Appendix A. Review of Bioaccumulation Model Applications at Other Contaminated Sediment Sites

1 Introduction

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). Table 1 includes the following information:

- Basis of modeling (i.e., the 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

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

Site Name by Region	Model Basis/Type	Modeling Objectives	Modeling Objective Categories				Target Taxa for Model	Chemicals Modeled	Input Media	Steady-State vs. Dynamic	Citation
			Develop Cleanup Goals	Evaluate Remedial Alternatives	Understand Chemical Uptake in Biota	Model Development / Methodology					
USEPA Region 1											
GE/Housatonic River (Massachusetts)	adapted from QEAFDCHN 1.0 (QEA 2001)	predict future PCB concentrations, assess relative performance 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 (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, understand the sensitivity of these predictions, and identify important uptake pathways of PCBs for higher-trophic-level species		✓	✓		fish	total PCBs	detritus, water	dynamic	Rashleigh et al. (2009)
USEPA Region 5											

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Lower Fox River and Green Bay (Wisconsin)	model for the lower Fox River adapted from Gobas (1993)	develop sediment quality thresholds, develop RAOs, and evaluate remedial alternatives by calculating projected alternative-specific risks	✓	✓			fish	total PCBs	sediment, filtered water	dynamic	ThermoRetec (2001); Gustavson et al. (2011)
	mass balance model for Green Bay/Fox River	test existing modeling framework for mass balance approach (that is coupled with a food chain model) and serve as a pilot for future modeling in the Great Lakes			✓	✓	fish	PCB congeners, dieldrin, lead, cadmium	sediment, water (from physical mass balance model)	dynamic	U.S. Environmental Protection Agency (1989, 1988)
Lake Erie (Ohio)	adapted from Gobas (1993) and Morrison et al. (1996)	develop model that could accurately predict transfer of PCBs in the complex Lake Erie food web, better understand contaminant transfer to biota and how changes in concentrations would impact ecosystem				✓	fish	PCB congeners	suspended solids, water	steady-state	Morrison et al. (1996; 1997)
Lake Ontario	based on Norstrom et al. (1976) and Jensen et al. (1982)	predict PCB concentrations in fish tissue and understand the mechanisms of PCB uptake			✓	✓	fish (salmonids)	PCB homologs	prey tissue, water	steady-state	Barber et al. (1991)
	Gobas (1993)	predict concentrations of hydrophobic organic chemicals in aquatic food webs (model applied to Lake Ontario for verification)				✓	fish	Total PCBs and other organochlorines	sediment, water	steady-state	Gobas (1993)
	food chain model adapted from Gobas (1993)	develop a combined lake model and food chain model that could describe the fate of chemicals in a lake (model applied to Lake Ontario for verification)			✓	✓	fish	Total PCBs	sediment, water	steady-state	Mackay et al. (1994)
	developed fugacity model based on Clark et al. (1990) and MacKay (1991)	develop and verify a model that could describe the bioaccumulation of hydrophobic organic chemicals in a complex food web (model for PCBs applied to Lake Ontario for verification)				✓	fish	PCBs (and other hydrophobic organic chemicals)	sediment, water	steady-state	Campfens and Mackay (1997)
	avian bioaccumulation model developed in this paper	develop a generalized model of avian bioaccumulation of persistent organic pollutants				✓	birds	DDE, dieldrin, Mirex, hexachlorobenzene	prey tissue	dynamic	Norstrom et al. (2007)
	based on stable isotope analysis and bioaccumulation model (model adapted from Sample et al. (1996))	develop model that can be used to predict chemical concentrations in mink; model could then be used as part of biomonitoring program to evaluate how mink tissue concentrations change as result of environmental changes relative to NOAEL/LOAEL				✓	mink	PCBs, dioxins/furans, mercury	water, prey tissue	steady-state	Wellman et al. (2009)
Sheboygan River and Harbor (Wisconsin)	based on Gobas (1993) and adaptations from Morrison et al. (1997)	estimate dietary exposure concentrations and calculate cleanup goals based on safe (risk-based) concentrations in tissue	✓		✓		fish	PCB congeners	sediment (estimated overlying water)	dynamic	EVS and NOAA (1998)
USEPA Region 9											
San Francisco Bay (California)	aquatic organism portion of the model based on Arnot and Gobas (2004)	estimate PCB concentrations in biota and derive sediment remediation targets that are protective of risk assessment receptors (ecological and human health)	✓			✓	fish, shellfish, birds, mammals	PCBs, evaluated as individual congeners	sediment, water, porewater	steady-state	Gobas and Arnot (2010)
South California Bight (California)	model developed by Thomann and Connolly (1984), Connolly and Tonelli (1985), Connolly (1991), Connolly et al. (1992)	determine whether observed dietary composition resulted in: 1) realistic contaminant levels in predators when used in model, and 2) a realistic picture of chemical exposure sources			✓	✓	birds	total PCBs and 4,4'-DDE	prey tissue concentrations	appears to be steady-state	Glaser and Connolly (2002)
USEPA Region 10											
East Waterway (Washington)	based on Arnot and Gobas (2004) and Gobas (1993)	establish relationship between sediment and tissue to develop cleanup goals (for ecological and human health) and evaluate remedial alternatives	✓	✓			fish and shellfish	total PCBs	sediment, water	steady-state	Windward and Anchor QEA (2014)
Lower Duwamish Waterway (Washington)	based on Arnot and Gobas (2004) and Gobas (1993)	same as for East Waterway (see above)	✓	✓			fish and shellfish	total PCBs	sediment, water	steady-state	Windward (2010)
Portland Harbor (Oregon)	based on Arnot and Gobas (2004) and Gobas (1993)	same as for East Waterway (see above)	✓	✓			fish and shellfish	PCBs, DDTs, dioxin/furans, and organochlorine pesticides	sediment, water	steady-state and dynamic	Windward (2009)

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Puget Sound (Washington)	based on Condon (2007) and Arnot and Gobas (2004)	evaluate protectiveness of SQS levels (for marine life and human health) by modeling chemical uptake from Puget Sound sediment to biota tissue	✓			✓	fish, birds, mammals	total PCBs, PAHs, phenols, phthalates, chlorinated benzenes, benzyl alcohol, benzoic acid	sediment	unknown	Ecology and Environment (2009)
Canada											
Fraser-Thompson River Basin (British Columbia)	EcoFate model, adapted from Gobas (1993), Gobas et al. (1995), and Morrison et al. (1996)	understand fate of chemicals in the ecosystem, with focus on transfer from chemical releases (from paper mills) to biota tissue			✓	✓	fish	2,3,7,8-TCDD and 2,3,7,8-TCDF	not clear; appears to be sediment, water	dynamic	Gobas et al. (1998)

DDD – dichlorodiphenyldichloroethane
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
SQS – sediment quality standards
SVOC – semivolatile organic compound
TBT – tributyltin
TCDD – tetrachlorodibenzo-*p*-dioxin
TCDF – tetrachlorodibenzofuran
total DDx – sum of all six DDT isomers (2,4′-DDD, 4,4′-DDD, 2,4′-DDE, 4,4′-DDE, 2,4′-DDT and 4,4′-DDT)
USEPA – US Environmental Protection Agency

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References

Anchor QEA. 2010. The Upper Hudson River PCB modeling system: Hudson River PCBs Superfund site. Prepared for General Electric Company. Anchor QEA, LLC, Glens Falls, NY.

Anchor QEA. 2013. Grasse River, Massena, NY, sediment management [online]. Anchor QEA. [Cited October 23, 2014.] Available from: http://www.anchorqea.com/index.php/grasse-river.

Arnot JA, Gobas FAPC. 2004. A food web bioaccumulation model for organic chemicals in aquatic ecosystems. Environ Toxicol Chem 23:2343-2355.

Barber MC, Suarez LA, Lassiter RR. 1991. Modelling bioaccumulation of organic pollutants in fish with an application to PCBs in Lake Ontario salmonids. Can J Fish Aquat Sci 48:318-337.

Campfens J, Mackay D. 1997. Fugacity-based model of PCB bioaccumulation in complex aquatic food webs. Environ Sci Technol 31:577-593.

Clark KE, Gobas FAPC, Mackay D. 1990. Model of organic chemical uptake and clearance by fish from food and water. Environ Sci Technol 24:1203-1213.

Condon CD. 2007. Development, evaluation, and application of a food web bioaccumulation model for PCBs in the Strait of Georgia, British Columbia. Master's thesis. School of Resource and Environmental Management, Simon Fraser University, Burnaby, BC, Canada.

Connolly JP, Tonelli R. 1985. A model of kepone in the striped bass food chain of the James River estuary. Cooperative Agreement No. R807827. Environmental Engineering & Science, Manhattan College, Bronx, NY.

Connolly JP. 1991. Application of a food chain model to polychlorinated biphenyl contamination of the lobster and winter flounder food chains in New Bedford Harbor. Environ Sci Technol 25:760-769.

Connolly JP, Parkerton TF, Quadrini JD, Taylor ST, Thuman AJ. 1992. Development and application of a model of PCBs in the Green Bay, Lake Michigan walleye and brown trout and their food webs. Report to the US Environmental Protection Agency, Grosse Ile, Michigan. Cooperative agreement CR-815396.

Ecology and Environment. 2009. Phase 2: Sediment flux/Puget Sound sediments bioaccumulation model - derived concentrations for toxics. Final summary technical report. Control of Toxic Chemicals in Puget Sound, Ecology pub no. 09-09-069. Ecology and Environment, Inc., Seattle, WA.

EPA. 2013. Record of decision, Grasse River Superfund site (a.k.a. Alcoa Aggregation site), Massena, St. Lawrence County, New York. US Environmental Protection Agency, Region 2, New York, NY.

EVS, NOAA. 1998. Sheboygan River and Harbor aquatic ecological risk assessment.

Prepared for US Environmental Protection Agency Region 5. EVS Environment Consultants, Inc. and National Oceanic and Atmospheric Administration, Seattle, WA.

Farley KJ, Thomann RV, Cooney TF, III, Damiani DR, Wands JR. 1999. An Integrated Model of Organic Chemical Fate and Bioaccumulation in the Hudson River Estuary. Final Report prepared for the Hudson River Foundation. Manhattan College, Riverdale, NY.

Farley KJ, Wands JR, Damiani DR, Cooney TF. 2006. Transport, fate, and bioaccumulation of PCBs in the Lower Hudson River. In: Levinton JS, Waldman JR, eds, The Hudson River ecosystem. Cambridge University Press, Cambridge, MA, pp 368-382. Available from: http://dx.doi.org/10.1017/CBO9780511550539.027.

Glaser D, Connolly JP. 2002. A model of p, p′-DDE and total PCB bioaccumulation in birds from the Southern California Bight. Cont Shelf Res 22:1079-1100.

Gobas FACP, Arnot JA. 2010. Food web bioaccumulation model for polychlorinated biphenyls in San Francisco Bay, California, USA. Environ Toxicol Chem 29(6):1385-1395.

Gobas FAPC. 1993. A model for predicting the bioaccumulation of hydrophobic organic chemicals in aquatic food-webs: application to Lake Ontario. Ecol Model 69:1-17.

Gobas FAPC, Z'Graggen MN, Zhang X. 1995. Time response of the Lake Ontario ecosystem to virtual elimination of PCBs. Environ Sci Technol 29:2038-2046.

Gobas FAPC, Pasternak JP, Lien K, Duncan RK. 1998. Development and field validation of a multimedia exposure assessment model for waste load allocation in aquatic ecosystems: application to 2,3,7,8-tetrachloro-*p*-dioxin and 2,3,7,8-tetrachlorodibenzofuran in the Fraser River watershed. Environ Sci Technol 32:2442-2449.

Gustavson KE, Von Stackelberg K, Linkov I, Bridges T. 2011. Bioaccumulation models: state of the application at large Superfund sites. DOER Technical Notes, ERDC TN-DOER-R17. US Army Engineer Research and Development Center, Vicksburg, MS.

HydroQual. 2007. Contamination Assessment and Reduction Project (CARP): A model for the evaluation and management of contaminants of concern in water, sediment, and biota in the NY/NJ Harbor Estuary. Contaminant fate & transport & bioaccumulation sub-models. Hudson River Foundation for Science and Environmental Research, Inc. and Port Authority of New York and New Jersey.

Iannuzzi TJ, Harrington NW, Shear NM, Curry CL, Carlson-Lynch H, Henning MH, Su SH, Rabbe DE. 1996. Distributions of key exposure factors controlling the uptake of xenobiotic chemicals in an estuarine food web. Environ Toxicol Chem 15(11):1979-1992.

Jensen AL, Spigarelli SA, Thommes MM. 1982. PCB uptake by five species of fish in

Lake Michigan, Green Bay of Lake Michigan, and Cayuga Lake, New York. Can J Fish Aquat Sci 39:700-709.

MacKay D. 1991. Multimedia environmental models: the fugacity approach. Lewis Publishers, Chelsea, MI.

Mackay S, Sang S, Vlahos P, Gobas F, Diamond M, Dolan D. 1994. A rate constant model of chemical dynamics in a lake ecosystem: PCBs in Lake Ontario. J Great Lakes Res 20(4):625-642.

Morrison HA, Gobas FAPC, Lazar R, Haffner GD. 1996. Development and verification of a bioaccumulation model for organic contaminants in benthic invertebrates. Environ Sci Technol 30:3377-3384.

Morrison HA, Gobas FAPC, Lazar R, Whittle DM, Haffner GD. 1997. Development and verification of a benthic/pelagic food web bioaccumulation model for PCB congeners in Western Lake Erie. Environ Sci Technol 31:3267-73.

Norstrom RJ, E MA, deFreitas ASW. 1976. A bioenergetics-based model for pollutant accumulation by fish. Simulation of PCB and methylmercury residue levels in Ottawa River yellow perch (*Perca flavescens*). J Fish Res Bd Can 33:248-267.

Norstrom RJ, Clark TP, Enright M, Leung B, Drouillard KG, MacDonald CR. 2007. ABAM, a model for bioaccumulation of POPs in birds: validation for adult herring gulls and their eggs in Lake Ontario. Environ Sci Tech 41:4339-4347.

QEA. 1999. PCBs in the upper Hudson River. Vol 2. A model of PCB fate, transport, bioaccumulation. Prepared for General Electric, Albany, NY. Quantitative Environmental Analysis, LLC, Liverpool, NY.

QEA. 2001. A model of PCB bioaccumulation in the Lower Fox River and Green Bay: GBFood. Quantitative Environmental Analysis, LLC, Montvale, NJ.

Rashleigh B, Barber MC, Walters DM. 2009. Foodweb modeling for polychlorinated biphenyls (PCBs) in the Twelvemile Creek Arm of Lake Hartwell, South Carolina, USA. Ecol Model 220:254-264.

Sample BE, Opresko DM, Suter GW. 1996. Toxicological benchmarks for wildlife. 1996 revision. ES/ERM-86/R3. Office of Environmental Management, US Department of Energy, Washington, DC.

TAMS, Menzie-Cura. 2000. Phase 2 report: feasibility study, Hudson River PCBs reassessment RI/FS. Prepared for US Environmental Protection Agency Region 2 and US Army Corps of Engineers, Kansas City District. TAMS Consultants, Inc., New York, NY.

ThermoRetec. 2001. Fox River food (FRFood) model documentation memorandum: Lower Fox River, Wisconsin remedial investigation and feasibility study. Prepared for Wisconsin Department of Natural Resources. ThermoRetec Consulting Corporation, Seattle, WA.

Thomann RV, Mueller JA, Winfield RP, Huang C. 1989. Report prepared for the Hudson River Foundation. Grant Nos. 007/87A/30 and 011/88A/030. 8 chapters

and appendices.Mathematical Model of the Long-Term Behavior of PCBs in the Hudson River Estuary.

Thomann RV, Mueller JA, Winfield RP, Huang C. 1991. Model of fate and accumulation of PCB homologues in Hudson Estuary. J Environ Engin 117(2):161-178.

Thomann RV, Connolly JP. 1984. Model of PCB in the Lake Michigan lake trout food chain. Environ Sci Technol 18(2):65-71.

Thomann RV, Connolly JP, Parkerton TF. 1992. An equilibrium model of organic chemical accumulation in aquatic food webs with sediment interaction. Environ Toxicol Chem 11:615-629.

U.S. Environmental Protection Agency E. 1988. GREEN BAY / FOX RIVER MASS BALANCE STUDY. Executive Summary. Great Lakes National Program Office, Chicago, Illinois.

U.S. Environmental Protection Agency E. 1989. Green Bay/Fox River Mass Balance Study Plan: A Strategy for Tracking Toxics in the Bay of Green Bay, Lake Michigan. Great Lakes National Program Office, Chicago, Illinois.

USACE, USEPA. 2004. Final modeling framework design: modeling study of PCB contamination in the Housatonic River. DCN: GE-042104-ACDP. Contract No. DACW33-00-D-0006, Task Order No. 0003. US Army Corps of Engineers and US Environmental Protection Agency, Pittsfield, MA.

USACE, USEPA. 2006. Final model documentation report: modeling study of PCB contamination in the Housatonic River. Volume 1. DCN: GE-111006-ADIH. Contract No. DACW33-00-D-0006, Task Order 0003. US Army Corps of Engineers and US Environmental Protection Agency, Pittsfield, MA.

USEPA. 2014. Aquatox. Linking water quality and aquatic life [online]. US Environmental Protection Agency. Updated May 16, 2014. Available from: http://www2.epa.gov/exposure-assessment-models/aquatox.

Wellman ST, Haynes JM, Pagano JJ. 2009. Model estimates bioaccumulation of total PCBs, dioxin-furan TEQs, and total mercury in mink liver based on concentrations in Lake Ontario water. Arch Environ Contam Toxicol 57:808-815.

Windward. 2009. Portland Harbor RI/FS bioaccumulation modeling report. Draft. WW09-0003. Prepared for Lower Willamette Group. Windward Environmental LLC, Seattle, WA.

Windward. 2010. Lower Duwamish Waterway remedial investigation. Remedial investigation report. Final. Prepared for Lower Duwamish Waterway Group. Windward Environmental LLC, Seattle, WA.

Windward, Anchor QEA. 2014. Port of Seattle East Waterway operable unit supplemental remedial investigation/feasibility study. Final supplemental remedial investigation report. For submittal to the US Environmental Protection Agency, Region 10. Windward Environmental LLC and Anchor QEA, Seattle, WA.

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