APPENDIX E

COLUMBIA RIVER CONCEPTUAL MODEL

APPENDIX E

Columbia River Conceptual Model Abstract

The objective of this appendix is to describe the Columbia River conceptual model developed for use in the System Assessment Capability (SAC), Rev. 0. The Columbia River environment to be considered in the river technical element includes the riparian zone and associated biota along the river, the groundwater/river interface, river bottom and sediments, the river water column, aquatic biota, and users of the river resources.

Output from the river element will include estimates of the spatial and temporal distribution of contaminants in the river water column, in the sediments on and below the river bottom, and concentration in and rate of bioaccumulation of contaminants in both terrestrial and aquatic biota. This information will be used to allow feasibility testing of SAC (Rev. 0) and to complete an initial assessment of risk and impact from Hanford Site waste. The data from this element feed into the risk and impacts technical element (Figure E-i).

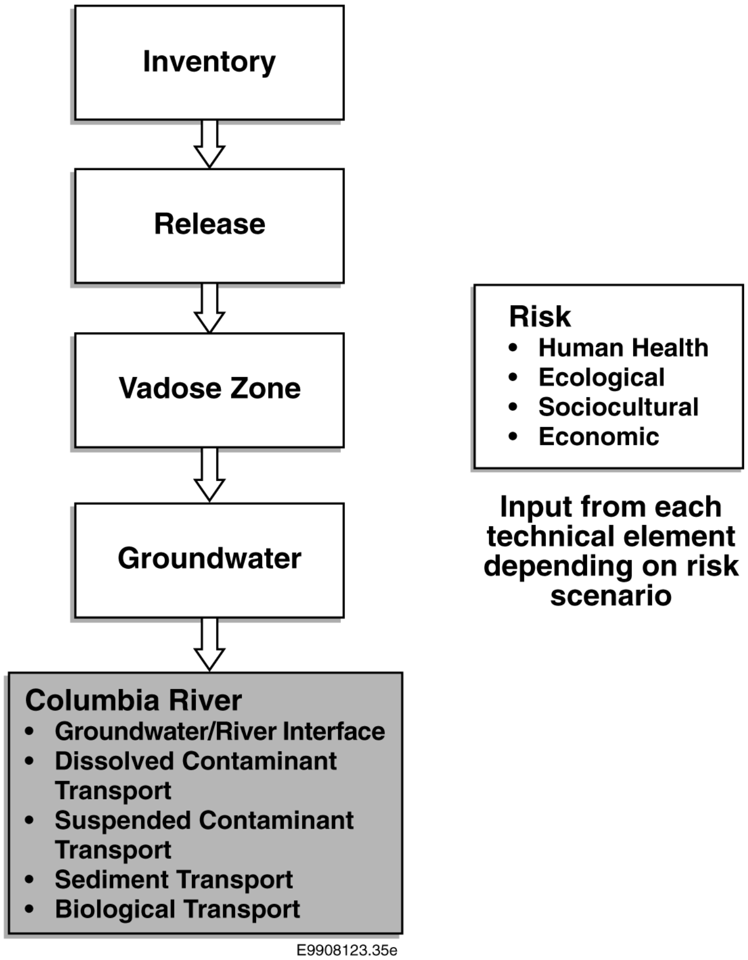
In light of the complexity of modeling the movement of contaminants into and through the river ecosystem, the river conceptual model has been broken into three components for the SAC (Rev 0). These include 1) the zone of groundwater/river interaction; 2) hydrodynamic, sediment, and contaminant transport in the river; and 3) biological transport. Biological transport is a unique component of the contaminant transport model.

The SAC (Rev. 0) river element will take the results of the analyses from the groundwater flow and transport technical element in the form of contaminant flux along the groundwater/river model boundary. In addition to the influx from the groundwater element, the river model requires data that define the physical characteristics of the groundwater/river interface, river transport parameters, chemical characteristics of the sediments and contaminants, operating transformation processes, and bioaccumulation processes.

Critical data to the river element model also include estimates of the river flow characteristics, including volume, mixing, turbulence, bed load, water level fluctuations, and background values for sediment and water chemistry. Additional information required includes estimates of sorption and desorption of contaminants to river sediments, oxidation-reduction reactions, biodegradation, photolysis, hydrolysis, bioconcentration, and biomagnification rates. These data will be taken primarily from previous studies and published references for the SAC (Rev. 0) demonstration.

The Columbia River element results will be used in the risk and impacts model for locations along the course of and in the river downstream of the site. Estimates of contaminant concentrations for four mobility classes of radionuclides and two chemicals will be provided as input data to the risk and impacts model element.

Figure E-i. System Assessment Capability System Conceptual Model.



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APPENDIX E

COLUMBIA RIVER CONCEPTUAL MODEL

E.1 BACKGROUND

The objective of this appendix is to describe the Columbia River conceptual model developed for use in the System Assessment Capability (SAC), Rev. 0. The Columbia River represents the final link in the environmental pathway (liquid) through which contaminants reach various receptors. The study area includes the Columbia River environment from upstream of the Hanford Site (establishing a background, or reference, segment), to a point downstream of Hanford, as determined appropriate by the assessment process for each iteration of the SAC. The Columbia River environment to be considered in the river technical element includes the riparian zone, associated biota along the river, the groundwater/river interface (bank storage, hyporheic zone, etc.), the river water column, the river bottom and associated sediments, aquatic biota, and users of the river environment. The technical element must provide an accurate understanding of current conditions over time, and the ability to assess potential future conditions (both near- and long-term). In addition, the evaluation must allow for the differentiation between contaminant contributions from the Hanford Site and other sources (natural and/or anthropogenic).

A credible conceptual model of the Columbia River ecosystem is critical in the success of any cumulative assessment of potential impacts of Hanford operations on the environment. The Hanford Reach of the Columbia River is a complex ecosystem that contains many receptors: human, ecological, socio-economic, and cultural. The conceptual model for the river technical element must account for the large number of different biological, chemical, and physical processes that control contaminant mobilization, immobilization, biodegradation, biotransformation, and transport in the river environment. The groundwater/river interface, which is included in the river technical element, encompasses not only the challenges of the vadose zone and groundwater technical elements, but a combination of these together with the complex river dynamics. All of these elements must be considered at an adequate level in the conceptual models in the current iteration of the SAC.

Conceptually, the pathway of contaminants from the Hanford Site to potential exposure points and receptors of interest in the river environment includes the entry of contaminants into the river, the transport and fate of contaminants within the river, and the export of contaminants out of the river. Figure E-1 illustrates a very simplified conceptual model of the movement of contaminants into, through, and out of the river environment.

Figure E-1. Upper Level Conceptual Model.

- Hanford and Non-Hanford Contributions
  - Atmospheric
  - Biotic
  - Surface Water
  - Vadose Zone
  - Groundwater
  - Direct Discharges
  - Existing Inventory

- Hydrodynamic
- Sediment
- Biological
- Contaminant

- Water
- Sediment
- Biotic
- Atmospheric

In light of the complexity involved in modeling the movement of contaminants into and through the river ecosystem, the river conceptual model has been broken into three components for the first iteration of the SAC (Rev. 0). These include 1) the zone of groundwater/river interaction; 2) hydrodynamic, sediment, and contaminant transport in the river; and 3) biological transport. Each of these components is discussed in detail in the subsequent sections.

E.2 ZONE OF GROUNDWATER/RIVER INTERACTION

The zone of interaction between Hanford Site groundwater and Columbia River water is an important interface along the environmental pathway between contaminant sources and the Columbia River. Groundwater characteristics may be modified by physical, chemical, and/or biological processes that occur in the zone. A significant amount of natural attenuation of contamination, caused by mixing between groundwater and river water, may occur in the zone. Conversely, some accumulation of contamination may occur where conditions are suitable to immobilize a contaminant. For example, a radionuclide may be concentrated within vegetation or aquatic organisms residing in the zone. Also, opportunities exist within the zone of interaction for a contaminant to enter biological transport pathways.

E.2.1 Past Projects/Existing Conceptual Models

Groundwater/river interaction has been a widely studied topic in the field of hydrology. An increased focus on groundwater/river interaction at the Hanford Site has occurred in recent years, in response to a need for information to support groundwater remediation decisions. Whether or not to conduct active remediation of a groundwater plume near the river is partially based on the contaminants, and their concentrations at points of exposure in the river, and the consequent risk associated with exposure.

Summaries of previous work are grouped under several topical areas: basic features and processes; groundwater remediation; salmon spawning habitat; and miscellaneous investigations.

E.2.1.1 Basic Features and Processes. The following subsections describe previous work involving the various features and processes associated with the zone of interaction. The Columbia River is a gaining stream as it passes through the Hanford Site, which means that its flow is increased (on the average) by the addition of groundwater and minor amounts of surface runoff. However, because the river rises and falls through a daily range that approaches 3 meters, river water moves into the aquifer as well as out of the riverbanks, when viewed at a local scale. The long-term net effect is one of discharge from the aquifer to the river.

Recently, a two-dimensional (2-D) numerical simulation of water movement in the zone of interaction at the 100 N Area was completed (Connelly et al. 1998). This model provides an excellent visualization of the path within the zone of interaction, followed by a hypothetical parcel of water in response to the rise and fall of the river through its daily cycle. The simulation may be viewed on the internet at the following web site: http://pnl145.pnl.gov/100k.

E.2.1.1.1 Bank Storage. Bank storage is defined as river water that infiltrates a riverbank during high stage, and approaching groundwater that is held up by the high river stage (Newcomb and Brown 1961, USGS 1987). A description and evaluation of the magnitude of bank storage for the Hanford Reach between China Bar (near Vernita Bridge) and Richland was completed by Newcomb and Brown (1961). Although their estimates are for conditions that existed prior to river discharge controls from Priest Rapids Dam, their work provides an excellent description of the main processes involved. During the pre-dam seasonal flood, river elevations in the Hanford Reach would rise and fall through a range of 6 to 10 meters (20 to 30 feet). Newcomb and Brown (1961) estimated that, during the annual flood, the pressure wave created by the high river levels is observable as much as 3,000 meters (10,000 feet) inland. The distance to which river water actually moved inland was much less, and on the order of 25 meters (75 feet). Under current dam-controlled river elevation conditions, the inland influence is less for both the pressure wave and infiltration of river water, because of the reduced annual range in river elevation, which is generally less than 4 meters.

E.2.1.1.2 Hydraulic Properties Near the River. The influence that the fluctuating Columbia River stage had on Hanford Site groundwater was addressed early on by Raymond and Brown (1963) to help solve practical problems related to the disposal of reactor coolant. They provided estimates for bank storage along the Hanford Site, and also addressed the hydraulics of flow adjacent to the fluctuating river.

The transmissivity of the aquifer within and near the zone of interaction may be estimated following a method developed by Ferris (1963) that uses water level data. Application of the method to Hanford Site water level data has been done several times (McMahon and Peterson 1992, Gilmore et al. 1992). These and other studies have improved the understanding of the relationship between aquifer hydraulic properties and the propagation of pressure waves caused by cyclic river stage fluctuations (Newcomer 1988, Gilmore et al. 1993). That hydraulic properties appear to be highly variable in the zone of interaction suggests that this heterogeneity will play an important role in understanding the uncertainty associated with modeling the movement of contaminants through the zone.

E.2.1.1.3 Riverbank Seepage and Springs. Another aspect of bank storage involves the return of river water that has infiltrated the bank to the river during periods of low-river stage. This manifests itself as riverbank seepage at many locations along the Hanford Reach. The seepage creates sites for potential surface exposure of contaminated groundwater. Several published reports of sampling and analysis of riverbank seepage are available (McCormack and Carlile 1984, Buske and Josephson 1988, Dirkes 1990, DOE-RL 1992). A study that related all available riverbank seepage data to contamination observed in nearby groundwater wells and to nearshore river water was conducted in 1992 (Peterson and Johnson 1992). Although a great deal of variability was observed, their general conclusion was that infiltrating river water frequently diluted the groundwater approaching the river prior to discharge as riverbank seepage. Monitoring riverbank seepage is included in the Site-wide Environmental Surveillance Program. The results are reported annually (Dirkes and Hanf 1998), and the annual report may be viewed at the internet web site address: http://hanford.pnl.gov/envrept.

E.2.1.2 Groundwater Remedial Actions Near the River. For groundwater contamination near the Columbia River, detailed information on some aspects of the zone of interaction is required. This information helps to (a) support the decision to proceed with remediation activities; (b) select the appropriate technology; and (c) set operating parameters. For a description of groundwater plumes currently located near the river, see the Hanford Groundwater Monitoring Project's annual report (PNNL 1999) or the Internet website at: http://hanford.pnl.gov/groundwater. Two groundwater remediation projects are currently operating near or within the zone of interaction in the 100 Areas.

E.2.1.2.1 Interim Remedial Action for Chromium. The U.S. Environmental Project Agency (EPA) and U.S. Department of Energy (DOE) agreed to conduct active remediation of chromium-contaminated groundwater at the 100 K, 100-D/DR, and 100 H Areas on the basis of concentrations observed in wells located near the Columbia River (EPA 1996). The observed concentrations were only slightly above the maximum contaminant level for drinking water supplies (100 ug/L), but significantly above standards set for the protection of freshwater aquatic organisms (11 ug/L). While existing groundwater data provided a sufficient basis to start an interim remedial action, it was also recognized that more information would be needed to support a final remedy decision. Two new projects were defined and implemented to help provide the additional information for the zone of interaction.

The first project involved collecting samples of pore water from the river bottom adjacent to areas where chromium plumes approached the river. The objective was to collect observational data on chromium concentrations in aquatic habitat that was potentially exposed to contamination. This work was completed along the 100 H Area shoreline during winter 1995 (Hope and Peterson 1996a), and along the 100 D/DR shoreline during fall 1995 (Hope and Peterson 1996b). A previously undetected chromium plume was discovered in the 100 D/DR Area; it is referred to as the 100 D/DR "hot spot." The discovery led to the installation of 16 new monitoring wells and implementation of an in situ remediation method to convert hexavalent chromium to trivalent chromium in the aquifer, effectively stopping the movement of chromium into the river (Williams et al. 1999a).

The second project focused on obtaining groundwater samples from the aquifer at locations as close to the river as practical, and from multiple depths in the aquifer. Temporary steel casing was driven into the ground at locations near the low-river stage shoreline. Polyethylene sampling tubes were then inserted, and the casing withdrawn. During fall 1997, the Hanford Reach shoreline from the 100-B/C Area to the Hanford Townsite was equipped with 70 new locations for sampling groundwater very near the river channel. Each location contained from one to three sampling tubes at various depths in the aquifer. The results of that project are described in Peterson (1998). The aquifer sampling tubes were resampled during fall 1998. The latter results are not yet available in a published document, but are stored in the Hanford Environmental Information System (HEIS) database. Existing data and new data from resampling the tubes provide information on the dimensions of the contaminated zone near the river, the portion of the zone that is diluted by the infiltration of river water, and the temporal variability of water quality in the zone.

E.2.1.2.2 Redox Manipulation Test for Chromium at 100-D/DR. An innovative in situ remediation technology is being applied near the river at the 100 D/DR Area chromium "hot spot." This technology creates reducing conditions in the aquifer that cause hexavalent chromium (mobile and toxic to aquatic organisms) to be reduced to trivalent chromium (essentially immobile and less toxic). The potentially negative consequences of the anoxic plume that forms downgradient of the treatment zone (i.e., in the zone of interaction at the 100-D/DR site) have been investigated (Williams et al. 1999b). The initial results suggest that re-oxygenation occurs relatively rapidly (within weeks) under the influence of the fluctuating water table, which causes atmospheric oxygen to be entrapped. Mixing with infiltrating river water, which is well oxygenated, also helps to reoxygenate the anoxic plume.

E.2.1.2.3 Expedited Response Action for Strontium-90. In 1994, a decision was reached to proceed with groundwater remedial actions to address strontium-90 contamination in groundwater at the 100 N Area (Ecology and EPA 1994). Because the initial design included a sheet pile barrier wall placed within the zone of interaction, considerable study of that region was undertaken. Numerical simulation of groundwater flow is addressed in several reports (Lu 1991; Connelly et al. 1991, 1994, 1998). The work completed at the 100 N Area presents the most comprehensive modeling effort to date that describes numerically the hydraulic aspects of the zone of interaction on the Hanford Site. The numerical work has a solid basis in the conceptual model (DOE-RL 1996) that has been assembled for the strontium-90 plume at the 100 N Area.

E.2.1.3 Characterization of Salmon Spawning Habitat. Research related to the influx of groundwater into the bottom sediments of the Hanford Reach has been directed at factors that control the use of the substrate by salmon for spawning habitat (Geist et al. 1994). This work included attempting to map out areas where groundwater enters the river bottom, using a towed sensor (Lee et al. 1997), and also the installation of piezometers to define hydraulic head relationships within the substrate (Geist et al. 1998). A significant finding from this research is that the horizontal flow of river water through spawning gravels may have a stronger influence on habitat than the influx of groundwater. How much river water moves through the bed sediment is partially controlled by the riverbed morphology.

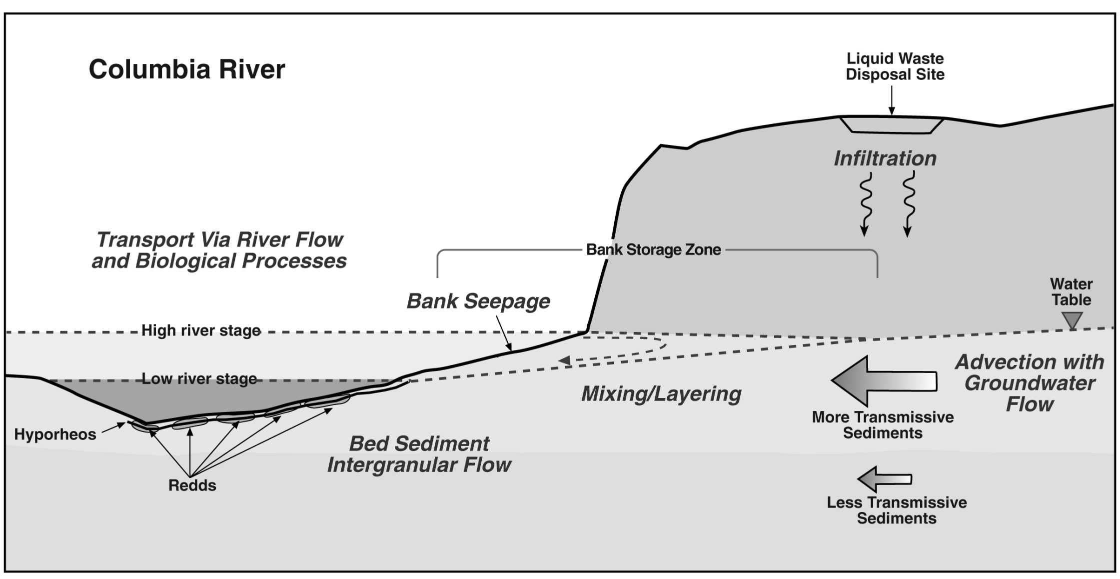
E.2.1.4 Miscellaneous Investigations. A detailed examination of the geologic and hydrologic controls on the movement of a tritium plume beneath the old Hanford Townsite was completed in 1992 (Luttrell et al. 1992). This investigation showed how changes in lithology helps direct the movement of groundwater through the zone of interaction; how the fluctuating river stage influences the rate and direction of flow; and how infiltrating river water dilutes the contaminant plume as it approached the river.

Earlier, in 1987, the U.S. Geological Survey conducted a review of groundwater discharge estimates completed by independent investigators near the Townsite (USGS 1987). SEARCH Technical Services of Davenport, Washington, completed field studies near that estimated the rate of discharge of groundwater by comparing nitrate concentrations in the river at locations upstream and downstream of a prominent riverbank spring, and inferring groundwater discharge from the differences observed (Buske and Josephson 1986). The USGS concluded that, although the SEARCH field experimental design was adequate, data uncertainties did not allow a unique interpretation for the relatively high rate of bank seepage discharge observed at this location.

E.2.2 Conceptual Model Proposed for System Assessment Capability (Rev. 0)

The environmental pathway for contaminants to travel through the zone of groundwater/river interaction begins at the interface (with approaching groundwater) and ends with discharge into the free-flowing stream of the river. The conceptual model for the zone of interaction includes descriptions of the features (e.g., stratigraphy, geographic locations, dimensions); processes (e.g., physical, chemical, and biological); and significant events (e.g., operations history, construction of dams; future natural events). These descriptions are followed by a discussion of uncertainty regarding the current state of knowledge and assumptions that are inherent in the model. Figure E-2 illustrates the principal features discussed in the following sections.

Figure E-2. Groundwater/River Zone of Interaction.



E.2.2.1 Features. The channel of the Columbia River is incised into the sediments comprising the Hanford gravels (an informal stratigraphic name), the Ringold Formation, and the Columbia River Basalt, depending on location. Recently, a river substrate map has been prepared by the U.S. Geological Survey (unpublished; work in progress 1999) which shows areas of various sediment classifications (e.g., cobble, sandy, etc.). This map provides parameters of potential use in modeling the release of groundwater into the free stream of the river.

Along the 100 Area, the stratigraphic units incised are primarily Hanford gravels or Ringold Unit E, both of which have a gravelly lithology that is generally transmissive (with some notable exceptions locally), and the Ringold Upper Mud unit, which has a fine-grained lithology and is much less transmissive than Unit E. The Ringold Upper Mud unit typically acts as an aquitard, and forms the bottom of the unconfined aquifer in the 100 Area. The riverbed substrate includes sands and gravels that have resulted from the weathering of these Ringold units, as well as other sediments brought into the Pasco Basin during the floods associated with the last glacial cycle. Some areas of the channel are relatively free of substrate sediment, such as Coyote Rapids (near the 100 K Area). The channel banks and nearshore areas adjacent to the reactor areas have been heavily modified by construction activities associated with the reactors--most notably, the construction of the river outfalls.

Downstream of the reactor areas, the river presumably incises similar lithologies as in the (100 Area). The U.S. Geological Survey work in progress indicates a predominantly cobble substrate for the entire channel from the 100 Area downstream to Richland.

The zone of interaction involves multiple interfaces with other environmental pathways for contaminant movement. The two main interfaces (i.e., with the approaching groundwater and with the free stream of the river) have already been mentioned. An additional interface includes where biota become exposed to groundwater, thus creating the potential to introduce contaminants to biological transport mechanisms. Mapping where these interfaces occur is required to provide parameters for numerical simulation of the natural system, and for conducting risk assessments. For example, combining data overlays showing where (a) the potentially contaminated aquifer is incised by the river channel, with (b) the locations of sensitive riverbed habitat, will produce insight as to the proportion of sensitive habitat that may be at risk.

Because the focus of the SAC includes the introduction of Hanford Site contaminants to the river, the conceptual model for the zone of interaction for SAC (Rev. 0) will likewise contain the greatest detail in areas where groundwater contamination is currently known to exist near the river channel. These areas contain the greatest number of wells, a primary data source, and have already been investigated as part of the environmental restoration effort. Areas apparently free of contamination will be included in the conceptual model to the extent of (1) verifying that they are indeed free of contamination; and (2) providing information on the relative proportions of discharge from the Hanford Site that may or may not be contaminated.

Dimensions for various features of the conceptual model for the zone of interaction include features on the following list. The lateral limits for these features include the Hanford facilities side of the Hanford Reach, extending from immediately upstream of the 100 B/C Area to the downstream side of the 300 Area, which is the approximate upstream boundary for the McNary Dam pool. Other factors include the following:

- The thickness of the potentially contaminated aquifer.
- The riverbed surface area where the channel intersects the potentially contaminated aquifer.
- The inland extent of the pressure wave created by daily and seasonal fluctuations of the river.
- The inland extent of water quality changes caused by infiltration of river water during high river stage.
- The vertical extent of water quality changes caused by infiltration of river water.

E.2.2.2 Processes. The most significant process currently known to contribute to natural attenuation in the zone of interaction is probably dilution of groundwater by river water that infiltrates the banks and substrate. This physical process is driven by cyclic fluctuations of discharge through the Hanford Reach, which are controlled by water management activities at upstream dams and by seasonal runoff characteristics.

At coarse spatial and temporal scales, observational data are available to support the general conclusion that some dilution of groundwater occurs in most areas (Peterson and Johnson 1992). At finer scales, more variability is observed. At times, nearly undiluted groundwater may present itself to the river substrate environment at specific locations. Examples for the latter can be found at the 100 D/DR Area "hot spot" (Hope and Peterson 1996b), and near the Hanford Townsite (Luttrell et al. 1992). Likewise, some riverbank seepage sites, shallow aquifer sampling tube sites and riverbed pore water sampling sites consistently reveal samples that are essentially river water that has infiltrated the bank or riverbed. Data from these sampling sites help to define the dimensions for the zone of infiltrating river water.

The extent to which dilution occurs within the zone of interaction varies during a river stage cycle. The duration of relatively high river stage increases the opportunity for river water to move farther into the river bank, with a resulting increase in the potential for dilution to occur. Therefore, the temporal variability of the dilution process is an important parameter in the conceptual model. Field observation methods are available to obtain data for this parameter. The specific conductance of water samples is used as a guide to the degree of mixing between river water and groundwater. Nearshore river water has a relatively constant specific conductance in the range 130 to 150 uS/cm, while groundwater has a specific conductance ranging from 350 to 1000 uS/cm at locations where plumes approach the river.

A second aspect of the infiltration of river water is whether river water and groundwater actually mix or, alternatively, form a layered system. Because the lateral transmissivity in the near-river aquifer is higher than vertical transmissivity, river water moves horizontally more easily than vertically, thus promoting layering. Where layered, riverbank seepage may show little evidence of admixture of groundwater, which has been observed at some seepage sites, using specific conductance as a guide. Vertical profiling in near river wells and further analysis of data from aquifer sampling tubes will help answer the question of layering vs. mixing. Currently, the conceptual model is based on the assumption that both processes occur (i.e., in some areas river water and groundwater mix, and in other areas, they remain separate as a layered system). This will become an issue of uncertainty in subsequent numerical models, unless some way to identify which process is dominant is developed during applied science and technology activities.

The chemical environment in the zone of interaction is likely to be different than in either the aquifer or the free stream of the river. This results from the closer association with the atmosphere, and increased biological activity, compared to within the aquifer or free stream. Also, there may be differences in sediment composition, depending on whether the zone has remained in its natural configuration, or has been modified by excavation and backfill associated with construction of reactor facilities. This possibility is greatest where the river outfalls and piping were installed.

Very little investigation of chemical changes in Hanford Site contaminants in the zone of interaction has been attempted to date. One study looked at possible changes in the valence state of chromium in groundwater as it passed through the zone and into the river (Thornton et al. 1995). This study found that the majority of hexavalent chromium (which is toxic to aquatic organisms) in groundwater passed through the zone unchanged; also, once in river water, it remained as hexavalent chromium. A small but measurable proportion did appear to be reduced and precipitated as trivalent chromium (less toxic) on riverbank sediment. Locations where conditions for reducing hexavalent chromium to trivalent chromium are probably limited in occurrence, because most of the interaction zone appears to have good exchange with well-oxygenated river water.

Information on biological activity within the zone of interaction is also limited, with salmon-spawning habitat being the most extensively studied topic (Geist et al. 1994; Hope and Peterson 1996a, 1996b; Geist and Dauble 1998). Sampling of other organisms, such as larvae and bacteria, that use the pore water of river sediments as habitat, has not yet occurred on the Hanford Site. However, there has been some work completed on organisms in the benthic environment that may be exposed to upwelling groundwater (Cushing 1993), and on sediments/periphyton coatings collected from within riverbank seepage (unpublished data, Environmental Restoration program).

E.2.2.3 Events. The natural features and processes that are currently characteristic of the zone of interaction can be viewed as remaining relatively constant since the construction of the Hanford Site. The exception is the fluctuation of the river stage in the Hanford Reach. The range through which the river stage fluctuates, and the frequency of the cycles, have changed significantly since construction of the Priest Rapids Dam upstream of Hanford. Prior to the dam, the Hanford Reach experienced one large fluctuation associated with the spring runoff. The range between the highest and lowest river stage may have reached 9 meters. After dam construction, the seasonal runoff peak became far less pronounced, and the range between seasonal highs and lows reduced to approximately 3 meters.

The change from pre-dam conditions in daily and seasonal stage fluctuations has changed the characteristics of the riparian zone (i.e., the area between high and low river stage), and also the characteristics of bank storage. In general, physical, chemical, and biological variability in the zone of interaction has probably decreased because of the reduced extremes in river elevation changes, and river flow rates, since the river started being controlled by the dams.

A second "event" that has changed the character of the zone of interaction involves the release of contaminated effluents to the soil column, either by intentional disposal or by unintentional leakage from pipelines and facilities. The biggest effect was probably on the chemical processes occurring in the zone, although the temperature of the zone was also raised significantly during the reactor operating years. Because most of the reactors were shut down in the mid-1960s, the zone has begun to recover to pre-operating conditions. Liquid effluent plumes and mounds on the normal water table have dissipated, and temperatures have returned to more natural geothermal levels.

Most of the groundwater contamination in the 100 Area observed currently has evolved during the approximately 30 years since active operations. In many areas, the tail of a plume is all that remains, and the core or highest concentrations have already entered the river. However, some plumes observed today near the river have characteristics suggestive of more recent introduction to groundwater (e.g., the 100 D/DR Area chromium hot spot). Also, plumes that have migrated for many years from the 200 Areas are now at the river along the shoreline between the Hanford Townsite downstream to the 300 Area.

Near-term events that have the potential to increase the level of contamination in the zone of interaction are few, although one is particularly significant. The 105-KE and 105-KW fuel storage basins contain irradiated fuel rods, some of which are corroding. Sludge, consisting of highly radioactive particles of fuel rods, corrosion products, and other debris, has accumulated on the basin floors. The million gallons-plus shielding water is radioactive, especially so in the 105-KE basin. The soil column beneath that basin contains an inventory of radionuclides estimated at over 2,000 curies, with strontium-90 and cesium-137 the principal radionuclides (UNC 1979). Catastrophic loss of shielding water from the basins, as might occur during an earthquake or breaching of the structures during removal of the fuel elements, could introduce significant quantities of radionuclides to the soil and possibly groundwater.

Other near-term events that could potentially increase contamination in the zone of interaction include remobilization of contamination currently held in the vadose zone. Remobilization could occur during soil column remediation activities in the 100 and 300 Areas, such as excavations associated with removal of contaminated soil and facilities. The remobilizing mechanism would be infiltration of dust control water and/or precipitation events, such as intense thunderstorm activity or snow melt.

Long-term events are plausible that would dramatically change the characteristics of the zone of interaction. These include removal of the upstream dams, such that discharge through the Reach returns to being controlled by natural precipitation cycles. Climate change and natural events (such as volcanic eruptions and earthquakes) could have a major impact on processes in the zone.

E.2.2.4 Issues of Scale. The conceptual model for the zone of interaction includes a description of the features, processes, and events occurring within the zone that might influence the environmental pathway for spread of contamination. The spatial and temporal scales at which each of these elements must be understood and characterized are determined by the assessment objectives. Therefore, several alternative levels of detail will be available in the conceptual model.

At the least complex end of the spectrum, the model alternative simply states that contaminated groundwater from beneath Hanford facilities ultimately discharges into the Columbia River. The key parameters become the contaminant, the amount available for discharge, the rate at which it is discharged, and the duration of discharge. Example assessment objectives relevant to this scale are (a) assessing river water quality at locations well downstream of the Hanford Reach; and (b) determining a radionuclide inventory for the river system and northeast Pacific Ocean. Very little detail regarding features, processes, and events in the zone of interaction is required.

A more complex alternative is necessary where the assessment objective involves exposure of humans and aquatic organisms to contaminated groundwater. Features, events, and processes of a very local scale must be considered to meet this objective. Data for many more parameters than in the example above are required. The exact locations where contaminants enter the river environment, the characteristics of the contaminant at the point of exposure, and how the characteristics change with daily and seasonal river cycles all become relevant. An example assessment objective might involve the exposure of salmon spawning grounds to contaminated groundwater that upwells through the riverbed.

The appropriate temporal scale is also determined by the specific assessment objective. For some assessments, instantaneous conditions are more appropriate than long-term average conditions. An example of the former might be exposure of a contaminant in riverbank seepage that only appears when the river stage falls to very low levels. Conversely, long-term average flux to the river may be appropriate for assessing the accumulation of radionuclides behind the McNary Dam.

E.2.2.5 Uncertainty. The zone of interaction is heterogeneous with respect to lithology, textures, and hydraulic parameters. It will not be feasible to obtain sufficient observational data to fully describe this heterogeneity. Consequently, uncertainty is introduced by the need to extrapolate and infer conditions between points of observation. This is true for features, processes, and events that are included in the conceptual model. Uncertainty will be addressed in two ways: quantitative assessment of measurement errors; and subjective assessment regarding inferences made without the benefit of direct observation or measurement.

Accuracy and precision associated with various measurable parameters used in numerical models can be used to illustrate the range of possibilities associated with model output. However, because a numerical model cannot include all parameters associated with the system, some uncertainty still remains that is not easily quantified. Conclusions drawn from numerical modeling must include a discussion of those elements of uncertainty that are subjective and not readily quantified.

E.2.2.6 Assumptions. The principal assumption associated with this conceptual model for the zone of interaction between groundwater and the Columbia River is that the model will be used to provide a framework for numerical modeling that leads to estimates, predictions, and risk assessments. The conceptual model is intended to illustrate the features, processes, and events that are represented by parameters in numerical models. It is recognized that several numerical models may be employed to achieve specific estimation or prediction objectives, depending on the spatial and/or temporal scale of the issue being addressed.

E.2.3 Outstanding Issues

The principal outstanding issues associated with this conceptual model are (a) spatial resolution of features within the zone; (b) field data to support ideas about physical, chemical, and biological processes occurring in the zone; and (c) temporal resolution associated with these processes. Given an improved understanding of these issues, numerical modeling of contaminant movement through the zone can be better designed to achieve the estimation and prediction objectives associated with an assessment of impacts to the river system.

Specific problems and issues to be addressed in the near term include the following:

- Attenuation of contamination within the zone of interaction by natural processes.
- Accumulation of contamination within the zone (e.g., bioaccumulation; precipitation).
- Spatial scales: (1) regional scale for issues involving Columbia River quality at locations away from points of entry; and (2) local scale, for issues involving potential exposure to contaminated groundwater.
- Predictability of mass transfer of contaminants through time.

E.2.4 Proposed Path Forward

Many of the information needs associated with improving this conceptual model have been described previously (e.g., during the Applied Science and Technology workshops held during the summer 1998). Obtaining this information can be achieved through (a) core project work scope; (b) new work under the Applied Science and Technology endeavor of the Groundwater/Vadose Zone (GW/VZ) Integration Project (Integration Project); and (c) basic research under other DOE programs.

E.2.4.1 Strategy to Enhance the Conceptual Model

The following sections highlight the general activities envisioned for the near term that will enhance the understanding of features, processes, and events associated with the zone of interaction.

E.2.4.1.1 Data Mining.

- Compile existing geologic and hydrologic data on the unconfined aquifer near the river for the purpose of better illustrating the zone, especially at locations where contaminant plumes are intersected by the river channel.

- Assemble a database on the dimensions of the zone at a scale appropriate for contaminant plumes that are currently near the river. The database will facilitate selection of input values for parameters in various numerical models.

E.2.4.1.2 Data Collection.

- Monitor the zone with in situ instruments to better define the variability in (a) hydraulic parameters (direction and steepness of gradients; transmissivity); and (b) water quality characteristics, especially changes induced by river level/discharge fluctuations.

- Coordinate collection of water, sediment, and biological sampling currently conducted in the zone, to add synergy to the information gained.

E.2.4.1.3 Field Methods.

- Increase the use of aquifer sampling tubes located near the Columbia River to characterize groundwater at several depths in the aquifer.

- Develop new field methods to (a) obtain pore water samples from the riverbed without using divers; and (b) obtain relatively undisturbed sediment samples from potential contaminant sink areas, such as F Slough.

- Develop new methods to obtain biological samples from the zone (hyporheos investigations).

E.2.4.2 Implementation of Conceptual Model for System Assessment Capability (Rev. 0). Alternatives for implementing conceptual models during SAC (Rev. 0) were presented and discussed at a recent SAC workgroup (August 25, 1999, Richland, Washington). The alternatives presented for the zone of groundwater/river interaction are summarized in Table E-1. The shaded area represents activities that are currently envisioned by the Integration Project for FY 2000 work.

An important aspect of implementing the conceptual model for SAC (Rev. 0) will be to develop a strategy to coordinate the input and output of several numerical models. These models include the transport of contaminants via (a) groundwater flow; (b) river flow; and (c) biological mechanisms. Parameters for discharge from the zone of interaction, such as rates, contaminant mass flux, and grid size, must be defined so that the output of one model feeds the input of subsequent models along the transport pathways. An attenuation factor may be assigned to grid elements if sufficient data are available to support doing so. In the absence of such data, an assumption of no attenuation will provide conservatism to estimates for output from the zone.

Table E-1. Zone of Interaction Options For SAC (Rev. 0).

Model Attributes:	Features	Processes	Events
Least Complex	• Interface with river channel defined by GW flow model boundary conditions	• Groundwater input and discharge predicted by GW flow model • Contaminant flux estimated by assigning concentrations to model cells	• Not considered
More Complex	• Interface with river channel defined by dimensions of currently contaminated aquifer • 2-D simulation of water movement in response to river cycles • Type locations as for vadose CM (e.g., 100-D/DR Area)	• Contaminant input from observational data • Estimates for dilution by river water prior to discharge • Discharge predicted by Darcy equation and/or GW flow model	• Considers seasonal cycle of river discharge
Most Complex	• Interface with river channel along entire Hanford Reach • 3-D simulation of water and contaminant movement • Provisions to include effect of GW remediation activities	• Contaminant input from GW flow model and VZ model • Attenuation within zone by physical, chemical, and biological processes	• Considers range of river discharge scenarios over the long term (e.g., climate change; dam removal)

The following elements highlight what is envisioned as a strategy to support the SAC (Rev. 0):

E.2.4.2.1 Initial Integration of Numerical Models.

- Define grid dimensions for Site-wide Groundwater Flow model (Section D), Columbia River Flow model (Section E.3), and Biological Transport model (Section E.4).

- Define vertical dimensions for distribution of contaminants currently near the river, to provide input parameters for Site-wide Groundwater Flow model.

- Correlate grid elements with sediment types mapped for the river channel (unpublished U.S. Geological Survey maps); assign sediment type to grid elements.

- Assign zone of interaction attenuation factor to grid elements where data exist to support estimates for an attenuation factor; assume no attenuation where data are non-existent.

E.3 CONTAMINANT FATE AND TRANSPORT

In this section the conceptual model for contaminant fate and transport in the Columbia River is presented. This element takes contaminant influxes from the zone of interaction (or direct discharges) and then analyzes the downstream transport of the contaminants in the river water, suspended and bed sediments, and biota. The spatial and temporal distribution of contaminants from this element feeds into the biological transport and risk elements.

E.3.1 Background

The Columbia River is the largest North American river to discharge into the Pacific Ocean. The Columbia River originates in Canada and flows south 1,953 km to the Pacific Ocean (Figure E-3). The watershed drains a total of 670,000 square km, and receives waters from seven United States and one Canadian province. Key contributors to the flow are runoff from the Cascade Mountains in the states of Washington and Oregon, and the western slopes of the Rocky Mountains, in the states of Idaho and Montana, and the province of British Columbia.

Figure E-3. Columbia River Basin and Location of Major Dams.

The flow of water on the main stem of the Columbia River is regulated by 11 dams within the United States, 7 upstream and 4 downstream of the Hanford Site. The Priest Rapids Dam is the nearest dam upstream of the Hanford Site, and McNary Dam is the nearest downstream. Dams were installed on the Lower Columbia (downstream from Priest Rapids) between 1938 and 1967, as shown in Figure E-4. The installation of these dams greatly slowed the water travel times from the upper reaches of the river to the mouth, resulting in much lower sediment loads being discharged downstream. The slowed travel times also allowed for greater radionuclide deposition and decay. Average annual flows below Priest Rapids and The Dalles dams are 120,000 ft3/sec and 192,000 ft3/sec, respectively.

Figure E-4. Profile of the Lower Columbia River from Priest Rapids to the Ocean and Construction Dates of Dams.

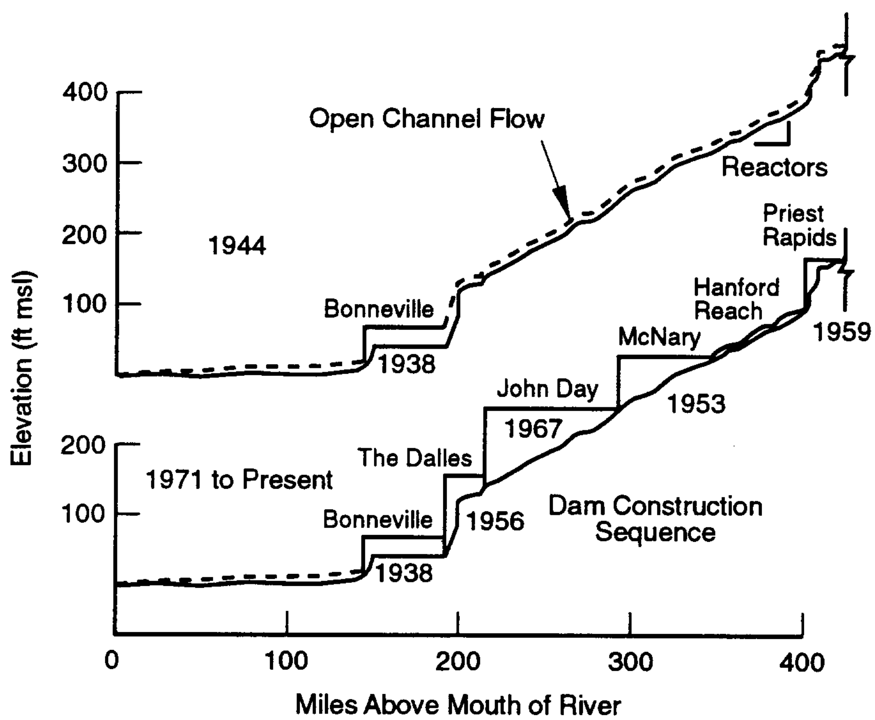
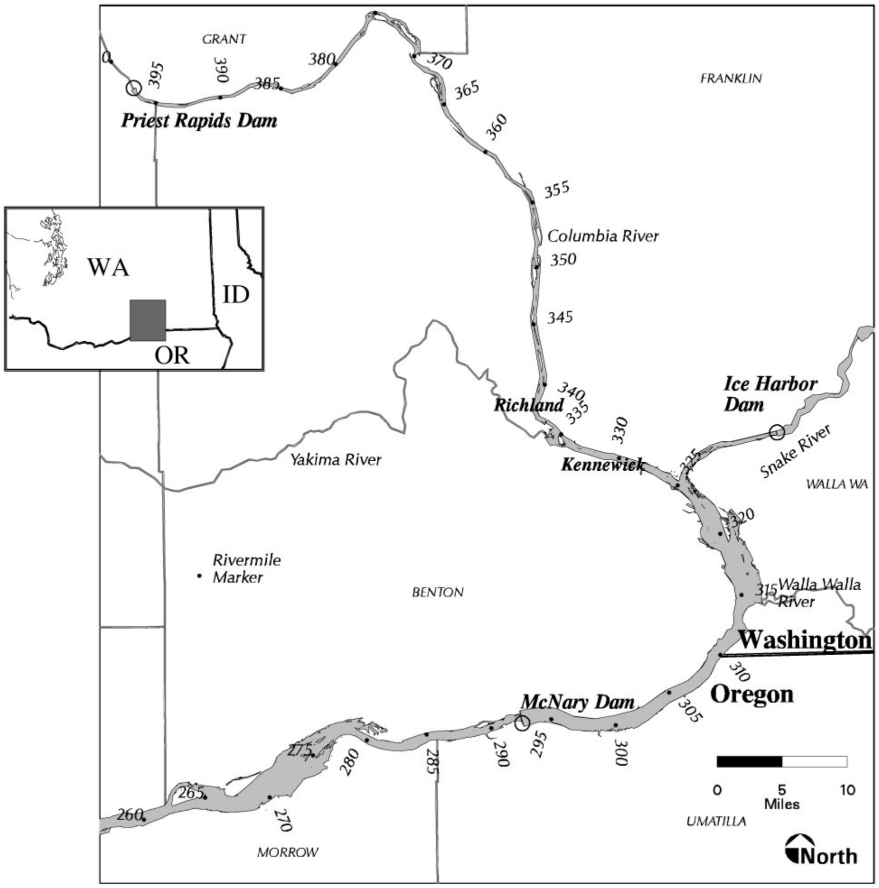


Figure E-5 shows the section of the Columbia River from Priest Rapids Dam to McNary Dam. Key tributaries in this region are the Snake, Yakima, and Walla Walla Rivers. The Hanford Reach starts below Priest Rapids Dam and extends downstream to the upstream end of the McNary pool. This location generally varies between Columbia River mile 340 to 350, depending on flow rate. Flows through the Hanford Reach fluctuate significantly, and are controlled primarily by power peaking operations at Priest Rapids Dam. As a result of fluctuations in discharges, the depth of the Columbia River varies significantly over time. River stage may change along the Hanford Reach by up to 3 meters (10 feet) within a few hours.

Figure E-5. Columbia River and Tributaries from Priest Rapids to McNary Dam.



Since construction of McNary Dam (completed in 1953), a significant amount of the sediment has been trapped behind the dam. However, as is true of the other Columbia River dams, some of the trapped sediment is re-suspended and transported downstream by seasonal high discharges. As expected, much of this material is redeposited behind dams located further downstream. The primary contributor of suspended sediment to the Columbia River is the Snake River, but the Yakima and Walla Walla rivers are also significant sources.

Sediment accumulates faster on the Oregon shore than the Washington shore, because sediment input from the Snake and Walla Walla rivers is constrained to the near shore (Oregon side). Based on visual observations from past sediment-monitoring samples taken for the Hanford Site-wide Surface Environmental Surveillance Project (SESP), characteristics of the top 1-5 centimeter portion of the bed sediment at Priest Rapids Dam appeared to be dominated by coarse-to-fine sands and silts. By contrast, cobble, coarse and fine-sand bed sediment was found at sampling locations along the Hanford Site. Silt and clay sediment was observed at the McNary Dam sampling site.

Seepage of groundwater from the Hanford Site into the Columbia River has been known to occur for many years. The presence of springs along the shoreline depends on the height of the water level of the Columbia River. Groundwater levels are influenced by fluctuations in the river stage from operations at Priest Rapids Dam, with locations near the river being most strongly influenced. The flow of groundwater, contaminated and uncontaminated, from beneath the Hanford Site into the Columbia River is estimated to be approximately 40 cfs.

E.3.2 Past Project/Existing Conceptual Models

Many existing publications document various conceptual models of contaminant fate and transport in surface water systems (NCRP 1984, EPA 1985). In addition to conceptual models, these publications also summarize the mathematical formulation of the conceptual model. These models vary in complexity from simple box-models to complicated three-dimensional (3-D), transient dispersion-advection-particle transport models for rivers, estuaries, or oceans. As noted in these reports, the degree of model complexity chosen depends on the system to be modeled, the availability of required data, the computational resources available, the skill of the user, and (most importantly), the types of questions to be answered.

Previous conceptual and mathematical models of the transport of Hanford origin radionuclides are described by Onishi (1977), Richmond and Walters (1991), and Walters et al. (1994). Onishi considered vertical variations, sediment transport, and contaminant transport. Horizontal mixing of plumes was not included. The other studies were done for the Hanford Environmental Dose Reconstruction (HEDR) project. These studies considered only the direct discharge of radionuclides from the once-through cooled plutonium production reactors. The conceptual model included only transient dilution and decay of radionuclides. Lateral mixing of effluent plumes and sediment transport were not directly modeled.

A conceptual and mathematical model for the transport and fate of dissolved contaminants and water temperature for the Columbia and Snake Rivers is documented in Richmond et al. (1999). This model in current use to assess the impacts associated with dissolved gas generated from spillway flows at dams. The model is a 2-D, transient depth-averaged model. The depth-averaging assumes that vertical variations in velocity and contaminants are small, and that lateral (bank-to-bank) variations are of primary interest.

These previous conceptual models and their mathematical implementations are limited. In each case they do not include one or more of the processes that are known to be important in assessing the fate and transport of existing and future Hanford releases to the Columbia River.

E.3.3 Conceptual Model Proposed for System Assessment Capability (Rev. 0)

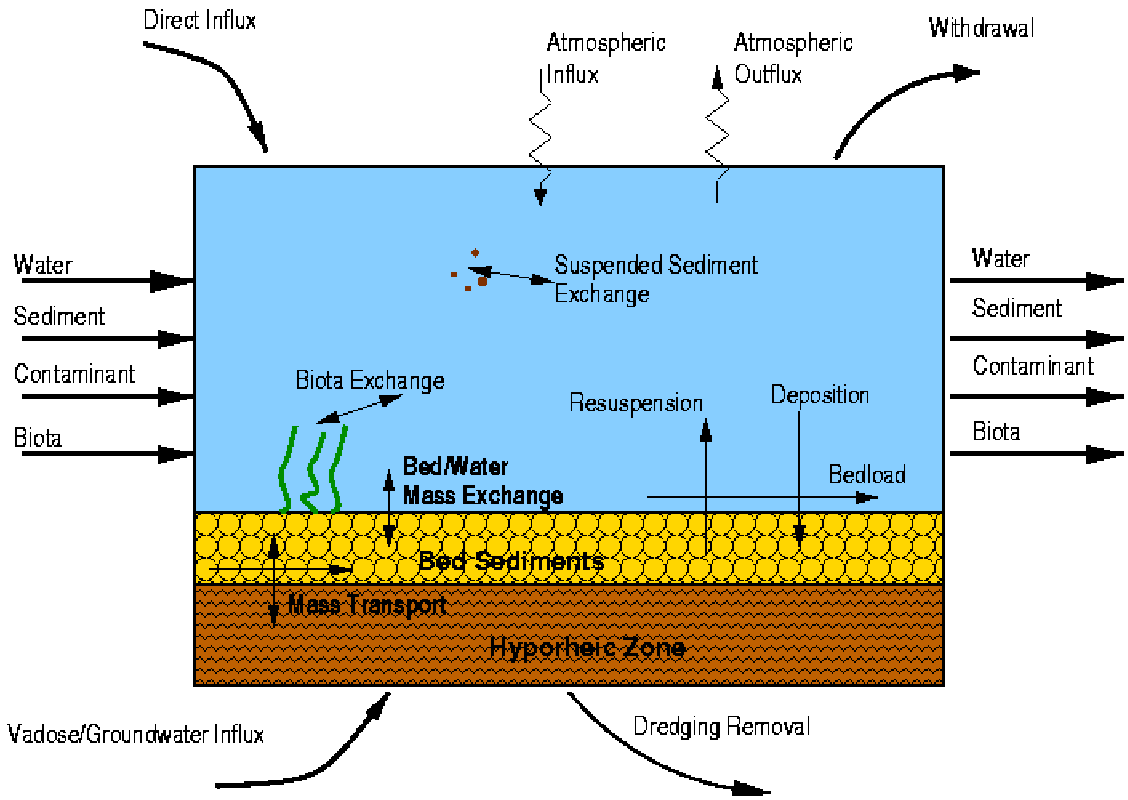
The conceptual model proposed for use in the SAC (Rev 0) includes the features, processes, and events associated with environmental pathways and transport processes that affect contaminant transport in surface water systems. These fundamental processes must be considered as contaminants are transported along the Columbia River, the estuary, and adjacent coastal ocean.

E.3.3.1 Features. The most important feature is the Columbia River basin itself. The transport and fate of contaminants in the river will be controlled not only by events on the Hanford Site, but by features of the entire basin. Conceptually, the main stem of the Columbia River can be divided into the Mid/Upper Columbia (upstream of Priest Rapids Dam), Lower Columbia (Priest Rapids to McNary, McNary to Bonneville), Tidal Zone and Estuary (Bonneville to Mouth), and the Coastal Pacific Ocean. Tributary rivers and basin also must be included to some extent as they provide influxes of water, sediment, and contaminants to the main stem of the Columbia River.

E.3.3.2 Processes. The transport processes included in the conceptual model are shown in schematic form in Figure E-6. These are the processes that should be considered for inclusion in the mathematical implementation of the conceptual model. These are also listed below:

- Influx or Loading
  - GW/VZ and other point/non-point discharges, atmospheric deposition, overland runoff
- River and Hyporheic Zone Hydrodynamics
  - Turbulent mixing
- Transport
  - Contaminant advection and dispersion in the river
  - Contaminant advection and dispersion in the hyporheic (sediment-surface water interaction) zone
  - Sediment transport, deposition, and resuspension
  - Biological transport
  - Volatilization
  - Removal/relocation by dredging or irrigation withdrawals
- Speciation
  - Sorption/desorption to sediments
  - Ionic state, reduction-oxidation

Figure E-6. Schematic of the Transport and Fate Processes in the River Conceptual Model.



- Transformation
  - Biodegradation, photolysis, hydrolysis, decay chain daughter nuclides
- Bioaccumulation
  - Bioconcentration, biomagnification

E.3.3.3 Events. Events that require consideration are not only Hanford related, but also include events which affect the Columbia Basin hydrologic system. Examples of events that should be considered are changes in the operations of the Columbia River hydropower system (flow modification for endangered species), removal/decommissioning of dams (which results in contaminated sediments becoming available for transport), extreme natural events (floods, earthquakes, volcanic eruptions), and potential changes in future climate.

The mathematical representation of the conceptual model can vary from simple, hand-calculations to complex, transient, 3-D numerical models that require supercomputer resources. At any level of complexity, the mathematical models will be based on physics that represent the conservation of mass, momentum, and energy. These can range from analytical solutions to 1-, 2-, or 3-D numerical models. In any model, physical processes can be incorporated at various levels of sophistication. For example, sediment-contaminant interaction can be simulated using equilibrium partition coefficients or geochemical models.

E.3.3.4 Dealing With Uncertainty. In the mathematical representation of the conceptual model uncertainty arises from several sources. These include uncertainties in the physical processes, temporal and spatial scales, initial and boundary conditions, and model parameters. Prime examples of uncertainty in process physics are fluid turbulence and cohesive sediment transport. The selection of temporal and spatial scales of resolution will also introduce uncertainty through averaging and the associated need to then represent sub-grid scale effects. Uncertainties in initial and boundary conditions can also have a large effect, and these include the existing distribution of sediments, contaminants, and influx of contaminants through the groundwater/vadose zone interface. Traditional parameter uncertainty also exists when selecting channel roughness coefficients, porosity, and sediment-contaminant interaction coefficients.

Uncertainty will be addressed primarily using Monte Carlo simulations and sensitivity studies. Alternate conceptual models and mathematical representations will also be used to assess uncertainty. For example, higher dimensional models (3-D or 2-D) can be used to assess the uncertainties in using a lower dimensional model (1-D) for simulating the mixing of a contaminant plume in the river.

E.3.3.5 Assumptions and Technical Rationale. The key assumption in the conceptual model is that it includes (or can be extended to include) all important features, processes, and events related to the fate and transport of contaminants in the Columbia River system. The purpose of the conceptual model is to provide a high-level representation of what should be included in a mathematical model of the system. The mathematical formulation that is implemented will have to be designed to meet the requirements of the assessment (temporal/spatial scales and domain, resource limitations, time constraints).

E.3.4 Outstanding Issues

These issues include time and space resolution requirements for the model, field data, boundary conditions, initial conditions, verification data, and parameter definition data.

E.3.5 Proposed Path Forward

The path forward consists of compiling existing Columbia River data, gathering new data to fill gaps, and performing exploratory studies. The exploratory studies will be valuable to test the value of enhanced models, identify additional data needs, and to perform a preliminary sensitivity/uncertainty analysis.

Many of the information needs described above are contained within the scope existing Hanford and non-Hanford programs. While efforts have been made to coordinate the activities of these organizations, improvements can be made. Activities identified and conducted under the RTE will be coordinated with other programs so as to maximize efficiencies and take advantage of existing expertise, experience, and capabilities while avoiding duplication of effort to the extent possible. Several agencies outside of the Hanford domain are also conducting various studies of the Columbia River environs. These include the Washington State Department of Ecology, the Washington State Department of Health, Army Corps of Engineers, U.S. Geologic Survey, Federal and State Fish and Wildlife Service, Environmental Protection Agency, Bonneville Power Administration, and local communities. Coordination with outside agencies conducting river-related studies along the Hanford Reach will also be pursued to the fullest extent practical.

E.4 BIOLOGICAL TRANSPORT

Contaminants entering the river environment will be affected by the biological as well as physico-chemical conditions within the river. Of special importance are biological factors that affect the fate, form, and transport of contaminants within the river environment. Early in the operation of the Hanford Site reactors, the movement of radioactive contaminants from the Columbia River into biota, and their subsequent redistribution to sediments and to the terrestrial ecosystem was recognized as a potentially significant influence on radionuclide fate and transport in the Columbia River (Foster and Davis 1956). The following analysis describes conceptual models of biological transport that have been applied to the Columbia River system, and describes the approach recommended for the SAC (Rev. 0).

E.4.1 Past Project/Existing Conceptual Models

One of the first evaluations of contaminant transport by biota of the Columbia River assessed radionuclide transfer primarily along a food web (Davis 1960). The first food web published that accounted for radionuclide transfer in the Columbia River is shown in Figure E-7. This conceptual model addressed essentially three compartments: water, sediment, and biota. Contaminants in the water entered the biological system primarily at the lowest trophic levels (i.e., bacteria, phytoplankton, and periphyton), from which the contaminant was distributed to the rest of the biological system through ingestion of plant and animal material. Vascular plants were exposed to contaminants in sediment only, suggesting that submerged macrophytic vegetation was not included in this conception.

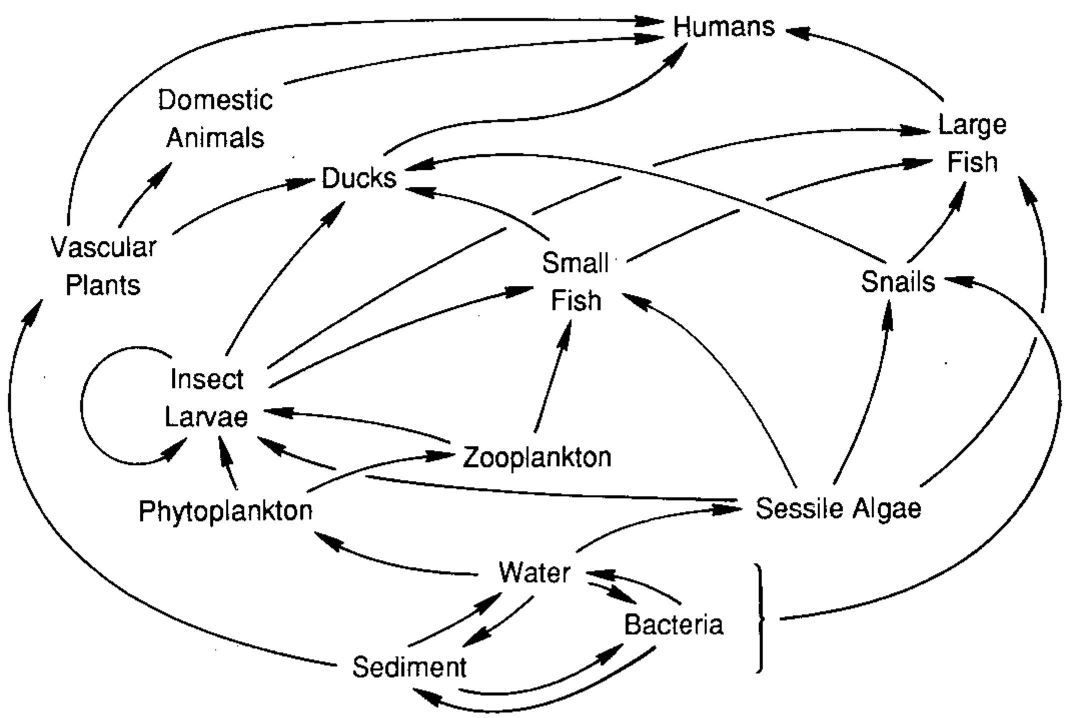
The greatest contribution of this model was that it recognized the importance of food ingestion as a significant factor in moving contaminants within the ecosystem. Limitations of this conceptual model include the following:

- Uptake from sediment through direct ingestion by biota was ignored.

- Uptake from water by organisms other than phytoplankton and periphyton was ignored.

- No catabolic pathways were included, such as excretion, defecation, or decay.

Figure E-7. Basic Conceptual Model for Transfer of Radionuclides Among Columbia River Organisms Based On a Simplified Food Web.



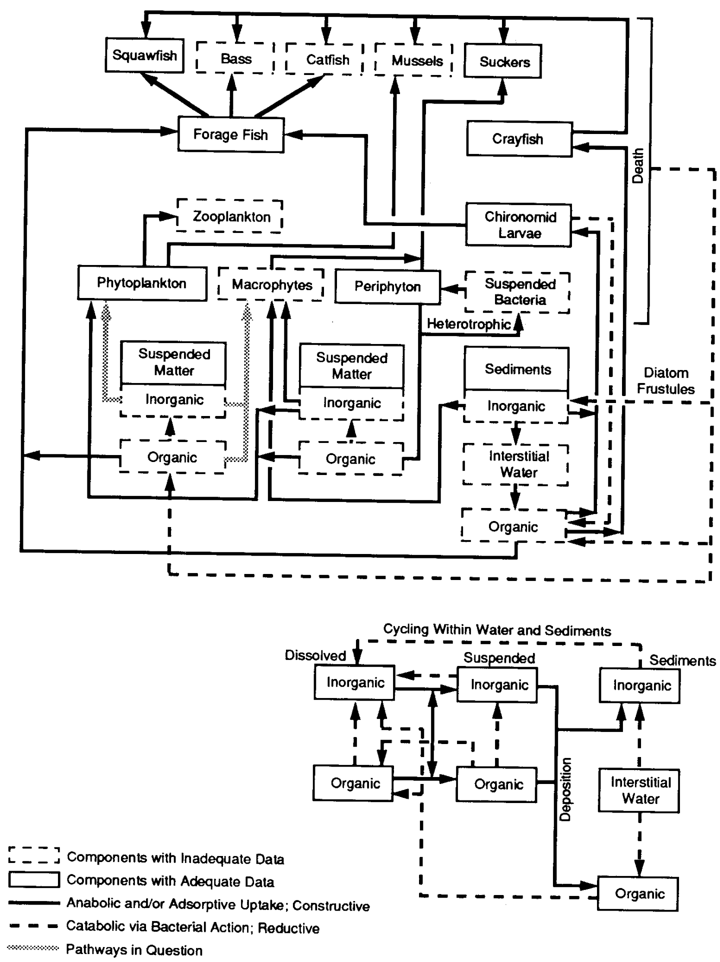
- Movement of contaminants from periphyton into phytoplankton was not addressed (the bulk of phytoplankton in the river derives from phytoplankton (Brandt et al. 1993).

- A single water component was used that does not take into account the concentration gradients arising from influx of groundwater into a river system.

- A limited food web structure was used to represent the aquatic system, and no movement out of the river system was included except for human consumption.

A more advanced conceptual model was later developed to account for biogeochemical cycling of nutrients and radionuclides remaining in the Columbia River after shutdown of the federal reactors (Thomas et al. 1974). This model attempted to describe the flows of mass and energy among components of the river ecosystem, and categorized the components and the flows according to whether or not adequate data existed to parameterize a model (Figure E-8).

Figure E-8. Biogeochemical Cycling Conceptual Model for the Columbia River System.



Advantages of this model include transfer of dead material back into the food chain, and recognition that the physico-chemical state of the contaminant affects movement into the biological system. For example, decaying material in the water column that remains in organic form may be directly ingested by organisms, whereas inorganic material in the water column must first pass through photosynthetic organisms before it can enter the food web. In addition, interstitial water is shown as a separate entity.

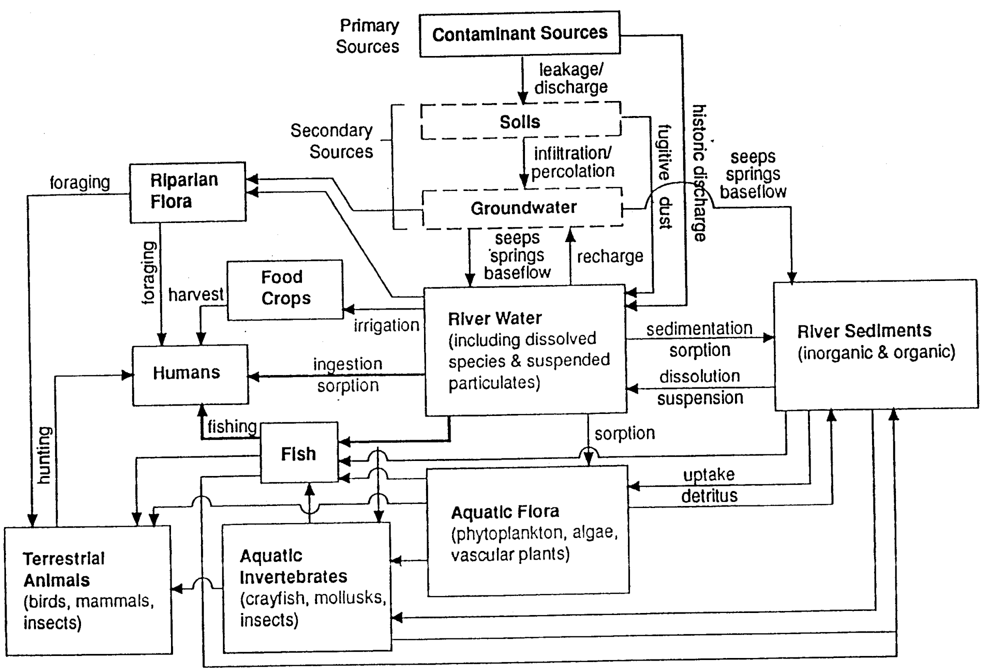
Limitations of the model include the following:

- A focus on nutrient and energy flows limits its applicability to contaminant transport.
- Retention of a simplified trophic structure is limited to the aquatic system.
- A lack of contaminant transport from the aquatic to the terrestrial system.

- A lack of an uptake pathway directly from surface water by any organism.
- No ingestion of sediments by other than chironomid larvae.

A conceptual model was developed specifically to evaluate impacts of 100 Area groundwater on Columbia River biota (DOE-RL 1993). This model incorporated both food ingestion and water exposure pathways for biota, as well as mass flows of contaminants from aquatic biota into sediments (Figure E-9). The model also distinguished between dissolved versus particulate contaminants in the water column, although their relative importance to biological transport was not addressed. This model is limited primarily in that it did not differentiate groundwater from pore water; it used an attenuated aquatic food web lacking a terrestrial component outside of humans; and it did not expose benthic organisms and life stages to pore water.

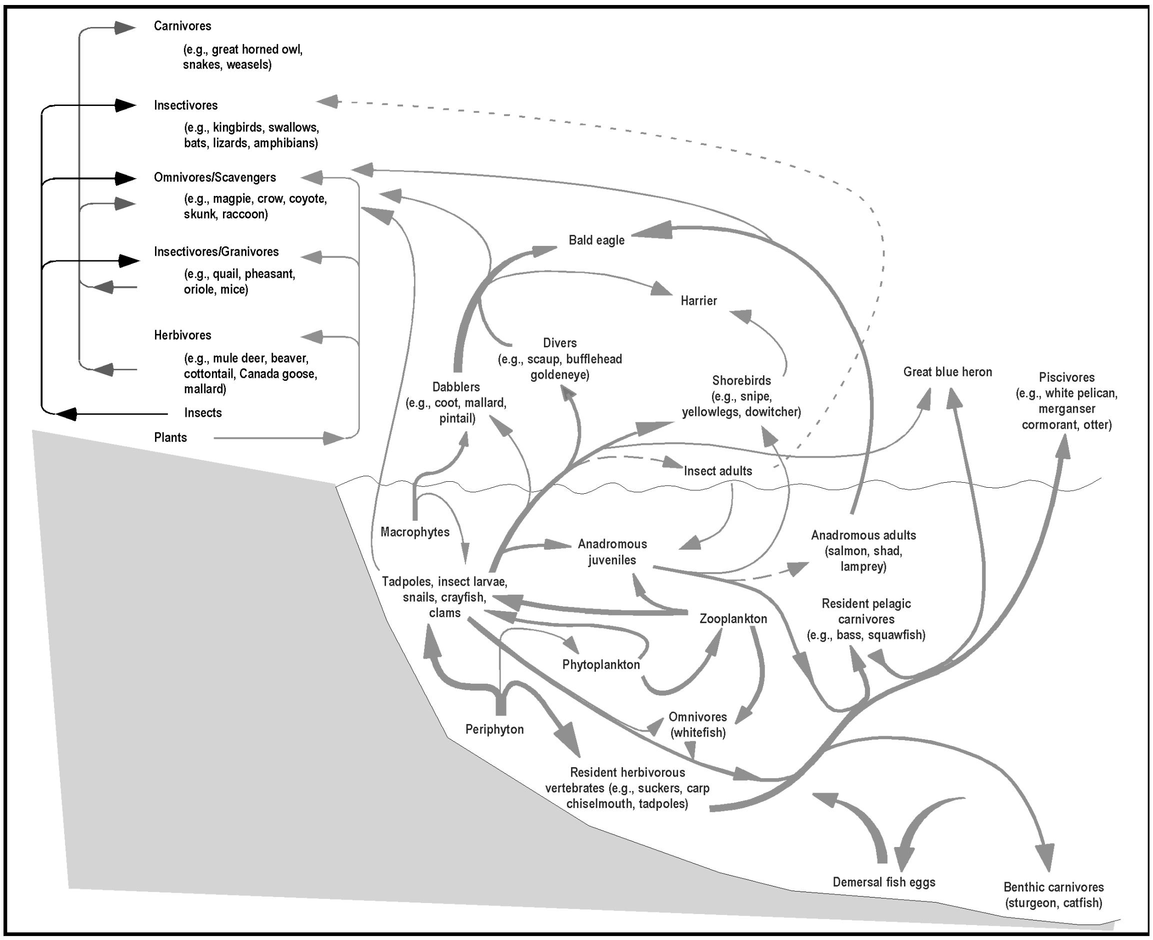
Figure E-9. Conceptual Model for Contaminant Movement from the Columbia River Impact Evaluation Plan.



The most recent conceptual model for contaminant transport and fate within the biota of the aquatic and terrestrial ecosystems associated with the Columbia River was developed for the *Columbia River Comprehensive Impact Assessment* (DOE 1998). This model was based on Hanford Site contaminants entering the river in groundwater, included a contaminant-bearing sediment component, and addressed aquatic and riparian food webs and the linkages between them (Figure E-10).

Exposures included those arising from water contact and ingestion, sediment contact and ingestion, and prey ingestion. The model contained a detailed food web based on the extensive ecological studies conducted on the river's biota, and incorporated 56 aquatic and riparian species. Contaminant concentration gradients from groundwater sources were recognized using three separate water terms: groundwater, porewater, and river water. The model was based on contaminant- and species-specific uptake and depuration from respiratory and ingestion exposures, and allowed for variation in bioavailability through the uptake portion of the ingestion/absorption parameters.

Figure E-10. Conceptual Model of Contaminant Exposure and Transport Pathways for Organisms of the Columbia River.



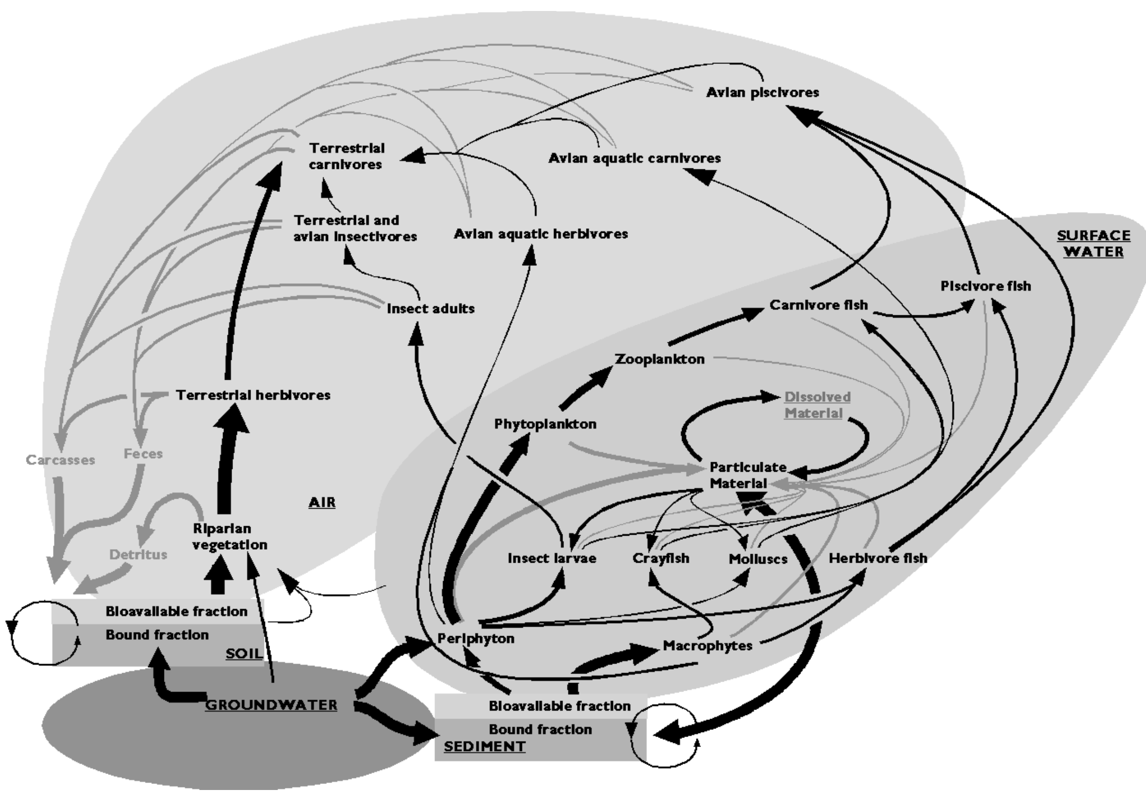
Shortcomings of this conceptual model, with regard to a comprehensive assessment of contaminant fate and transport, include the following:

- The model did not explicitly account for transport of contaminants from periphyton to phytoplankton.
- The model did not account for transport from live organisms to detritus via mortality and defecation.
- The model did not explicitly account for the spatial component of exposure and transport.

E.4.2 Conceptual Model Proposal for System Assessment Capability (Rev. 0)

E.4.2.1 Description. The conceptual model for of the SAC (Rev. 0) is based on a useful level of understanding of mass flows in the aquatic and riparian systems that are associated with groundwater contamination, and includes the necessary elements of the abiotic and biotic environment (living and once-living). It also accounts for materials reintroduced to the abiotic environment through defecation and mortality. Contaminant inputs from biota to the dissolved phase in water are not shown in the pictorial representation in Figure E-11, but are included as a general feature of all aquatic biota. Biomass input from the terrestrial into the aquatic system (termed allochthonous matter) is not accounted for in Rev. 0, but will be incorporated in later revisions of the SAC conceptual model.

Figure E-11. Proposed Conceptual Model for Biological Transport for SAC (Rev. 0).



The scope of the conceptual model includes all of the elements necessary to account for transport and reaction of COPC through biological media at a useful level of resolution. Further subdivision of the elements of the model could be performed, such as subdividing herbivorous, carnivorous, and piscivorous fish into the several components that make up these three groups. However, such a subdivision would not significantly increase the accuracy of the transport estimates obtained from the model (based on CRCIA Part I results), and would greatly increase the model's imprecision.

The proposed conceptual model explicitly includes a combined terrestrial and aquatic food web that is exposed to contaminants entering the system via groundwater, surface water, and air. In Rev. 0, the air pathway will not be implemented. Contaminants entering the system from groundwater will include bioavailable and nonbioavailable fractions. Within the water column itself, contaminants are viewed as being associated with two abiotic phases: sorbed to or incorporated in particulate material or as dissolved material. Contaminants move into the biological system through direct uptake from the abiotic media and through ingestion of food. Once in the biological components, contaminants may be concentrated as a function of differences between uptake and depuration, and may be physically transported under the active movement of the organism or as passive components of the abiotic fluid medium (air or water) in which they occur. Contaminants exit the biological system through depuration, defecation, and death (either of whole organisms or parts such as leaves).

The conceptual model for biological transport provides the basic elements necessary to estimate biological transport within and between arbitrary sections of the river. The spatial setting is limited to the Hanford Reach to the McNary Dam.

The conceptual model is not designed to address biological transport outside the Rev. 0 spatial area. For example, the model will not assess transport of COPC into the Yakima River as part of the body burden of fish (such as bass), nor will it address transport below the McNary Dam within salmon fry tissue. The model, however, could be used to estimate these transport elements if the appropriate fish mass transfer data were available. The conceptual model will not be useful for estimating concentrations in any specific individual or species. This will be done, instead, in the Risk Module.

This conceptual model integrates with the Fate and Transport and Groundwater-River Interface Elements in the following manner: the Groundwater-River Interface Element provides concentrations of contaminants in groundwater at all points along the river shoreline, where it becomes available to riparian plants. This element also provides concentrations in pore water where groundwater enters the river. The Fate and Transport Element provides concentrations in surface water and sediment within cells defined by coherent areas of bottom substrate (soft bottom or cobble), which then serve as additional sources of exposure for aquatic and terrestrial species. The Biota Transport Element will estimate mass fluxes for contaminants leaving these abiotic components and entering the biological system, and mass fluxes leaving the biological system and returning as particulate- or dissolved-phase material into the aquatic cells, where they will be used as inputs to the Fate and Transport Element.

E.4.2.2 Uncertainties.

Scale of Resolution (Temporal and Spatial): The organisms comprising the conceptual model cover a range of scales (both physically and temporally). The model must be able to address transport at a scale useful for determining mass flows and concentrations in the river system, which may not be at the scale of any single organism within the model. Instead, we will examine the model as a process model in which parameters reflect an average value for a useful segment of the river. This segmentation will be set by the river transport module for the purposes of Rev. 0. This issue is discussed further below.

Transient vs. Equilibrium Modeling: Transient modeling accounts for the temporal nature of exposure and the temporal variability in the factors influencing exposure and transport (e.g., water temperature). Equilibrium models are computationally simpler, and assume conditions have reached a steady state. In some cases, transient exposures and resulting tissue concentrations may exceed those found in steady state or equilibrium models (Newman 1995); however, an equilibrium model will perform adequately for the conditions to be evaluated under Rev. 0.

Biomass/Productivity of Biological Elements: A key information need for this conceptual model consists of biomasses and productivities of all the biological groups identified explicitly in the model. Some of these data exist for aquatic species in the Hanford Reach, based on studies conducted since 1948 (Becker 1990, Brandt et al. 1993, Weiss and Mitchell 1992). However, many of the productivity values for the aquatic species will require estimation. Few (if any) data are available for these parameters for terrestrial or riparian portions of the system. These also will be estimated for Rev. 0, probably on the basis of consultations with regional biologists.

Bioavailable vs. Nonbioavailable Dynamics: The conversion of chemicals (primarily heavy metals) from bioavailable to nonbioavailable states is an important issue for the model. However, data are limited that will allow predictive, mechanistic estimations of mass within these two states. Our approach will utilize calibration using regional data sets on water, sediment, and organismal concentrations of heavy metals to address this issue.

Production Rates and Sizes of Fecal Particles: Estimating the conversion of contaminants within the biota into non-biological compartments will require data on the fecal production rates by each of the groups of organisms in the model, and estimates of excretion rates by each group. Excretion rate data are available from the literature (DOE 1998), but fecal production rates may not be available. In that case, this term will be neglected.

Uptake/Depuration Behavior of Nutrients, Micronutrients, and Analogue COPC:
A number of elements that have toxicological consequences are essential to biological systems or are chemical analogues of essential elements (Table E-2). Most organisms are able to regulate the concentrations of macronutrients and micronutrients within their tissues (Chapman et al. 1996, Phillips and Rainbow 1989). Thus, the concentration of nutrients (such as calcium or iron) in the various environmental media to which an organism is exposed can greatly affect the uptake and retention of those elements and their analogues (Chapman et al. 1996).

Table E-2. A Classification of Elements According to Essentiality for Life (after Beeby 1991) Using the Period Table of the Elements.

Period	Macronutrient		Micronutrient					Nonessential	
3	Na	Mg							
4	K	Ca	Cr	Mn	Fe, Co, Ni	Cu	Zn		
5		Sr					Cd		
6	Cs							Hg	Pb

Two studies involving strontium-90 transfer using water and organisms from the Hanford Reach illustrate the importance of background concentrations and tissue regulation on net accumulation of strontium-90. The first study monitored tissue concentrations of strontium-90 in rainbow trout exposed to strontium-90 either in food or water or in both simultaneously (Schiffman 1959). Through the first 20 days of the study, the tissue concentration was found to be the sum of the water and food exposure pathways. However, by day 25, the food pathway dominated the transfer, indicating the fish were actively altering their uptake in response (probably) to calcium levels in their diet (Figure E-12). The second study compared strontium-90 uptake from water by a suite of aquatic organisms when the water source was directly from the once-through-cooling reactors, versus after it had been run through a vadose/groundwater system (Cushing et al. 1988). The water-to-organism transfer factors differed by 6 to 7 orders of magnitude (Figure E-13). Although not ascertained by this study, calcium differences in the two water sources are the probable source for much of the observed difference.

Figure E-12. Concentrations of Strontium-90 in Rainbow Trout Exposed to Strontium-90 in Food, Water, or Both Together.

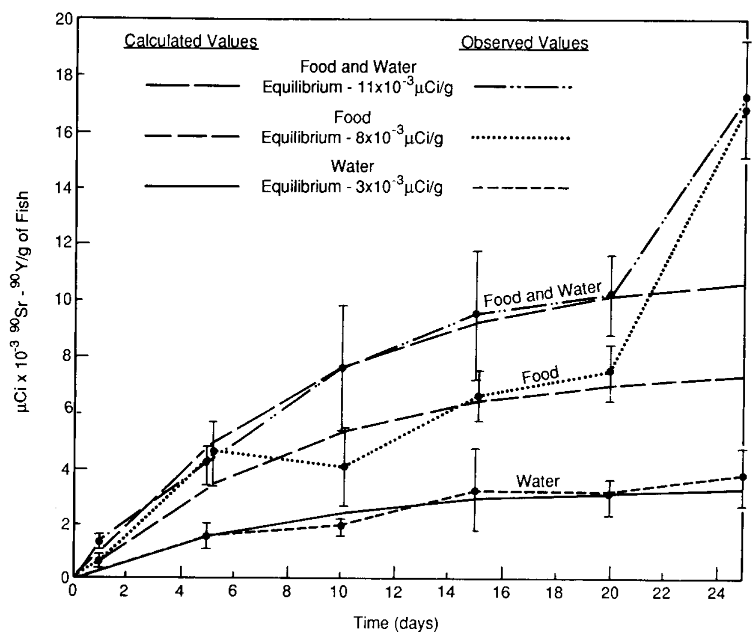
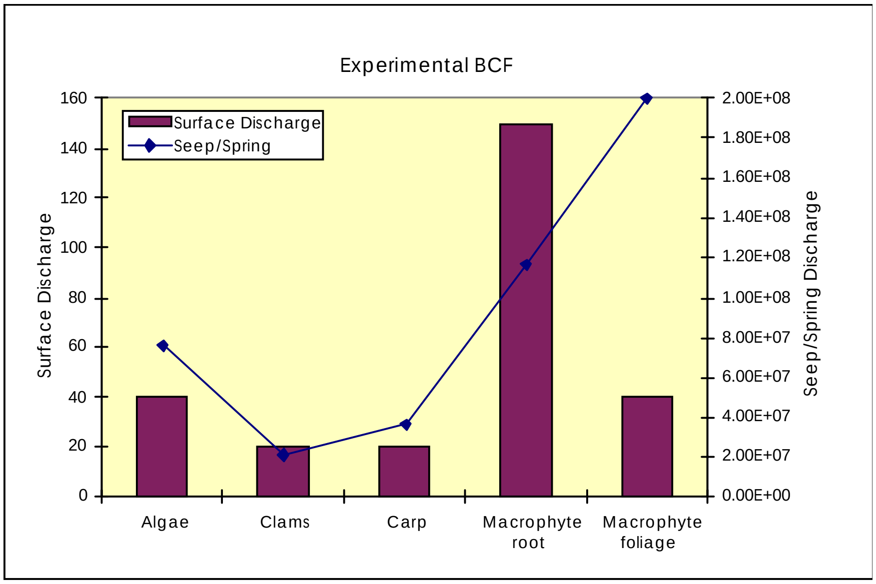


Figure E-13. Bioconcentration Factors (Tissue Concentration/Water Concentration) for Strontium-90 for Exposures Direct to Reactor Cooling Water vs. Water Passed Through a Vadose/Groundwater Matrix.



E.4.2.3 Assumptions/Technical Rationale. The primary assumptions guiding development of this conceptual model include the following:

- The conceptual model must account for the major movements of mass within the biological system. Influences on mass transfers within the biological system are a function of the relative exposure of each group of organisms, the relative biomass of each group, and the mass flux of each group into other ecological components (e.g., predation, parasitism), abiotic components (e.g., death, defecation), or physical locations within the region.

- The conceptual model must account for the major transfers of mass between the biological system and the abiotic system. These transfers include adsorption and uptake of dissolved-phase contaminants from river water by periphyton, phytoplankton, and macrophytes; extraction of dissolved-phase contaminants from sediments (pore water) by macrophytes and riparian vegetation; movement of material from sediments into the surface water through physical dislocation of periphyton; and movement of biotic material into sediment, particulate, and dissolved-phase contaminants through excretion/defecation, death, and decay. The latter flows are expected to be relatively minor in comparison to the remainder of the transfers.

- The conceptual model must account for biological transformations of contaminants. Organic contaminants and nutrients will be metabolized to some degree once these enter the biological system. Metabolism will change the toxicological properties of these contaminants, thereby altering their significance as COPC. Also, most inorganic contaminants will be altered to some degree once in the biota, which will change both their toxicological and biological transfer properties.

- The conceptual model will not account for the toxic effects of contaminants that would affect biotic transfer. Most toxic effects (i.e., narcosis, decreased growth and/or reproduction, and mortality) would reduce transfer rates. Accounting for these effects will greatly enhance the accuracy of a quantitative model, resulting in lower estimated movement within a given portion of the biota within a specific portion of the ecosystem, but would require more data than will be available for Rev. 0.

The model must account for the major sources of variation (i.e., dominant factors) in mass transfers involving biota. There has been a good deal of study on radionuclide movements within the Hanford Reach of the Columbia River, and elsewhere, that provides information bearing on dominance.

Within the biological component itself, the primary mechanisms of uptake are the following:

Periphyton: Adsorption of particulate matter from the water column and uptake of dissolved-phase contaminants from the water column (Cushing et al. 1975).

Macrophytes: Uptake of dissolved-phase contaminants from the sediment (Jackson 1998); uptake of dissolved-phase contaminants from the water column (Kelly and Pinder 1996); and adsorption of particulate matter from the water column (Thomas et al. 1974).

Phytoplankton: Uptake of dissolved-phase contaminants from the water column, and adsorption of particulate matter from the water column, although the primary source of phytoplankton in the Hanford Reach is periphyton that has been displaced by currents and changing water depth (Cushing and Rancitelli 1972).

Aquatic Insects: Gill uptake of dissolved-phase contaminants from the water column, and ingestion of particulate matter from the water column (Cushing 1979).

Mussels: Gill uptake of dissolved-phase contaminants from the water column, and ingestion of particulate matter from the water column (Cushing 1979).

Gastropods: Gill uptake of dissolved-phase contaminants from the water column, and ingestion of periphyton and macrophytes (Cushing 1979).

Crayfish: Gill uptake of dissolved-phase contaminants from the water column, and ingestion of particulate matter from the water column, macrophytes, and periphyton (Becker 1990, Cushing 1979).

Fish: Gill uptake of dissolved-phase contaminants from the water column, and ingestion of food (Schiffman 1959, Thomann et al. 1992). These pathways may differ in importance depending on the specific contaminant involved.

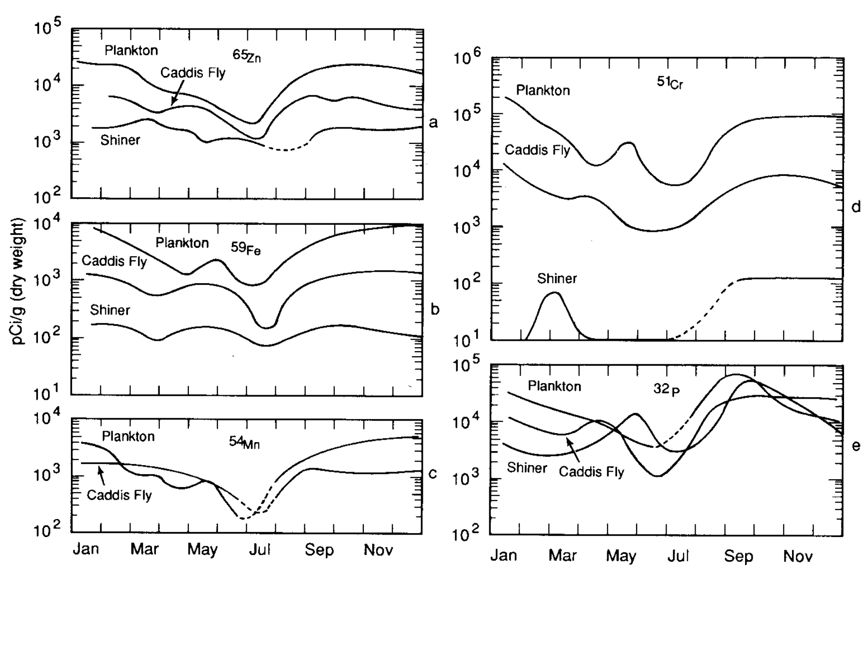
Terrestrial Vegetation: Uptake of bioavailable contaminants from groundwater and soil (Cline and Rickard 1972, Rickard and Price 1989), and adsorption of aerially-deposited soil on leaves and other above-ground parts (Djingova and Kuleff 1994).

Terrestrial Animals: Ingestion of food, water, and soils (Eberhardt et al. 1969), dermal uptake from water and soil, and inhalation of particulate and gas-phase contaminants in air (EPA 1993).

The primary pathways for transport of contaminants from the biota to the abiotic compartments include death and decay of living organisms, and defecation by animals, as well as depuration (excretion) of contaminants (Cushing 1979, Thomann et al. 1992).

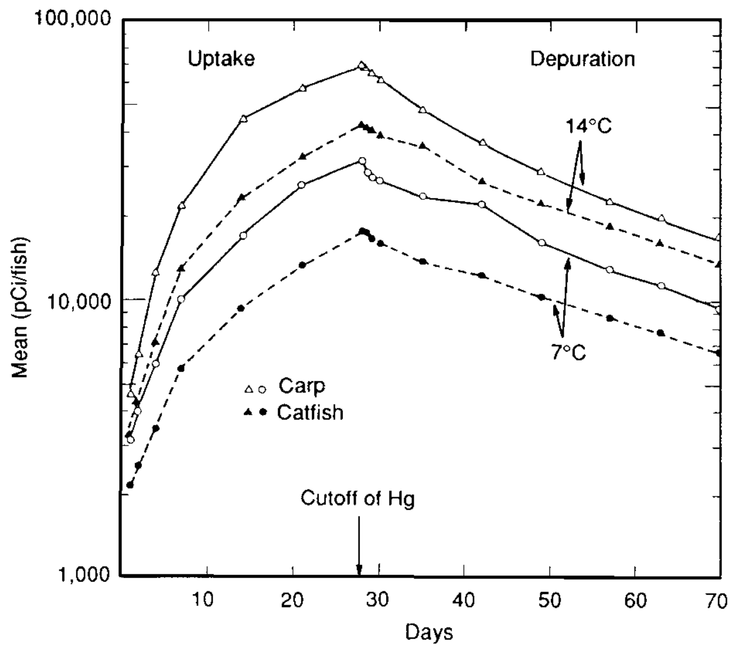
Features of the ecosystem that affect biological transport include season, temperature, and concentration of micronutrients within the system. A number of conditions vary seasonally within the Columbia River, including water temperature, water volume, flow rates, sediment loading, and ambient light levels. Light, sediment load, and water depth all affect the growth of periphyton and macrophytes, with the highest growth rates being in the spring and summer (Watson and Cushing 1969). However, the high river flows during this time lower the concentrations of Hanford-derived contaminants within the river, resulting in lower tissue concentrations of contaminants in all species (Figure E-14). The increased primary productivity, along with decreasing water flows in the late summer and fall, produce the highest tissue concentrations in all species through the winter months (Watson and Cushing 1969). The resulting seasonal variation encompasses approximately an order of magnitude.

Figure E-14. Seasonal Changes in Radionuclide Concentrations in Columbia River Biota During Operation of the Once-Through-Cooling Reactors.



Temperature changes also directly affect uptake and depuration rates of aquatic organisms, primarily because external temperatures control metabolic rates for the vast majority of species other than birds and mammals (Schmidt-Nielsen 1979). A 7°C change in water temperature may produce a 2-fold change in uptake and depuration rates (Figure E-15).

Figure E-15. Uptake and Depuration of Hg-203 by Juvenile Carp and Brown Bullhead Catfish at Two Temperatures.

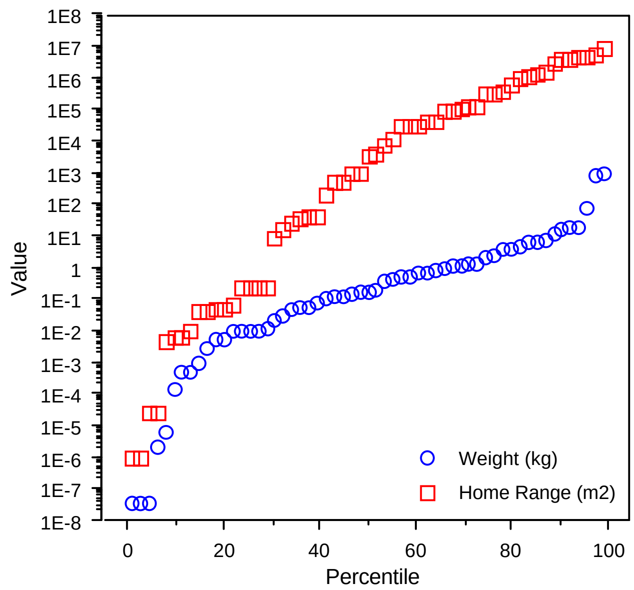


E.4.3 Outstanding Issues

One of the primary issues regarding this conceptual model concerns the range of temporal and physical scales that is inherent in the model itself. The organisms in the model cover 11 orders of magnitude in mass, and 13 orders of magnitude in area of use (Figure E-16). The average lifespan of the organisms ranges from days to decades, or 4 orders of magnitude. Defining a common scale, or at least a narrower range of scales, will be necessary in order to implement a numeric version of the conceptual model. Such refinement will also be required to define the necessary scale of resolution of the groundwater/vadose model, and the groundwater model that is its input.

An approach to simplifying the scale issues would be to dispense with the individual-centered view at the lower end of the spatial scale and focus (instead) on aggregate properties (such as biomass or productivity per unit area and mass). Organisms at this lower end include all the primary producers and planktonic species, as well as the benthic invertebrate fauna. This aggregating approach will suffice for the purposes of estimating mass transfers of contaminants, but may be more limited in certain risk assessment applications where the endpoint involves protection of individuals (e.g., protection of the Columbia pebble snail).

Figure E-16. Range of Body Weights and Use Areas by Organisms Used in the CRCIA Part 1 Screening Assessment.



Conversion of the conceptual model into a numeric model will require obtaining parameters on biomass, productivity, and uptake/depuration/metabolism rates for each group of organisms identified in the model, at a spatial scale that is relevant to the risk assessment. The availability of such data for the Hanford Reach is spotty, with the bulk of the data in the aquatic system rather than the riparian system.

E.4.4 Proposed Path Forward

The conceptual model must be converted into an equilibrium quantitative model that should incorporate stochastic input, or which may be operated in a stochastic mode. Parameters needed for the model will be collected from existing compilations (DOE 1998), Hanford Site research, and the open literature. Uncertain parameters will be estimated where possible using a consensus approach of regional biologists.

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