEA (2013), EPA (2013)                         |
| Hudson River (New York)                                          | QEA (1999) based on Connolly (1991) and Connolly et al. (1992)                                                                                     | evaluate effectiveness of remedial alternatives (dredging vs. natural recovery) and impact of re-suspension of PCBs during dredging                                                                                                                                                    |                               | ✓                                    | ✓                                            |                                      | fish                        | total PCBs                                         | sediment, particulate matter, water                   | dynamic                     | Anchor QEA (2010)                                     |
|                                                                  | FISHRAND model based on Gobas (1993)                                                                                                               | evaluate remedial actions with regard to time frame for achieving risk-based cleanup goals (no action vs. other alternatives) and potential for buried contaminated sediment to become exposed during storm events                                                                     |                               | ✓                                    |                                              |                                      | fish                        | total PCBs                                         | sediment, freely dissolved water                      | dynamic                     | TAMS and Menzie-Cura (2000); Gustavson et al. (2011)  |
| Lower Passaic River Study Area (New Jersey)                      | developed based on equations from Thomann et al. (1992) and Gobas (1993)                                                                           | develop a mechanistic food web model using distributions for key exposure parameters that could be used to estimate the bioaccumulation of xenobiotic chemicals in the food web (Passaic River used as a case study)                                                                   |                               |                                      |                                              | ✓                                    | crab, fish                  | PCB congeners (PCB 77, 126, 105, 118, 169)         | sediment, water                                       | steady-state                | Iannuzzi et al. (1996)                                |
| New York/New Jersey Harbor (New York/New Jersey)                 | developed based on equations from Thomann et al. (1992) and previous models for NY/NJ Harbor (Thomann et al. 1989, 1991; Farley et al. 1999; 2006) | conducted as part of the CARP project to understand the relative significance of contaminant inputs and how they relate to biota tissue concentrations, evaluate remedial scenarios/predict future biota concentrations, and inform remedial decision to reduce levels of contaminants |                               | ✓                                    | ✓                                            |                                      | fish                        | PCB homologs, dioxins/furans, cadmium, and mercury | sediment, water                                       | steady-state and dynamic    | HydroQual (2007)                                      |
| USEPA Region 3                                                   |                                                                                                                                                    |                                                                                                                                                                                                                                                                                        |                               |                                      |                                              |                                      |                             |                                                    |                                                       |                             |                                                       |
| James River (Virginia)                                           | based on equations from Thomann and Connolly (1984)                                                                                                | understand changes in Kepone concentrations in fish tissue over time relative to FDA action level and fishery closure                                                                                                                                                                  | ✓                             |                                      | ✓                                            |                                      | fish                        | Kepone (pesticide)                                 | sediment, water                                       | time-variable               | Connolly and Tonelli (1985)                           |
| USEPA Region 4                                                   |                                                                                                                                                    |                                                                                                                                                                                                                                                                                        |                               |                                      |                                              |                                      |                             |                                                    |                                                       |                             |                                                       |
| Sangamo-Weston Superfund Site/ Twelvemile Creek (South Carolina) | AQUATOX (USEPA 2014)                                                                                                                               | help inform management decisions regarding the recovery of the fishery by predicting future concentrations of PCBs in fish tissue, understanding the sensitivity of these predictions, and identifying important uptake pathways of PCBs for higher-trophic-level species              |                               | ✓                                    | ✓                                            |                                      | fish                        | total PCBs                                         | detritus, water                                       | dynamic                     | Rashleigh et al. (2009)                               |

| Site Name<br>by Region                          | Model Basis/Type                                                                                                              | Modeling Objectives                                                                                                                                                                                                                                          | Modeling Objective Categories |                                      |                                              |                                      | Target<br>Taxa for<br>Model              | Chemicals<br>Modeled                                 | Input Media                                                 | Steady-state<br>vs. Dynamic   | Citation                                          |
|-------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------|--------------------------------------|----------------------------------------------|--------------------------------------|------------------------------------------|------------------------------------------------------|-------------------------------------------------------------|-------------------------------|---------------------------------------------------|
|                                                 |                                                                                                                               |                                                                                                                                                                                                                                                              | Develop<br>Cleanup<br>Goals   | Evaluate<br>Remedial<br>Alternatives | Understand<br>Chemical<br>Uptake in<br>Biota | Model<br>Development/<br>Methodology |                                          |                                                      |                                                             |                               |                                                   |
| USEPA Region 5                                  |                                                                                                                               |                                                                                                                                                                                                                                                              |                               |                                      |                                              |                                      |                                          |                                                      |                                                             |                               |                                                   |
| Lower Fox River and<br>Green Bay<br>(Wisconsin) | model for the lower Fox River<br>adapted from Gobas (1993)                                                                    | develop sediment quality thresholds, develop RAOs,<br>and evaluate remedial alternatives by calculating<br>projected alternative-specific risks                                                                                                              | ✓                             | ✓                                    |                                              |                                      | fish                                     | total PCBs                                           | sediment, filtered<br>water                                 | dynamic                       | ThermoRetec (2001);<br>Gustavson et al.<br>(2011) |
|                                                 | mass balance model for Green<br>Bay/Fox River                                                                                 | test existing modeling framework for mass balance<br>approach (coupled with a food chain model) and use<br>as a pilot for future modeling in the Great Lakes                                                                                                 |                               |                                      | ✓                                            | ✓                                    | fish                                     | PCB congeners,<br>dieldrin, lead, cadmium            | sediment, water<br>(from physical<br>mass balance<br>model) | dynamic                       | USEPA (1989a,<br>1989b)                           |
| Lake Erie (Ohio)                                | adapted from Gobas (1993) and<br>Morrison et al. (1996)                                                                       | develop model that could accurately predict transfer<br>of PCBs in the complex Lake Erie food web and<br>better understand contaminant transfer to biota and<br>how changes in concentrations would impact<br>ecosystem                                      |                               |                                      |                                              | ✓                                    | fish                                     | PCB congeners                                        | suspended solids,<br>water                                  | steady-state                  | Morrison et al. (1996;<br>1997)                   |
| Lake Ontario                                    | based on Norstrom et al. (1976)<br>and Jensen et al. (1982)                                                                   | predict PCB concentrations in fish tissue and<br>understand the mechanisms of PCB uptake                                                                                                                                                                     |                               |                                      | ✓                                            | ✓                                    | fish<br>(salmonids)                      | PCB homologs                                         | prey tissue, water                                          | steady-state                  | Barber et al. (1991)                              |
|                                                 | Gobas (1993)                                                                                                                  | predict concentrations of hydrophobic organic<br>chemicals in aquatic food webs (model applied to<br>Lake Ontario for verification)                                                                                                                          |                               |                                      |                                              | ✓                                    | fish                                     | total PCBs and other<br>organochlorines              | sediment, water                                             | steady-state                  | Gobas (1993)                                      |
|                                                 | food chain model adapted from<br>Gobas (1993)                                                                                 | develop a combined lake model and food chain<br>model that could describe the fate of chemicals in a<br>lake (model applied to Lake Ontario for verification)                                                                                                |                               |                                      | ✓                                            | ✓                                    | fish                                     | total PCBs                                           | sediment, water                                             | steady-state                  | Mackay et al. (1994)                              |
|                                                 | developed fugacity model based<br>on Clark et al. (1990) and MacKay<br>(1991)                                                 | develop and verify a model that could describe the<br>bioaccumulation of hydrophobic organic chemicals<br>in a complex food web (model for PCBs applied to<br>Lake Ontario for verification)                                                                 |                               |                                      |                                              | ✓                                    | fish                                     | PCBs (and other<br>hydrophobic organic<br>chemicals) | sediment, water                                             | steady-state                  | Campfens and<br>Mackay (1997)                     |
|                                                 | avian bioaccumulation model<br>developed in this paper                                                                        | develop a generalized model of avian<br>bioaccumulation of persistent organic pollutants                                                                                                                                                                     |                               |                                      |                                              | ✓                                    | birds                                    | DDE, dieldrin, Mirex,<br>hexachlorobenzene           | prey tissue                                                 | dynamic                       | Norstrom et al. (2007)                            |
|                                                 | based on stable isotope analysis<br>and bioaccumulation model (model<br>adapted from Sample et al. (1996))                    | develop model that could be used to predict<br>chemical concentrations in mink; model could be<br>used as part of biomonitoring program to evaluate<br>how mink tissue concentrations change as a result<br>of environmental changes relative to NOAEL/LOAEL |                               |                                      |                                              | ✓                                    | mink                                     | PCBs, dioxins/furans,<br>mercury                     | water, prey tissue                                          | steady-state                  | Wellman et al. (2009)                             |
| Sheboygan River and<br>Harbor (Wisconsin)       | based on Gobas (1993) and<br>adaptations from Morrison et al.<br>(1997)                                                       | estimate dietary exposure concentrations and<br>calculate cleanup goals based on safe (risk-based)<br>concentrations in tissue                                                                                                                               | ✓                             |                                      | ✓                                            |                                      | fish                                     | PCB congeners                                        | sediment<br>(estimated<br>overlying water)                  | dynamic                       | EVS and NOAA<br>(1998)                            |
| USEPA Region 9                                  |                                                                                                                               |                                                                                                                                                                                                                                                              |                               |                                      |                                              |                                      |                                          |                                                      |                                                             |                               |                                                   |
| San Francisco Bay<br>(California)               | aquatic organism portion of the<br>model based on Arnot and Gobas<br>(2004)                                                   | estimate PCB concentrations in biota and derive<br>sediment remediation targets protective of risk<br>assessment receptors (ecological and human<br>health)                                                                                                  | ✓                             |                                      |                                              | ✓                                    | fish,<br>shellfish,<br>birds,<br>mammals | PCBs, evaluated as<br>individual congeners           | sediment, water,<br>porewater                               | steady-state                  | Gobas and Arnot<br>(2010)                         |
| South California Bight<br>(California)          | model developed by Thomann and<br>Connolly (1984), Connolly and<br>Tonelli (1985), Connolly (1991),<br>Connolly et al. (1992) | determine whether observed dietary composition<br>resulted in 1) realistic contaminant levels in<br>predators when used in model, and 2) a realistic<br>picture of chemical exposure sources                                                                 |                               |                                      | ✓                                            | ✓                                    | birds                                    | total PCBs and<br>4,4'-DDE                           | prey tissue<br>concentrations                               | appears to be<br>steady-state | Glaser and Connolly<br>(2002)                     |

| Site Name<br>by Region                               | Model Basis/Type                                                                                | Modeling Objectives                                                                                                                                    | Modeling Objective Categories |                                      |                                              |                                      | Target<br>Taxa for<br>Model | Chemicals<br>Modeled                                                                                  | Input Media                                    | Steady-state<br>vs. Dynamic | Citation                          |
|------------------------------------------------------|-------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------|--------------------------------------|----------------------------------------------|--------------------------------------|-----------------------------|-------------------------------------------------------------------------------------------------------|------------------------------------------------|-----------------------------|-----------------------------------|
|                                                      |                                                                                                 |                                                                                                                                                        | Develop<br>Cleanup<br>Goals   | Evaluate<br>Remedial<br>Alternatives | Understand<br>Chemical<br>Uptake in<br>Biota | Model<br>Development/<br>Methodology |                             |                                                                                                       |                                                |                             |                                   |
| USEPA Region 10                                      |                                                                                                 |                                                                                                                                                        |                               |                                      |                                              |                                      |                             |                                                                                                       |                                                |                             |                                   |
| East Waterway<br>(Washington)                        | based on Arnot and Gobas (2004)<br>and Gobas (1993)                                             | establish relationship between sediment and tissue<br>to develop cleanup goals (for ecological and human<br>health) and evaluate remedial alternatives | ✓                             | ✓                                    |                                              |                                      | fish and<br>shellfish       | total PCBs                                                                                            | sediment, water                                | steady-state                | Windward and Anchor<br>QEA (2014) |
| Lower Duwamish<br>Waterway<br>(Washington)           | based on Arnot and Gobas (2004)<br>and Gobas (1993)                                             | same as for East Waterway (see above)                                                                                                                  | ✓                             | ✓                                    |                                              |                                      | fish and<br>shellfish       | total PCBs                                                                                            | sediment, water                                | steady-state                | Windward (2010)                   |
| Portland Harbor<br>(Oregon)                          | based on Arnot and Gobas (2004)<br>and Gobas (1993)                                             | same as for East Waterway (see above)                                                                                                                  | ✓                             | ✓                                    |                                              |                                      | fish and<br>shellfish       | PCBs, DDTs,<br>dioxin/furans, and<br>organochlorine<br>pesticides                                     | sediment, water                                | steady-state<br>and dynamic | Windward (2009)                   |
| Puget Sound<br>(Washington)                          | based on Condon (2007) and Arnot<br>and Gobas (2004)                                            | evaluate protectiveness of SQS levels (for marine<br>life and human health) by modeling chemical uptake<br>from Puget Sound sediment to biota tissue   | ✓                             |                                      |                                              | ✓                                    | fish, birds,<br>mammals     | total PCBs, PAHs,<br>phenols, phthalates,<br>chlorinated benzenes,<br>benzyl alcohol, benzoic<br>acid | sediment                                       | unknown                     | Ecology and<br>Environment (2009) |
| Canada                                               |                                                                                                 |                                                                                                                                                        |                               |                                      |                                              |                                      |                             |                                                                                                       |                                                |                             |                                   |
| Fraser-Thompson<br>River Basin (British<br>Columbia) | EcoFate model, adapted from<br>Gobas (1993), Gobas et al. (1995),<br>and Morrison et al. (1996) | understand fate of chemicals in the ecosystem, with<br>focus on transfer from chemical releases (from<br>paper mills) to biota tissue                  |                               |                                      | ✓                                            | ✓                                    | fish                        | 2,3,7,8-TCDD and<br>2,3,7,8-TCDF                                                                      | not clear; appears<br>to be sediment,<br>water | dynamic                     | Gobas et al. (1998)               |

Note: Table compiled as of June 2015.

CARP – Contamination Assessment and Reduction Project  
DDE – dichlorodiphenyldichloroethylene  
DDT – dichlorodiphenyltrichloroethane  
FDA – Food and Drug Administration

LOAEL – lowest-observed-adverse-effect level  
NOAEL – no-observed-adverse-effect level  
PAH – polycyclic aromatic hydrocarbon

PCB – polychlorinated biphenyl  
RAO – remedial action objective  
SQS – sediment quality standards

TCDD – tetrachlorodibenzo-*p*-dioxin  
TCDF – tetrachlorodibenzofuran  
USEPA – US Environmental Protection Agency

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