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Guide for Developing Conceptual Models for Ecological Risk Assessments

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Guide for Developing Conceptual Models for Ecological Risk Assessments

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PREFACE

This white paper was prepared to present guidance for preparing conceptual models for ecological risk assessments, which are an important component of the Remedial Investigation process. This work was performed under Work Breakdown Structure 1.4.12.2.3.04.07.02 (Activity Data Sheet 8304). Publication of this document meets an Environmental Restoration Risk Assessment Program milestone for FY 95. Use of this guidance document will standardize the conceptual models used in ecological risk assessment so that they will be of high quality, useful to the assessment process, and sufficiently consistent so that connections between sources of exposure and receptors can be extended across operable units.

CONTENTS

FIGURES

ACRONYMS

CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
DOE-OR	U.S. Department of Energy's Oak Ridge Operations
DQO	data quality objective
EPA	U.S. Environmental Protection Agency
FFA	Federal Facilities Agreement
OU	operable unit
RI/FS	remedial investigation/feasibility study
WAG	waste area grouping

EXECUTIVE SUMMARY

Ecological conceptual models are the result of the problem formulation phase of an ecological risk assessment. They may be thought of as a hypothesis concerning the nature of ecological risks at a contaminated site. They include the hypothesized sources of contaminants, routes of transport of contaminants, contaminated media, routes of exposure, and endpoint receptors. They are presented in the form of a flow chart and a descriptive narrative. Conceptual models should be developed in draft form as input to the data quality objectives (DQOs) process, developed and agreed upon during the DQO process, and modified as necessary during the remedial investigation (RI) process as new information changes the understanding of the site. All screening and baseline ecological risk assessments should use and present the conceptual model.

Conceptual models should be presented for the current case and for any credible future cases that could result in increased risk. The same conceptual model can be used for the baseline ecological risk assessment in the RI and for the reductions in risk associated with the remedial actions assessed in the feasibility study (FS). However, the ecological risks associated with the physical damage caused by remedial actions require separate conceptual models.

Generic conceptual models are presented for four types of operable units (OUs): source OUs, aquatic integrator OUs, groundwater integrator OUs, and terrestrial integrator OUs. The guidance describes the use of these generic models to develop site-specific models including how to represent sources, routes of transport, contaminated media, routes of exposure, endpoint receptors, and indirect effects. It also describes how the ecological conceptual model should be integrated with a conceptual model for the site and made consistent with the conceptual model of human health risks.

1. INTRODUCTION

In the U.S. Environmental Protection Agency's (EPA's) framework for ecological risk assessments, the conceptual model is the output of the problem formulation phase of the assessment (EPA 1992). It presents a working hypothesis of how the site contaminants might affect the ecological components of the site. It includes descriptions of the source, the receiving environment, and the processes by which the receptors come to be exposed directly to the contaminants and secondarily to the effects of the contaminants on other environmental components.

This document presents guidance for the development and presentation of conceptual models for ecological risk assessments. It builds on relevant documents from the EPA (1989, 1992 and 1994) and on previous guidance documents developed for the U.S. Department of Energy's Oak Ridge Operations (DOE-OR) (Suter et al. 1995, Barnthouse and Suter 1995). The *Approach and strategy for performing ecological risk assessments for the U.S. Department of Energy's Oak Ridge Reservation* report (referred to hereafter as *Approach and Strategy*) (Suter et al. 1995) defines different types of Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) operable units (OUs) and presents generic conceptual models for each of them. That document, now in its third version, is the product of an extended data quality objectives (DQO) process by the Federal Facilities Agreement (FFA) parties, of revision in response to regulator comments, and of the accumulated experience in ecological risk assessment at Oak Ridge, Tennessee; Portsmouth, Ohio; and Paducah, Kentucky.

The DQO guidance document for ecological risk assessment presents the results of the generic ecological DQO process that was conducted for the Oak Ridge Reservation (ORR) and explains how they can be used to efficiently conduct DQO processes for individual OUs (Barnthouse and Suter 1995). This conceptual model guidance document should not be used without first reading these more general guidance documents.

2. CONCEPTUAL MODEL DEVELOPMENT AND THE RI/FS PROCESS

Conceptual models are developed and used iteratively in the remedial investigation/feasibility study (RI/FS) process. First, following the initial site survey, draft conceptual models should be developed as input to the DQO process. These models should be inclusive in that they should include all sources, receptor classes, and routes of exposure that are of plausible concern. These preliminary conceptual models also serve as the conceptual model for the screening assessment that should be performed to support the DQO process.

During the DQO process, the FFA parties, with input from their technical staffs, refine the conceptual model thereby making it more focused. This refinement is created by eliminating (1) receptors that are not deemed to be suitable assessment endpoints, (2) routes of exposure that are not credible or important, (3) routes of exposure that do not lead to endpoint receptors, and (4) potential sources that are not deemed credible or important. In addition, the DQO process makes the conceptual model more specific by identifying particular endpoint species, defining the spatial and temporal scale of the assessment, and other judgments (Barnthouse and Suter 1995). The results of the DQO process are presented in the conceptual models published in the RI work plan. If a new screening assessment is performed for the RI work plan or for an interim report of a phased RI, it should be based on this conceptual model. The conceptual models reappear in the RI/FS, and in most cases, they will be the same as in the RI work plan. However, the results of ongoing communications among the FFA parties and the results of the RIs may result in modification of the conceptual model.

The bases for developing the conceptual models depend on the stage of the assessment and the amount of prior assessment that has been done at that stage.

- The first conceptual model is based on qualitative evaluation of existing information and expert judgment. It should be conservative in the sense that sources, pathways, and receptors should be deleted only if they are clearly not applicable to the site.

- Early in the RI/FS process, preferably before or during the DQO process, a screening assessment should be performed using existing data. The results of the screening assessment can be used to eliminate receptors or even an entire medium for which no contaminants present a potentially significant risk.

- The participants in the DQO process can apply their professional judgment and managerial authority to modify the draft conceptual model presented by DOE's assessment scientists. For example, the FFA parties may decide that the results of the screening assessment are not based on data of sufficient quality and quantity to justify deleting media or receptors. Some receptors may be eliminated because they are not judged to be sufficiently important or sensitive or not sufficiently related to the remedial decision.

- If the RI is conducted in phases, the screening assessment performed at the end of the preliminary or intermediate stages should be used to modify the conceptual model. Typically, this involves reducing the model by eliminating components that were shown by the assessment to be unimportant or even not present.

3. CONCEPTUAL MODELS OF CURRENT AND FUTURE RISKS

The *Approach and Strategy* report specifies that a separate ecological risk assessment should be performed if ecological risks could increase in the future. This could occur if contaminant transport has not brought wastes to the surface or if succession or other changed ecological conditions could bring more susceptible species onto the site. In simple cases, this will not require a different conceptual model. For example, if range expansion is hypothesized to bring a more susceptible species to the site in place of the current representative species for a trophic group (e.g., river otters in place of mink) or a more protected species (e.g., bald eagles in place of osprey), the model need not change except to add the future endpoint species to the list of current endpoint species. However, other cases such as development of a forest ecosystem on a currently bare or closely mowed site will require a separate model for future conditions.

4. COMPONENTS OF A CONCEPTUAL MODEL

A conceptual model should be presented in both graphic and narrative form. The graphic form may be pictorial (i.e., with drawings of plants and animals), but pictorial representations are typically costly to produce and often ambiguous. Therefore, flow charts are generally recommended. The charts should include (1) sources, (2) routes of transport from sources to contaminated media, (3) routes of exposure of receptors to media, (4) endpoint receptors, and (5) output to other OUs. The narrative should describe the contents of the diagram in sufficient detail to ensure that it can be understood by an educated layperson. However, the narrative conceptual model should not duplicate information that is present in other sections of the document in which it occurs, such as the site description.

In addition, the narrative conceptual model should explain the underlying logic of the model including the following.

- It should describe the spatial bounds of the assessment and any subdivision of the site into reaches or other subunits.

- If receptors or routes of exposure are omitted due to lack of information or knowledge, that omission should be acknowledged and included in the analysis of uncertainty.

- If receptors or routes of exposure are omitted because of the judgment of the FFA parties to limit the scope of the assessment to critical pathways and receptors, that judgment should be acknowledged and explained. However, it should not be treated as an uncertainty because it is a risk management decision.

- If receptors are representative of a class of receptors, then that relationship should be explained.

The following graphical conventions are used in the flow charts for the generic ecological conceptual models. The distinctions among compartments can enhance the readability of the model and the use of these conventions in conceptual models for individual OUs will result in consistency and comparability among assessments. Rectangles represent components of the OU, rounded rectangles represent inputs from other OUs, and circles represent components of other OUs that receive input from the depicted OU. Rectangles with heavy borders represent receptors that are potential assessment endpoints.

4.1 OU TYPES AND DEFAULT CONCEPTUAL MODELS

The *Approach and Strategy* report divides OUs into four classes: source OUs, aquatic integrator OUs, groundwater OUs, and the terrestrial integrator OU which corresponds to the entire reservation. For each of these classes of OUs, this guidance report provides generic conceptual models including a flow diagram of the routes of transport and exposure and generic assessment and measurement endpoints (Figs. 1, 2, 3, and 4). In addition, a generic conceptual model of an aquatic ecosystem is presented which is an elaboration of the aquatic biota compartment in the conceptual models for source and aquatic integrator OUs (Fig. 5). Chapter 3 of the *Approach and Strategy* report describes each of these generic models in terms of the compartments that are relevant, the composition of each compartment, inputs to the compartment, and outputs from the compartment. All developers of conceptual models should determine which type of OU they are assessing and begin the development process with the generic model. The following discussions explain how to modify those models to make them OU-specific.

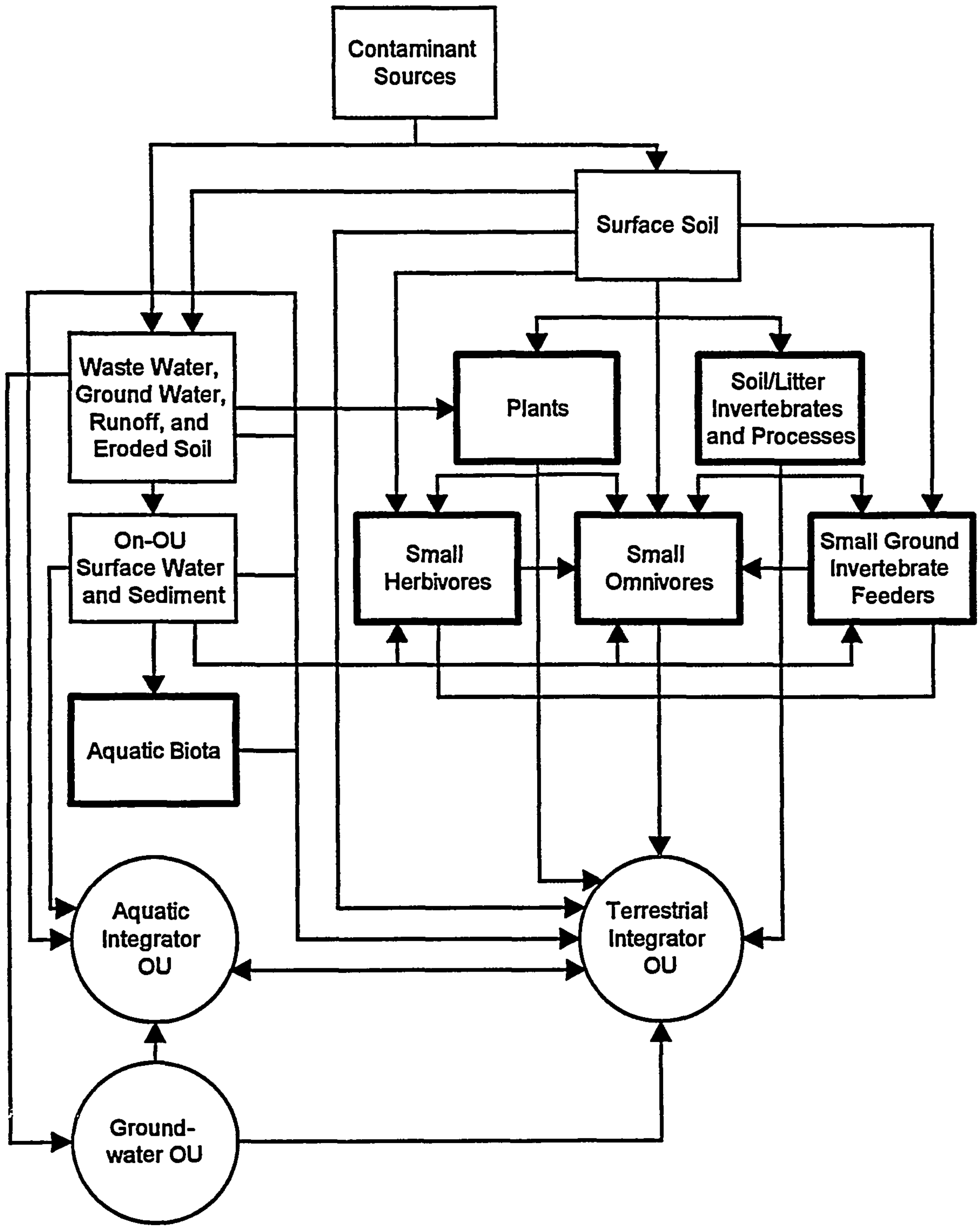

Fig. 1. Generic conceptual model for a source OU.

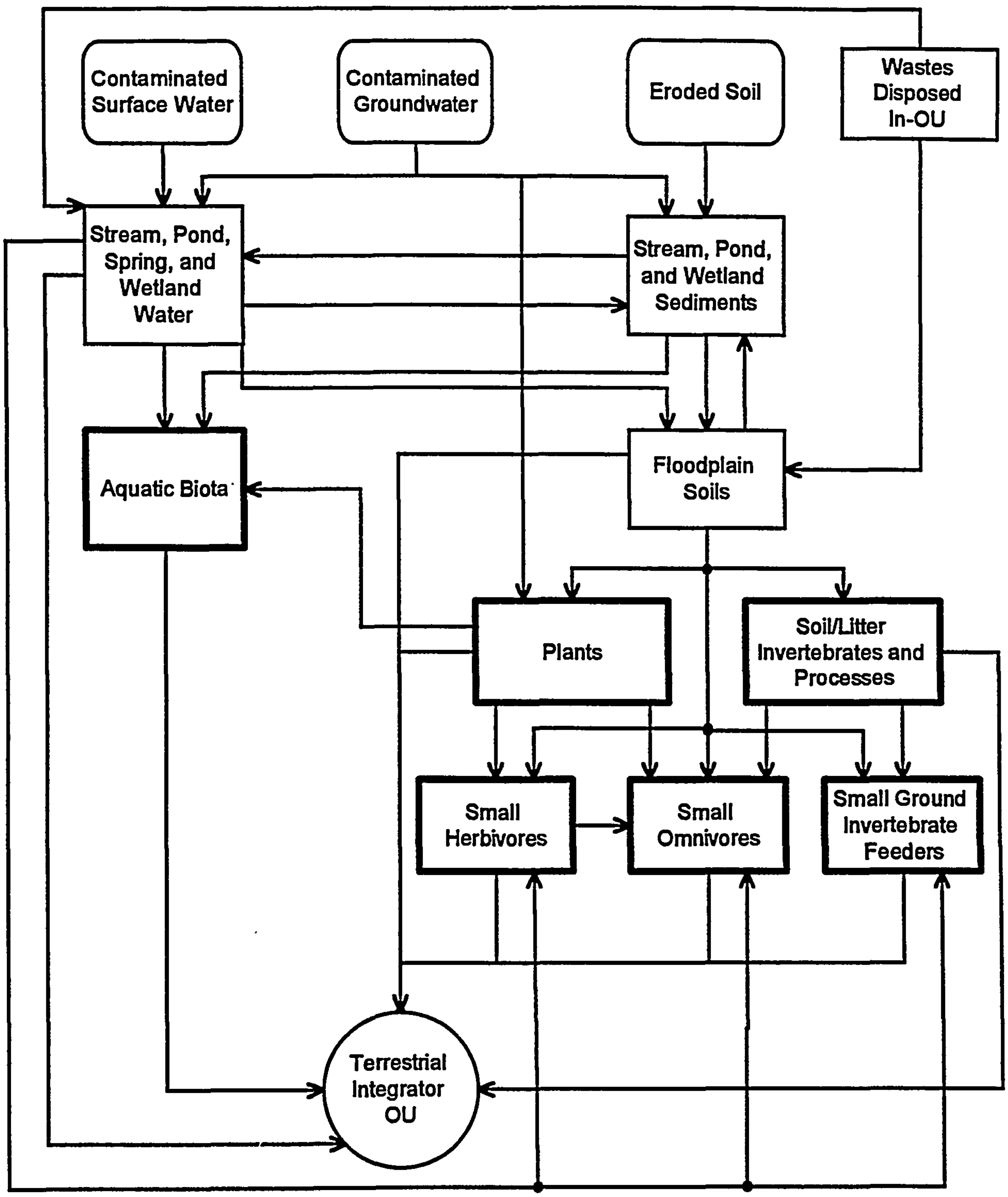

Fig. 2. Generic conceptual model for an aquatic integrator OU.

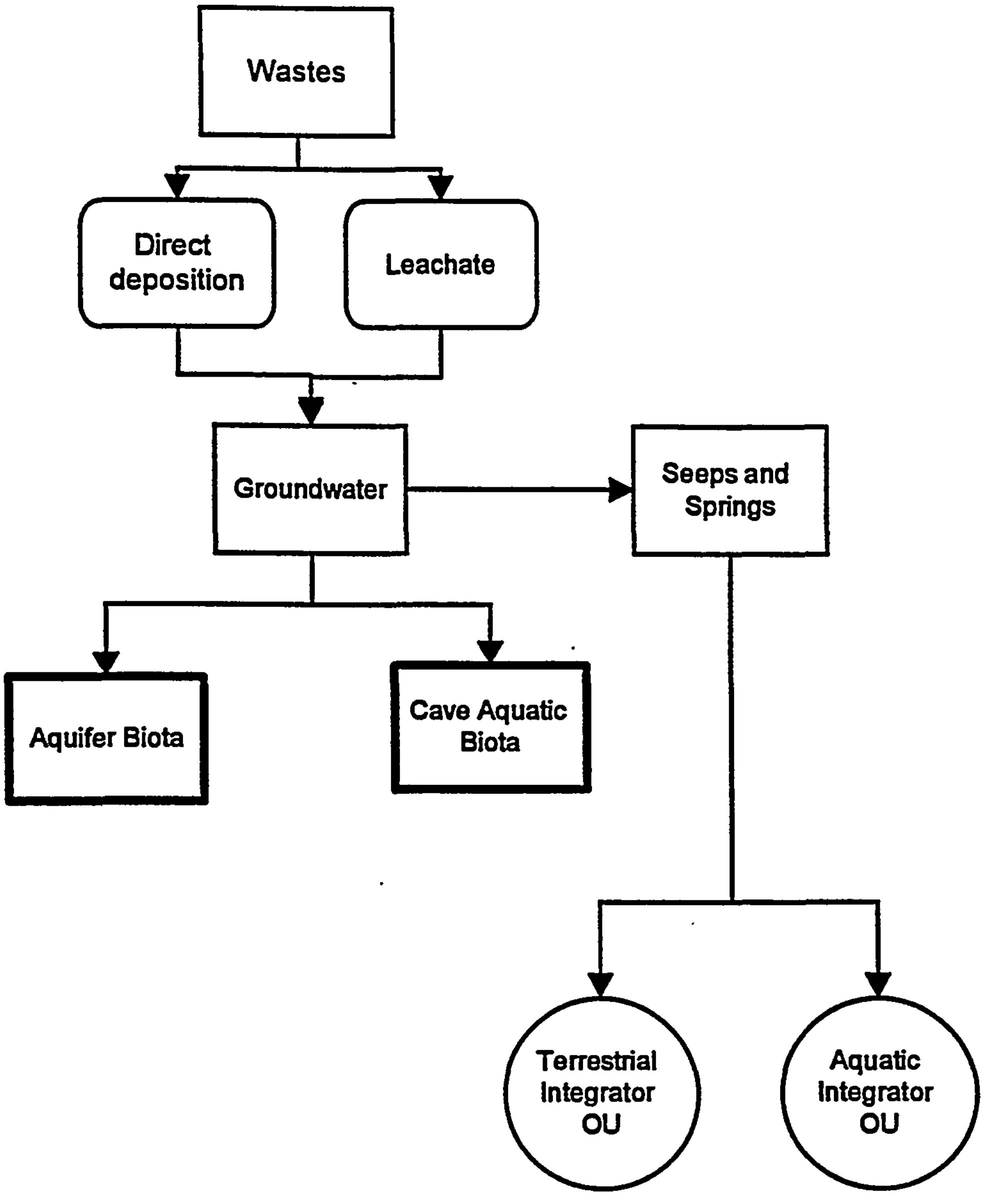

Fig. 3. Generic conceptual model for a groundwater integrator OU.

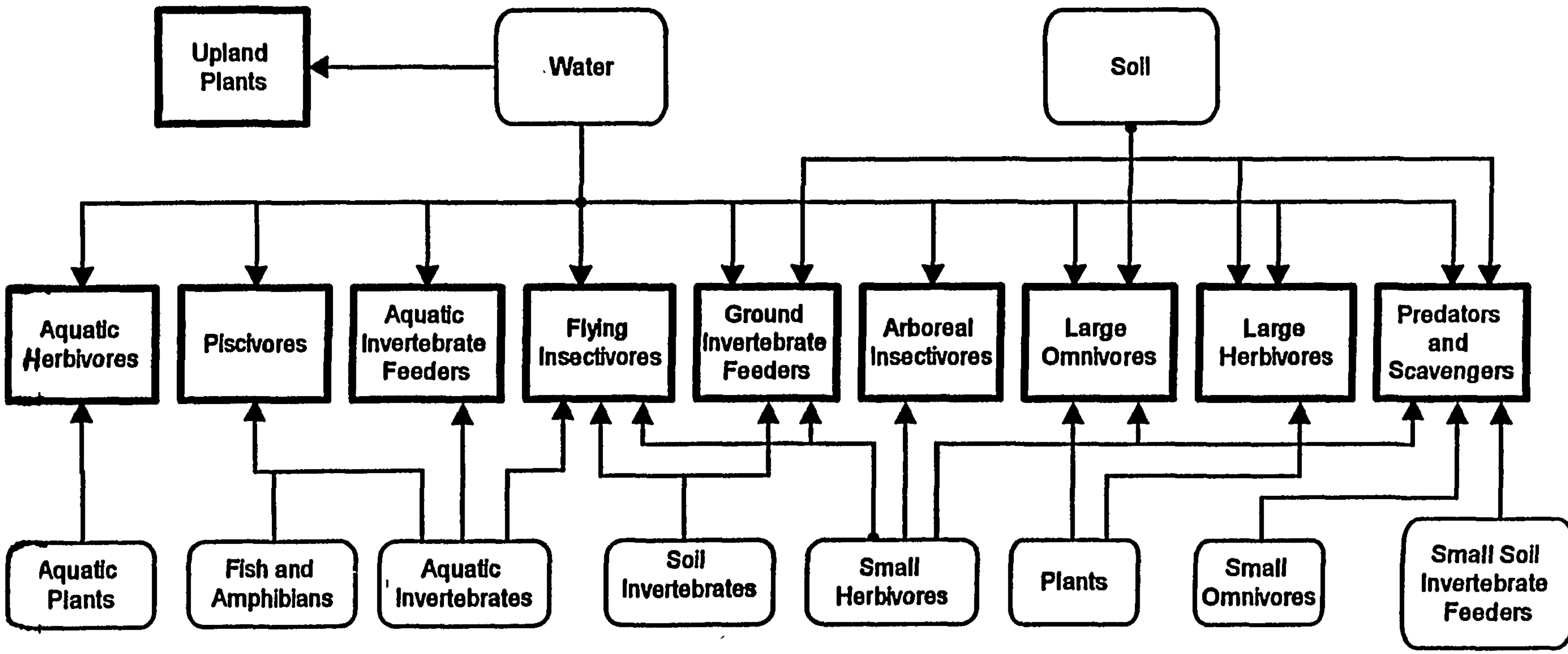

Fig. 4. Generic conceptual model for the terrestrial integrator OU.

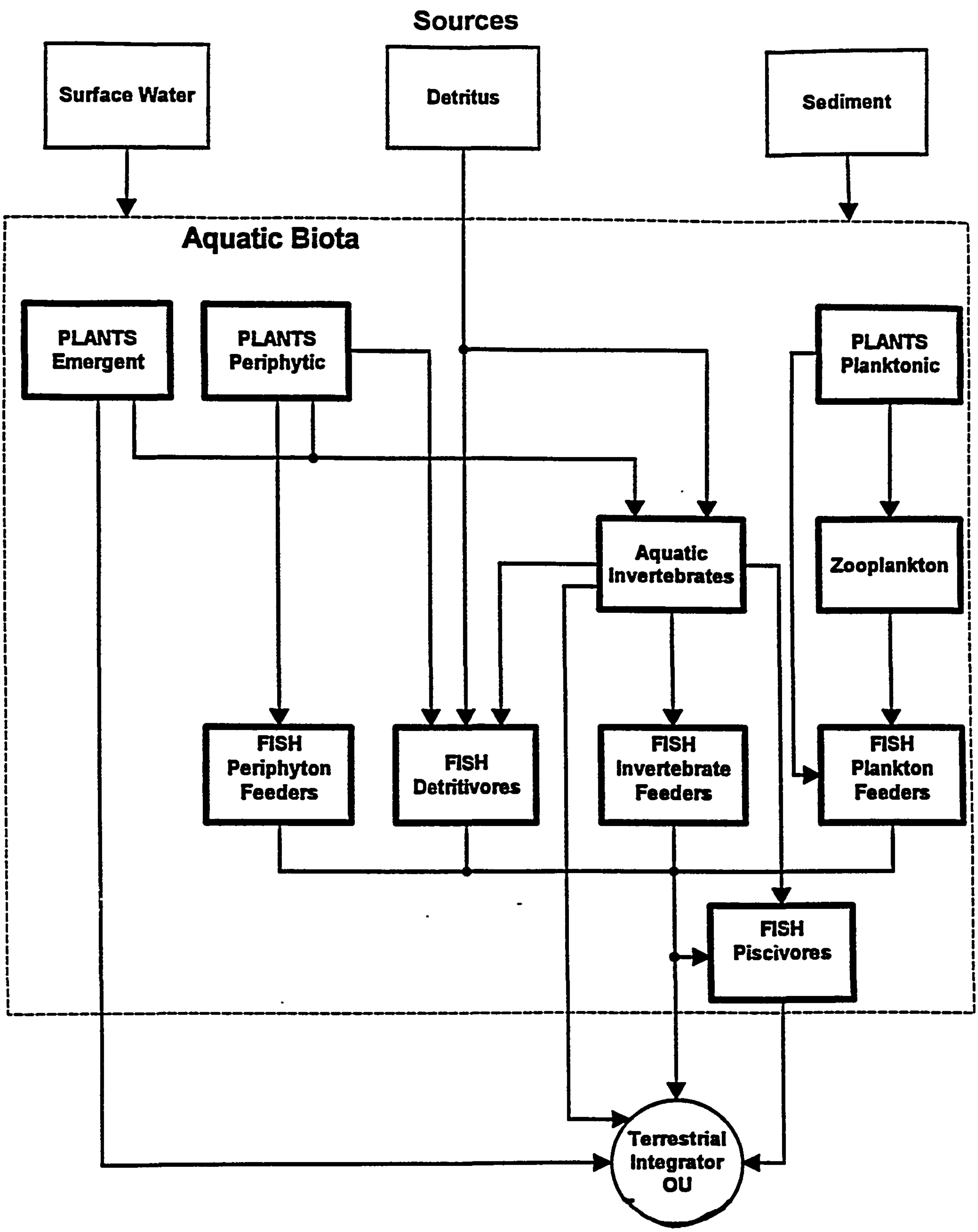

Fig. 5. Generic conceptual model for aquatic biota.

4.2 SOURCES

All conceptual models for contaminated sites begin with sources. On source OUs, the wastes deposited in pits, trenches, ponds, tanks, etc., are treated as the ultimate sources. Each distinct type of ultimate source should be identified in a separate box. Types of sources should be distinguished when they contain wastes that are distinctly different in form or composition or when the wastes are disposed of in different manners (e.g., ponds versus tanks) or in situations that would result in different modes of transport (e.g., floodplains versus uplands). Because of the disagreements that have occurred among the FFA parties about whether to treat waste sumps and ponds as sources or as aquatic ecosystems that are incidentally contaminated, it is important to clearly explain the nature of all such bodies including the purpose for which they were created and their current ecological condition.

Integrator OUs usually have no ultimate sources, but they have as proximate sources the contaminated inorganic media: surface water, shallow groundwater, sediments, and soils. These may be in the form of fluxes of surface water, groundwater, eroded soil, or suspended sediments and should be identified in terms of their nature and source. For example, sources to Waste Area Grouping (WAG) 2, the OU that includes McCoy Branch and lower White Oak Creek on the Oak Ridge Reservation, include contaminated surface water from WAG 1 (upper White Oak Creek) and shallow groundwater from seeps at the toe of WAG 5. In addition, some proximate sources are not associated with any ultimate source. For example, soils may be contaminated by past spills or other actions to which no ultimate source or upstream source is contributing.

4.3 ROUTES OF TRANSPORT

The conceptual model should identify the routes by which contaminants in the sources are transferred to ambient media to which organisms may be exposed. The specific routes of exposure should be described. For example, the transport from sources to surface water should be identified as occurring in leachate emerging at seeps, in leachate mixed with groundwater entering streams through gaining reaches, by erosion of contaminated soil, etc.

The routes of transport for ecological conceptual models do not normally include deep groundwater transport because it does not contribute to surface water contamination and because wildlife do not drink well water. However, the FFA parties included a generic conceptual model for groundwater (Fig. 3) largely because of concern for the biota of caves that are known to occur on the reservation. That conceptual model has not been invoked at any OU to date, but it is important to avoid rejecting that mode of transport without considering the possibility that cave biota may be exposed. This aspect of the ORR is currently uncharacterized.

Except for movement into downstream OUs, these conceptual models do not include fate processes that remove contaminants from the system (e.g., degradation and sequestration) because these conceptual models are intended to illustrate how ecological receptors come to be exposed rather than illustrating the fate of the contaminants. These fate processes may be included in the overall conceptual model of the OU, which is included in Sect. 2 of the RI.

4.4 EXPOSURE MEDIA

The conceptual model should identify the media that are known to be significantly contaminated, are hypothesized to currently be significantly contaminated, or are predicted to be significantly contaminated in the future. If possible, significance of contamination should be based on the results of an assessment that compares screening of measured contaminant concentrations against ecotoxicological benchmarks and background concentrations (Suter 1995). Alternatively, modeled concentrations may be screened in the same way. In the absence of measured or modeled concentrations, expert judgment should be conservatively applied. A medium should be included in the model if any chemical in the medium is retained by the screening process or any chemical is judged to potentially be present at significant concentrations.

In some cases, the contaminated medium is also the waste (i.e., the source of the contaminant chemicals). This is true of the coal ash in the filled coal ash pond on Chestnut Ridge OU 2. It would also be the case for any waste sumps that are treated as receptor ecosystems rather than as sources. In such cases, the source box is simply combined with the soil, water, or sediment box.

4.5 ROUTES OF EXPOSURE

The conceptual model should identify the routes of exposure that are assumed to result in uptake of chemicals from contaminated organic and inorganic media. The number of routes of exposure is limited to those that are deemed to be important for the endpoint receptors. The following points should be considered.

- Fish, aquatic invertebrates, and aquatic plants are assumed to be exposed to contaminants in water. Conventionally, the EPA and most risk assessors have assumed that dietary exposures are negligible and that is likely to be true for most chemicals. For example, the National Ambient Water Quality Criteria for Protection of Aquatic Life are based on toxicity tests in which organisms are unfed or fed clean food. This is reasonable given the relatively high rate of exposure of organisms to chemicals in the water that pass their respiratory surfaces and the fact that most chemicals are not highly bioaccumulative and do not biomagnify.

- Dietary exposures should not be routinely included for fish or aquatic invertebrates. Dietary exposure is important for a few long-lived and biophilic chemicals such as polychlorinated biphenyls (PCBs) and dioxins and may be important for a wider variety of chemicals than is currently recognized. However, appropriate dietary exposure models are not available for chemicals in streams such as occur on the ORR, and toxicity information based on dietary exposure is uncommon and poorly standardized. Fish body burdens integrate dietary and direct aqueous exposures, but toxicity information is not standardized or available for exposures to most chemicals in terms of body burdens. Therefore, dietary exposures should be included only if the assessors have reason to believe that they are a significant route and have a method for assessing risks due to that route.

- Benthic invertebrates are exposed to sediment pore water and whole sediment. Although the graphic version of the conceptual model need not depict this distinction, it is important to include in the narrative. Although EPA's sediment quality criteria are based on exposure to the aqueous phase of sediments (i.e., pore water), the evidence is strong that some benthic invertebrates are significantly exposed to a variety of chemicals by ingestion of sediment particles. Pore water concentrations cannot be reliably estimated from whole sediment concentrations for chemicals other than neutral organic compounds, but pore water may be extracted and analyzed. Therefore, it is important to characterize risks due to both modes of exposure.

- Wildlife exposure routes usually include ingestion of food, drinking water, and incidental soil ingestion. Soil ingestion may be excluded for species that have little exposure to soil (e.g., ospreys).

- Dermal exposure of wildlife should not normally be included. Unlike humans, birds and mammalian wildlife are covered with feathers and fur. These coverings exclude most dermal exposures. However, they create another route of exposure: grooming and preening, which contribute to incidental soil ingestion. Amphibians are likely to experience significant dermal uptake, but neither exposure models nor toxicity data are available to address this route and receptor for terrestrial exposures. Aqueous dermal exposures for amphibians are equivalent to respiratory exposure of fish in that they are assumed to be due to direct uptake of dissolved chemicals through the respiratory epithelium, which is the skin.

- Respiratory exposure of wildlife is not normally included. Few if any OUs on the ORR have significant concentrations of contaminant chemicals in the air. This judgment has been confirmed by the FFA parties who have not called for measurements of atmospheric contamination in the RIs conducted to date.

- Plants, soil invertebrates, and soil microbes are assumed to be directly exposed to whole soil.

- In cases where shallow groundwater is contaminated, plants are exposed to that water.

4.6 RECEPTORS

The receptors presented in the conceptual model should be those that have been proposed to be or designated as assessment endpoint receptors (organisms, populations, communities, or ecosystems). The *Approach and Strategy* report presents generic assessment endpoints for each type of OU and provides guidance for selecting endpoint receptors for particular sites. This section explains how they should be presented in the conceptual model.

Ecosystems. Ecosystems are assessment endpoints if the properties to be protected are ecosystem properties. This is the case for wetlands which are protected for their habitat value to wetland-dependent species and their roles in nutrient retention and cycling and hydrologic regulation. If significant areas of wetlands are present (i.e., areas sufficient to significantly contribute habitat, nutrient cycling, and hydrologic regulation functions to the watershed in which they occur), they should be included in the graphical model and their size, type, and assumed functional properties defined in the narrative. A component of an ecosystem that is valued for its functional properties rather than its community or population properties may also be considered an ecosystem-level endpoint. Soils, which degrade natural and anthropogenic organic materials, recycle nutrients, and support plant growth, are identified in the *Approach and Strategy* report as valued for their functions.

Community. Fishes, benthic macroinvertebrates, soil invertebrates, and upland plants are community level assessment endpoints. That is, the species richness and abundance of the communities are the endpoint properties rather than properties of the component populations. Cases where components of the community such as benthic-feeding fish or trees are believed to differ in their susceptibility should be distinguished in the conceptual model. The model should describe each community or subcommunity both in biological terms (e.g., all benthic macroinvertebrates) and in operational terms (e.g., all invertebrates collected by a Surber sampler and retained by a 1-mm mesh screen).

Population. Most wildlife are population level assessment endpoints. The endpoint properties are abundance and production of individual populations. The populations used are chosen to represent a particular trophic group and taxonomic class (i.e., birds and mammals). The conceptual model should identify these receptors both in terms of the species and location of the population (e.g., short-tailed shrews in WAG 2) and the group that they represent (e.g., ground invertebrate feeding mammals). Some trophic/taxonomic groups will have more than one representative species (e.g., kingfishers and osprey for piscivorous birds). Others such as reptiles may have none because of the paucity of toxicological information concerning those species. The narrative for these receptors should indicate why the representative species was chosen and exactly what other species it represents.

4.7 INDIRECT EXPOSURE AND EFFECTS

The generic conceptual models include indirect routes of exposure (i.e., food web transfers) but not indirect effects. An endpoint may be affected indirectly through toxic effects on lower trophic groups, by toxic effects on groups that provide physical habitat, or by other mechanisms. The importance of explicitly including indirect effects depends on the nature of the ecological relationship that causes the indirect effect and the relative sensitivity of the groups involved. For example, it is assumed for most chemicals that aquatic invertebrates and fish are more sensitive than the algal community on which they depend. Therefore, while that trophic relationship should be acknowledged in the conceptual model, it should be made clear that the indirect effects on fish and invertebrates of direct toxicity to algae are not included (if that is the case). The indirect effect that is most likely to be of concern in aquatic ecosystems is the reduction in food for fish due to toxic effects on invertebrates. Planktonic crustaceans and benthic insects are often more sensitive than fishes, and benthic invertebrates are more exposed to contaminated sediments than are fish.

When indirect effects are included in the conceptual model, it is important to distinguish them from transfer of contaminants. The generic conceptual models are based on chemical transport and transfer. If indirect effects are hypothesized instead of or in addition to those relationships, they should be distinguished by a different sort of arrow (e.g., a dashed line) in the graphical model, and they should be explained and justified in the narrative.

4.8 OUTPUT TO OTHER OUs

The *Approach and Strategy* report indicates that all OUs are responsible for characterizing their contributions of contaminants to other OUs. This responsibility is obvious with respect to hydrologically transported contaminants. However, it is also true of the contribution of source and aquatic integrator OUs to the contaminant burden of wide-ranging wildlife species that are associated with the reservation-wide terrestrial integrator OU. Therefore, the conceptual model should show connections to downstream aquatic integrator OUs and groundwater OUs and connections to the terrestrial integrator OU. The routes of transport in the former case would be identified as dissolved chemicals in surface water or groundwater flow and transport of chemicals sorbed to suspended particles. In the latter case, the routes of exposure would be consumption of contaminated food, soil, or water on the subject OU by wide-ranging species.

5. RELATIONSHIP TO OTHER CONCEPTUAL MODELS

The conceptual model for ecological risks must be consistent with the conceptual model for human health risks. That is, it should identify the same contaminant sources, routes of transport of contaminants, and contaminated media. However, the routes of exposure and receptors will be different.

Some RIs will have an overall conceptual model for the OU. Such models depict the sources and routes of transport of contaminants. They may emphasize particular physical aspects of the site such as surface flow patterns or the relationship between groundwater transport and geological stratigraphy. They may be in the form of maps showing, for example, the location of streams and seeps relative to wastes and drainage patterns. The ecological conceptual models should be consistent with these more general conceptual models and should refer back to them to provide the reader of the ecological risk assessment a context for the ecological conceptual model.

Ideally, the ecological conceptual models should be an extension and elaboration of a generic conceptual model for the site. The generic conceptual model would identify the sources, the routes of transport of contaminants from the sources, the contaminated media, and the transport of contaminants out of the OU. The ecological conceptual model as well as the human health conceptual model could then be limited to the components that are particular to ecological and health risks: contaminated media, routes of exposure, and receptors.

6. CONCEPTUAL MODELS FOR THE FEASIBILITY STUDY

Ecological assessments for the FS have not always followed the conventions of ecological risk assessment although the choice of remedial options depends on a balancing of risks and benefits. The decision to leave in place mercury in the East Fork Poplar Creek floodplain that presents a risk to shrews and wrens was based on such a balancing of the benefits of remediation against the risks of remediation to the floodplain ecosystem. One component of the EPA's ecorisk framework that could potentially increase the clarity and rigor of the assessments in FSs is the presentation of conceptual models. The FS must consider both the benefits of reducing exposure and the risks of habitat loss associated with each remedial option. The conceptual models in the RI could serve for the former purpose, but separate conceptual models would be needed for the risks associated with the remedial options. Often it is not clear which of the risks from remediation are included in the FS.

Very generic conceptual models for physical disturbances were developed for terrestrial, wetland, and aquatic ecosystems during the DQO process for ecological risks on the ORR (Suter et al. 1995, Figs. 8–10). Because of the great diversity of physical disturbances that could occur during remediation, these generic models will require even more adaptation to specific cases than the generic models for contaminant risks. However, they do incorporate some hypotheses about often neglected risks from remediation that were of concern to the FFA parties during the DQO process for ecological risk assessment on the ORR.

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