10. Risk/Impact Module

C.A. Brandt, A.L. Bunn, P.W. Eslinger, B.A. Napier, T.B. Miley,
L.A. Nieves, E.L. Prendergast, and M.J. Scott

Contaminants in the environment may adversely affect human health, economic and cultural values, and other biological systems when two conditions are met: the key components of a system are exposed to the contaminant, and the exposure exceeds a threshold above which effects are probable. Impact is defined as an adverse change in the system being examined. The transport modules of SAC provide estimates of contaminant concentrations from Hanford Site sources in a time-dependent manner in the vadose zone, groundwater, and the Columbia River and its associated sediments (Figure 10.1). The Risk/Impact Module uses these estimates of media- and time-specific concentrations to estimate potential impacts on the ecology of the Columbia River corridor, the health of persons who might live in or use the corridor or the upland Hanford environment, the local economy, and the cultural resources. Each of these specific areas is discussed below.

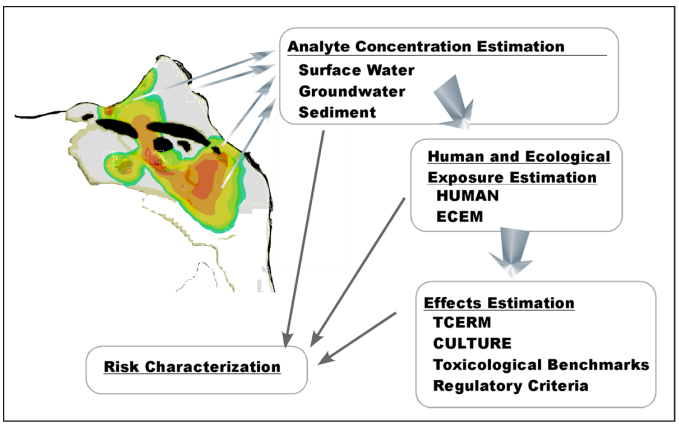

Figure 10.1. *Generalized conceptual model for predicting risk/impact in the initial assessment.*

The results shown in this chapter should not be interpreted as definitive predictions of total radiation doses or other impacts. They are representative results based on the inventory, release, and transport model outputs. Definitive predictions must rely on further studies to confirm that additional contaminants do not contribute appreciably to the impacts. In addition, the inventory issues described in Chapter 4 must be addressed before definitive predictions can be performed.

The results from the Risk/Impact Module should not be interpreted as definitive predictions of total radiation dose or other impacts.

Ecological Component

The ecological assessment focuses on the locations where plants and animals can be exposed to contaminants that are transported by groundwater from upland sources to the Columbia River, specifically in the river and near-shore environment (riparian zone). The assessment uses predictions of radionuclide and chemical contaminant concentrations in pore water, surface water, sediment in the river and groundwater, seep water, and soil in

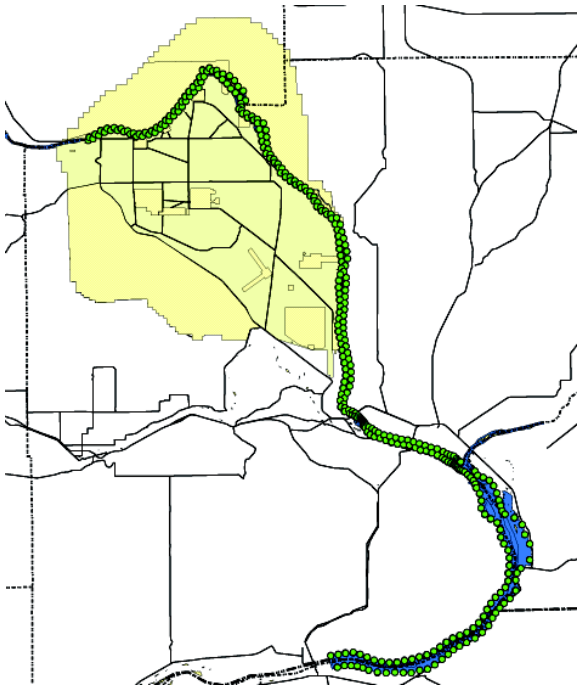

Figure 10.2. *Locations where risk/impact to biota were estimated for the initial assessment.*

the riparian zone. Radiological doses and ecological hazard quotients are estimated for 57 species representing the biota of the Columbia River and its riparian zone.

Organisms in the river and riparian zone that live some portion of their lives where the groundwater enters the river, and organisms that consume them, are most likely to be impacted. For the initial assessment, impacts to larval mayfly and juvenile salmon are discussed. Mayflies are invertebrates that spend most their life in the river bottom before emerging as a flying adult. Salmon eat both the larval and adult Mayflies. Juvenile salmon are common to the study area and spend much of their time near the bottom of the river. "Juvenile" is the stage from the time the salmon has emerged from the gravel and started eating to when it begins moving downstream toward the ocean.

Risk/impact is estimated at 674 paired locations (riparian and river) on the Columbia River from the Vernita Bridge to McNary Dam (Figure 10.2). The riparian zone extends approximately 5 meters (16.4 feet) onto land from the outermost river location, and the river location extends approximately 2 meters (6.6 feet) into the river. Although impacts are estimated for both shorelines, this discussion focuses only on locations on the Benton County side of the river.

Results

The maximum combined radiation doses (including background) for the larval mayfly in the Columbia River occur in 1990 and 2000 (Figure 10.3). All peak doses from river miles 385 (Vernita) to 342 (Richland pumphouse) are due to contributions from Hanford groundwater; background levels are much lower. The dose from river miles 385 to 367 is from the contaminated groundwater in the 100 Areas, where the primary contributors are tritium and strontium-90. The dose around river mile 362 is from the contaminated groundwater from the 200 Areas moving toward the Hanford townsite, where the primary contributor is tritium. The dose around river miles 345 to 342 is from contaminated groundwater in the 300 Area, where the primary contributor is uranium-238. Over time, the dose in this stretch of the river decreases and is no longer a significant contributor to total dose by the year 2100.

Throughout the Columbia River, the radiation dose to the mayfly diminishes to background levels with time due to flushing of near-shore contaminated groundwater into the river and radionuclide decay, especially for that of tritium and strontium-90. However, doses begin to increase again starting around the year 2200 in river miles 383 to 375 due to contributions from uranium-238. The dose peaks in the year 2600 at about 0.001 rad/day.

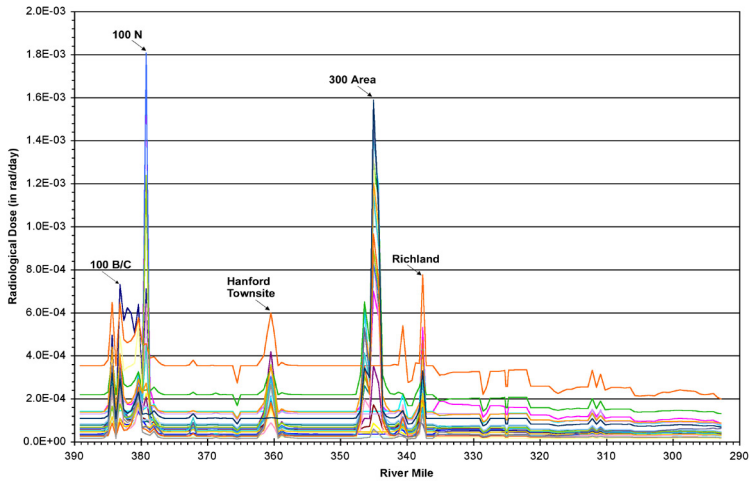

Figure 10.3. *Combined radiological dose to larval mayfly for the year 2000 along the length of the Columbia River. Each realization is represented by a different color.*

Figure 10.4 shows the range from 25 stochastic realizations of the combined radiological dose to a juvenile salmon in the year 2000 within the study region. The contributors to dose are the same as those for Mayflies. However, the maximum dose to the juvenile salmon is more than an order of magnitude less than the maximum dose to the larval mayfly due to the different lifestyle of the two species. For the purpose of illustration only, these results may be compared to the DOE benchmark of 1 rad/day as protective of populations of all ecological species.

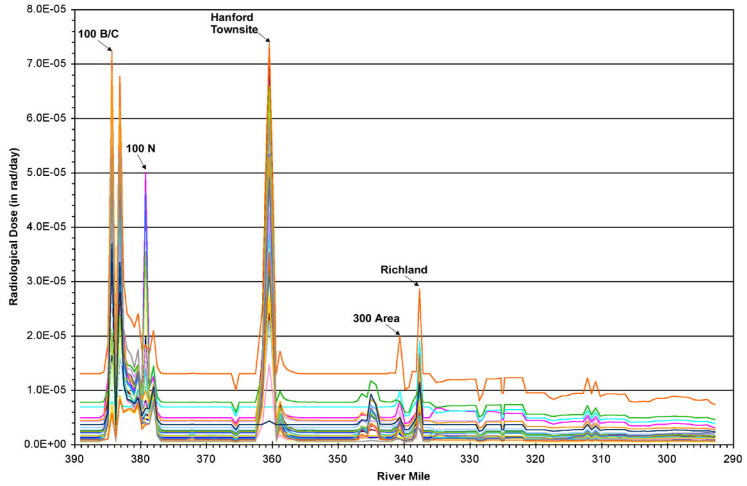

Figure 10.4. *Combined radiological dose to juvenile salmon for the year 2000 along the length of the Columbia River. Each realization is represented by a different color.*

Risk/impact from chromium (expressed as a hazard quotient) to the larval mayfly and juvenile salmon in the year 2000 are shown in Figure 10.5. These impacts include contributions from a constant background level in the Columbia River and from groundwater entering from Hanford. The effects from contaminated groundwater in the 100 Areas begin at river mile 387 and continue through river mile 365. The order of magnitude difference between the results of the mayfly and the juvenile salmon is related to the difference in exposure of the two species. Over the 1,000-year assessment period, the impacts due to chromium decrease in the upper portion of the river and increase slightly farther downstream. For the mayfly, the hazard quotient exceeds 1 in some portions of the region in 2000, but all realizations are below 1 by 2080.

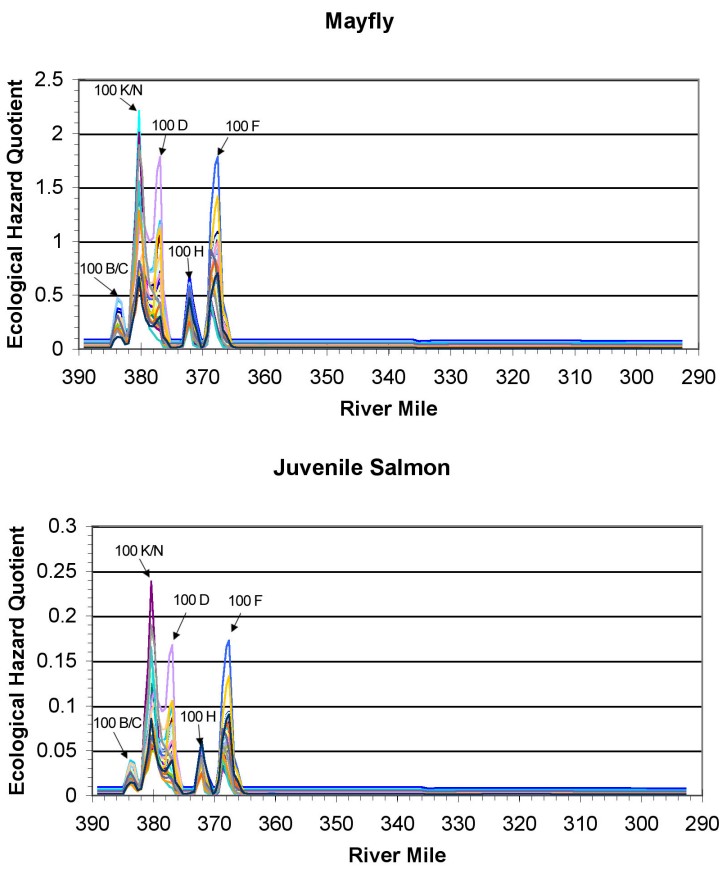

Figure 10.5. *Ecological hazard quotient to mayfly (top) and juvenile salmon (bottom) for the year 2000 along the length of the Columbia River. Each realization is represented by a different color.*

The hazard quotient is based on the lowest observable adverse effects level. For chromium, the lowest observable adverse effects level is the U.S. Environmental Protection Agency's Ambient Water Quality Criterion of 11 micrograms per liter. An ecological hazard quotient exceeding 1 indicates that an impact is possible, and further investigation may be warranted. The chromium concentrations exceed the level of concern for the larval mayfly in about half of the 25 realizations. The order of magnitude difference between the results of the mayfly and the juvenile salmon are consistent with the difference in the two species exposure to pore water.

Conceptual Model

The conceptual model for assessing ecological risk/impact for the initial assessment has two parts: quantifying exposure to contaminants and translating exposure into effect. Organisms in the Columbia River environment may be exposed to contaminants in surface water, sediment, or pore water (Figure 10.6). Estimates of contaminant concentrations in these media are generated by other components of the initial assessment model. Organisms include plants, herbivores, and carnivores or omnivores (consumers of both flesh and plant material) in terrestrial and aquatic environments. An organism's exposure to contaminated food, sediment, surface water, or pore water is a function of its way of life.

Exposures for all animals are estimated at each of the paired aquatic and riparian locations represented in the model; all the species in the model are assumed to occur at each paired location. This allows a complete estimation of risk from contaminant exposure for all species, even though some species may in reality avoid contaminated areas. The model assumes equilibrium conditions (exposures are estimated based on the assumption

that the organism spends enough time in a given location that the concentration of contaminants in its tissue is in equilibrium with the environment; there is no net gain or loss of contaminant from the organism). This estimate of tissue concentration is compared to toxicological benchmarks (in the case of aquatic species) to obtain a chemical hazard quotient. For radiological doses, the values reflect total dose from all pathways: external and internal.

Implementation Model

The ecological code, ECEM, uses the environmental concentrations produced by the transport codes as the basis for estimating the exposure to ecological species. The species included in the initial assessment are identified in Table 10.1. One criterion for inclusion was that enough species were included to represent all levels in the food web. Other species were included because they were of interest to Native American tribes (DOE/RL 1998b)

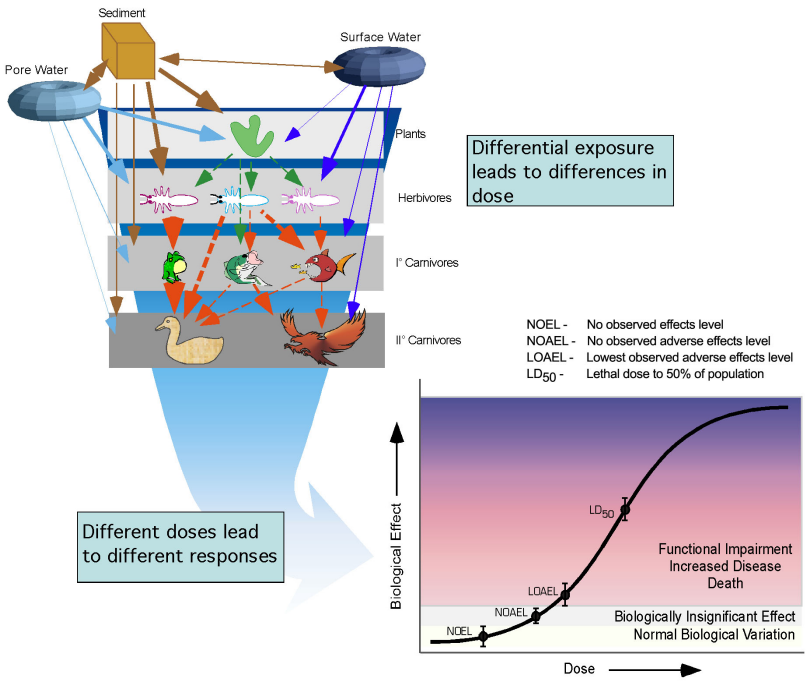

Figure 10.6. *General conceptual model for biological exposure and effects in the Columbia River system. Arrows show contaminant movement between compartments in the exposure model.*

The ecological code provides the framework to estimate impacts from contaminants as they move through the food chain. The uptake and exposure equations are documented in Eslinger et al. (2002a and b). The model allows estimation of effects from radioactive or nonradioactive contaminants, each of which can be inorganic, or organic in nature. In essence, ECEM implements 16 submodels – one for each combination of species type shown in Table 10.1 and class of contaminant. All of the models were developed using equilibrium concepts, thus only chronic exposures can be evaluated. The model is based on the assumption that the entire food web continues to function, even in the presence of deadly concentrations of contaminants. No concentrations in the initial assessment were high enough to initiate breakdown of the food web.

Hazard quotient is the ratio of an organism's estimated exposure to contaminants to the level of contaminant that produces adverse effects on similar organisms in experimental tests.

Table 10.1. Species used in the initial assessment.

Aquatic Animals	Riparian Animals	Aquatic Plants	Riparian Plants
Carp	American coot	Periphyton	Black cottonwood
Channel catfish	American kestrel	Phytoplankton	Columbia yellowcress
Clams	American white pelican	Water milfoil	Dense sedge
Columbia pebblesnail	Beaver		Fern
Crayfish	Bald eagle		Fungi
Daphnia magna	Bufflehead		Mulberry
Hyallela	Canada goose		Reed canarygrass
Largescale/Mountain sucker	Cliff swallow		Rushes
Mayfly	Common snipe		Tule
Mountain whitefish	Coyote		
Mussels	California quail		
Pacific lamprey (juvenile)	Forster's tern		
Rainbow trout (adults)	Great blue heron		
Rainbow trout (eggs)	Harvest mouse		
Rainbow trout (juvenile)	Lizards		
Salmon (adults)	Mallard		
Salmon (eggs)	Mule deer		
Salmon (juvenile)	Muskrat		
Smallmouth bass	Northern harrier		
Woodhouse's toad (tadpole)	Racoon		
White sturgeon	Terrestrial arthropods		
	Western aquatic garter snake		
	Weasel		
	Woodhouse's toad (adult)		

The implementation currently focuses on the riparian zone, and assumes that all species spend their entire lifetime in the small region defined by a single modeling location. Changes recommended for the future include adding home-range concepts for mobile species, and updating the species list to represent upland terrestrial species. The addition of an irrigation model is recommended to allow estimation of effects for species that frequent irrigated fields. This change would support a direct linkage between the ecological code and the human exposure code whereby the ecological code would provide food crop concentrations for use in human exposure calculations.

Human Health Component

The human health assessment uses the time-dependent predictions of radionuclide and chemical contaminant concentrations at locations throughout the study area to estimate radiation dose and risk, a chemical hazard index, and carcinogenic chemical risk. Estimates of risk are functions of human lifestyles, which are defined as exposure scenarios. For the initial assessment, the following exposure scenarios were evaluated: a hypothetical farmer who lives on the current Hanford Site and raises and eats food using groundwater for irrigation, a Native American who has a historically defined subsistence way of life along the banks of the Columbia River, and individuals who consume drinking water from the city water treatment plant. Farming is not anticipated on the Hanford Site in the foreseeable future; however, this scenario was used to provide a consistent measure for examining the cumulative impact from all contaminants included in the assessment.

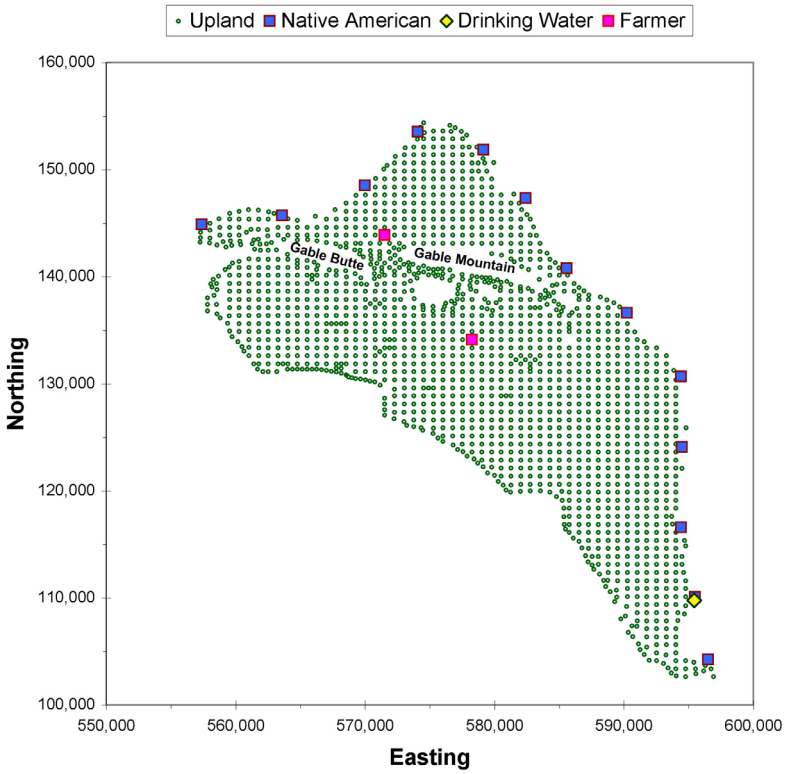

Figure 10.7. *Locations for which human exposures to radionuclides and chemicals may be estimated in the initial assessment. Locations discussed in the text are highlighted.*

Figure 10.7 shows the geographical locations for which the initial assessment estimated radiation doses and hazardous chemical exposures to people. Additional locations along the river at regular intervals from Richland to McNary Dam are included in the model although not shown in the figure.

Figure 10.7 also shows the specific locations for which representative results are provided in this section. Three types of representative calculations were performed:

- Estimation of potential lifetime radiation dose to an individual living a traditional Native American subsistence way of life at specific locations along the banks of the Columbia River who

Exposure Scenarios *– People may be exposed to contaminants in the environment through many different routes. For each route the time, frequency, and amount of exposure per event may vary by person and depends on an individual's way of life. Coherent parameters that describe the total exposure for a particular type of individual is called an "exposure scenario."*

consumes a diet of fish from the river and foods grown in the riparian zone (blue squares in Figure 10.7).

- Estimation of the risk of cancer from chemical contamination to a member of the general population of the city of Richland who consumes drinking water taken from the Columbia River and treated at the city water treatment plant (yellow diamond in Figure 10.7).

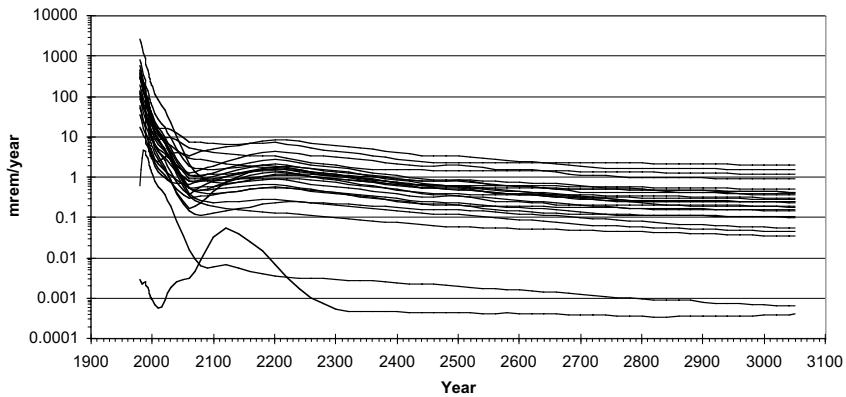

Figure 10.8. *Time series of estimated annual doses to individuals using irrigation water at the Central Plateau boundary to support a small farm east of the Hanford 200 Areas.*

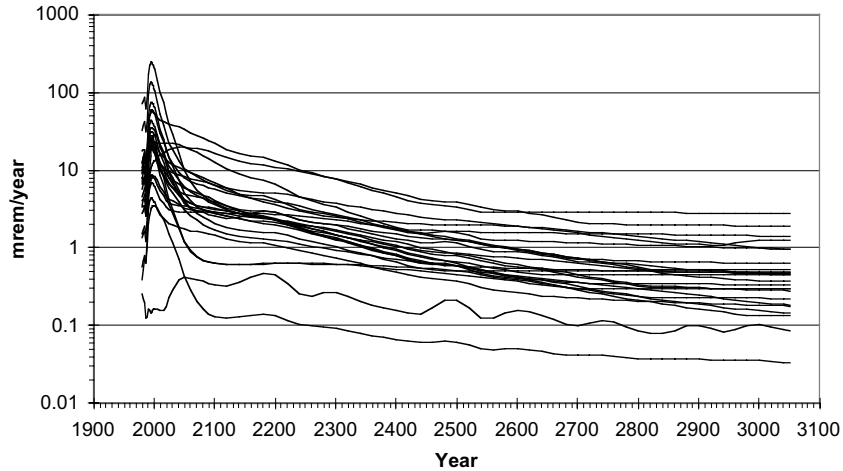

Figure 10.9. *Time series of estimated annual doses to individuals using irrigation water to support a small farm north of the Hanford 200 Areas near the gap between Gable Mountain and Gable Butte.*

- Estimation of potential annual radiation dose to an individual who uses groundwater to irrigate a small farm and consumes a diet of drinking water, food crops, and animal products from that farm (red squares in Figure 10.7). Locations discussed here are the approximate edge of the waste management buffer zone east of the 200 East Area, and a point to the north of the 200 Areas, where some contaminants from the 200 Areas are projected to be transported between Gable Mountain and Gable Butte.

Results

The range from the 25 stochastic realizations of projected annual doses to an individual in the location east of the 200 East Area is shown in Figure 10.8. Twenty-four of the 25 realizations have the same general pattern and vary only in total magnitude. (One realization, for which the release rate of tritium to the groundwater was very low, has a much lower initial dose.) In these realizations, dose calculations begin in 1980, and in many cases the peak dose occurs about the year 1980 from past releases of tritium to the groundwater. The magnitude of the dose is compat-

ible with estimates that may be made using existing monitoring data. The rapid decrease of the annual doses to about the year 2050 is directly related to the radioactive decay of the existing tritium plume. After about 2050, the primary contributor to dose is technetium-99.

Similar results are shown in Figure 10.9 for the location north of the gap between Gable Mountain and Gable Butte. The early peak, projected to occur near the year 2000, rapidly reduces as the tritium decays. The longer-term plateau between 0.1 and 10 millirem per year primarily results from the modeled technetium-99 concentrations. The shift in plume motion into this northern area from the historically monitored plume to the east (illustrated in Figure 10.8) is caused by the declining water table beneath the 200 Areas since the major Hanford Site wastewater disposal operations ceased.

The Native American Subsistence Lifestyle scenario was applied at a series of locations along the Hanford Reach and downriver to McNary Dam. Although this series was continued to McNary Dam, the highest exposures were consistently found within the current Hanford Site boundaries. Consequently, only the latter are shown here. The maximum (during the 1,000-year simulation period) lifetime Hanford radiation dose (calculated as the total dose minus the background dose) to individuals at each of these locations are shown in Figure 10.10. The three main areas of potential future concern are along the river near the old production reactors at about river mile 380, in the vicinity of the old Hanford townsite around river mile 359, and at the 300 Area near river mile 345. The doses result primarily from contaminated groundwater entering the Columbia River at these locations. The doses in the 100 Areas are the result of contamination in those areas; doses near the Hanford townsite originate primarily from the 200 Areas, and the discharges near the 300 Area are dominated by contributions from that location.

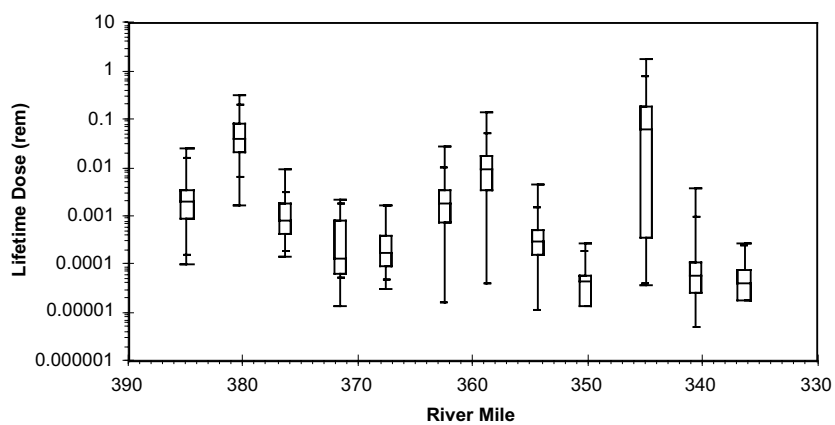

Figure 10.10. *Estimated lifetime (70-year) doses above background to individuals living a Native American subsistence lifestyle along the Columbia River in 2000.*

The largest projected lifetime dose is to individuals living along the river near the 300 Area. The time sequences estimated for the Hanford

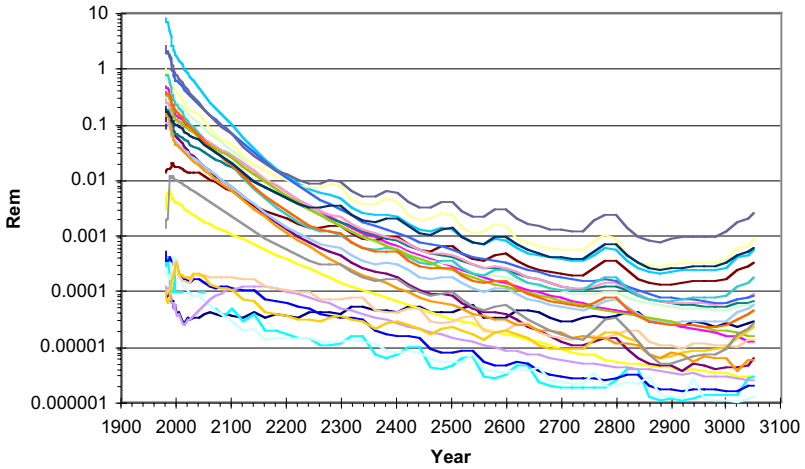

Figure 10.11. *Time series of estimated lifetime doses above background to individuals living a Native American subsistence lifestyle near the Hanford 300 Area (river mile 345).*

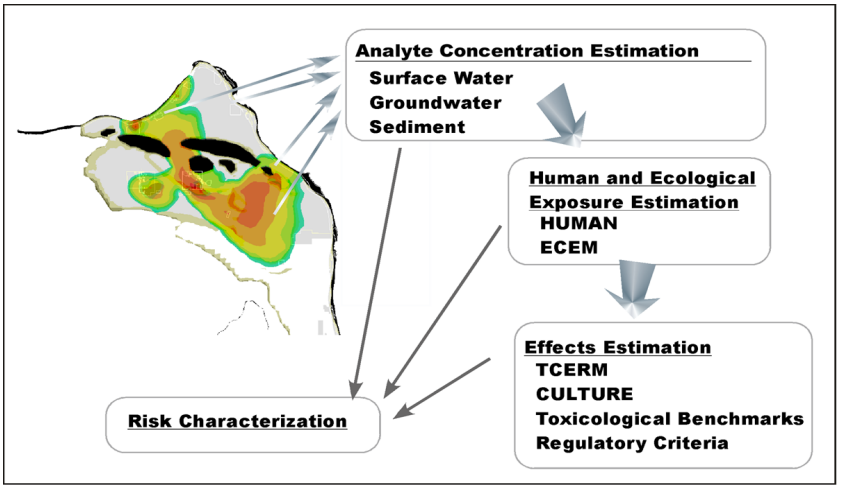

Figure 10.12. *Conceptual human health model for the initial assessment. Abiotic media concentrations from the initial assessment are in blue; those derived within the HUMAN code are in yellow.*

contribution at that location are shown in Figure 10.11. Dose estimates at any time range over several orders of magnitude due to uncertainties in the groundwater (and consequently, in near-river spring water concentrations), and uncertainties in the behavior of individuals at this location. The general trend, with time, for all of the 25 realizations is downward due to decreasing concentrations of uranium isotopes in groundwater that resulted from past disposal operations.

Conceptual Model

The SAC was developed to provide a comprehensive tool to examine all Hanford releases in the context of all other releases, with realistic transport mechanisms in all environmental media and a full suite of impact assessment modules. The human health risk assessment module used for the initial assessment is an upgrade of the HUMAN code as implemented in the Columbia River Comprehensive Impact Assessment (DOE/RL 1998a) and is documented in Eslinger et al. (2002b) Volume 2. The conceptual human health impact model (Figure 10.12) includes exposure pathways of ingestion, inhalation, dermal/contact, and direct radiation exposure from all abiotic and biotic media. Relative exposures to these sources depend on individual lifestyles or exposure scenarios. Exposure scenarios include those of a resident farmer using groundwater from upland areas or river sources, several Native American lifestyles, river recreational users, and Richland residents.

The human risk model is a screening-level chronic exposure model. It is intended for use in situations where the environmental contamination conditions are static or only slowly varying. These conditions are met with the contaminant sources the initial assessment evaluated, which are slowly released to the accessible environment and primarily transported via groundwater. The models are not appropriate for estimating risks from short-term accidental releases.

Implementation/Numerical Model

The HUMAN code addresses pathways related to long-term contamination of surface water and groundwater, with the associated contaminated media of seeps, springs, and sediments. With these as starting points, the code estimates the contaminant concentrations in surface soil from irrigation, air from resuspension and volatilization, aquatic foods, terrestrial crops, and animal products (both domestic and wild). Exposure pathways explicitly modeled include external irradiation, dermal contact, inhalation, and ingestion. Special models are included for unique Native American exposure situations. The code deals with first-order decay of radionuclides, but not with degradation processes for chemicals.

A risk conversion factor converts ingestion or inhalation of a contaminant into the probability of contracting cancer from the exposure.

The HUMAN code provides flexibility in combining the various pathways into exposure scenarios. Scenarios are defined by representative sets of input parameters to simulate annual average or lifetime average exposure conditions. The scenarios focus on individual exposures. Individuals are assumed to spend specified amounts of time at the location of analysis; the scenarios do not support individuals moving throughout the analysis domain. Population risks are addressed only for the pathway of consuming drinking water from the Columbia River.

The initial assessment models consider impacts from contaminant movement through the groundwater and river pathway only. Atmospheric transport pathways were not included. The HUMAN model, as currently constituted, could easily be modified to accommodate this transport pathway. Additionally, the original modeling design was intended to use similar transfer factors in both the ecological modeling (the ECEM code) and the human modeling (the HUMAN code). This has not yet occurred. The environmental transfer factors (e.g., soil-to-plant, plant-to-animal-product, water-to-fish) used in the human assessment have been taken from recent literature. It would be more appropriate for these factors to be coordinated with, or derived from, the ECEM model. The recommendation is made to implement the capability to obtain concentrations in human food products from the ECEM code.

Cultural Component

The initial assessment examined cultural impacts caused by groundwater contamination. Federal drinking water standards were chosen as impact thresholds in the absence of resource- and culture-specific thresholds. In lieu of spatial data on culturally sensitive entities on the Hanford Site, the present analysis assumes all of Hanford is equally important culturally.

Results

The Hanford Site covers 1,517 square kilometers (586 square miles). The maximum predicted area where groundwater concentrations exceed the federal drinking water standards among the 25 realizations is ~275 square kilometers (106 square miles), or 19% of the Hanford Site (Figure 10.13). This is modeled to occur in the year 2000. Between 2000 and 2040, the area drops significantly to 20 square kilometers (8 square miles). After 2040, most realizations show virtually no impact.

Contributions to impacts by contaminant are shown for a representative simulation (#19) in Figure 10.14. Tritium is the primary source of the total spatial impact between 2000 and 2060. As expected, with a half-life of 12.3 years, tritium impacts disappear by 2100. After 2100, iodine-129 is the primary contributor to sitewide impact. Other contributors include carbon tetrachloride, chromium, strontium-90, technetium-99, and uranium-238. Cesium concentrations are not predicted to exceed the drinking water standard at any time.

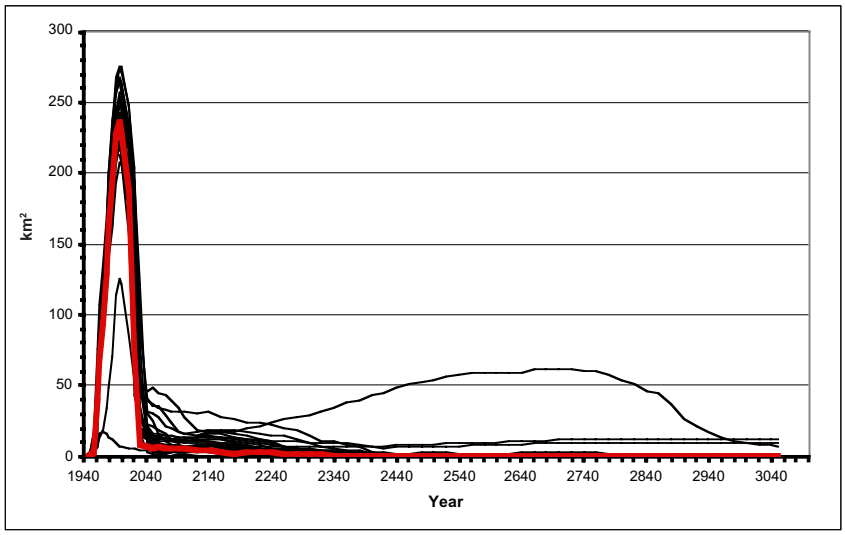

Figure 10.13. *Area of the Hanford Site where at least one contaminant in groundwater exceeded drinking water standards. Data are from 25 stochastic realizations; the median case is shown in Red.*

Contributions to impacts by contaminant for another realization (number 5) are shown in Figure 10.15. The increase in affected area in realization #5 is due to iodine-129, which exceeds the drinking water standard after year 2000 through the end of the simulation, with a maximum affected area of 62 square kilometers (24 square miles). The

source of this modeled plume is the State-Approved Land Disposal Site facility.

To demonstrate how the initial assessment could be interpreted for cultural impacts, the following analysis focuses on the Hanford Reach as a culturally sensitive area. The green and red shaded areas in Figure 10.16 depict all locations where the drinking water standard is exceeded by any contaminant for at least one realization during any year. Red shows where this area also occurs within the Hanford Reach National Monument boundary.

Between 1965 and 2010, effects within the Hanford Reach National Monument Boundary are largely due to tritium and chromium. The maximum plume size is 19.33 square kilometers (7.45 square miles). By 2040, the predicted maximum affected area drops to 3.02 square kilometers (1.16 square miles). After 2040, the predicted maximum area stays relatively stable, but iodine-129 and uranium-238 are major contributors. There are no predicted impacts from carbon tetrachloride, technetium-99, cesium-137 and plutonium-239/240 within the Hanford Reach National Monument for this impact metric.

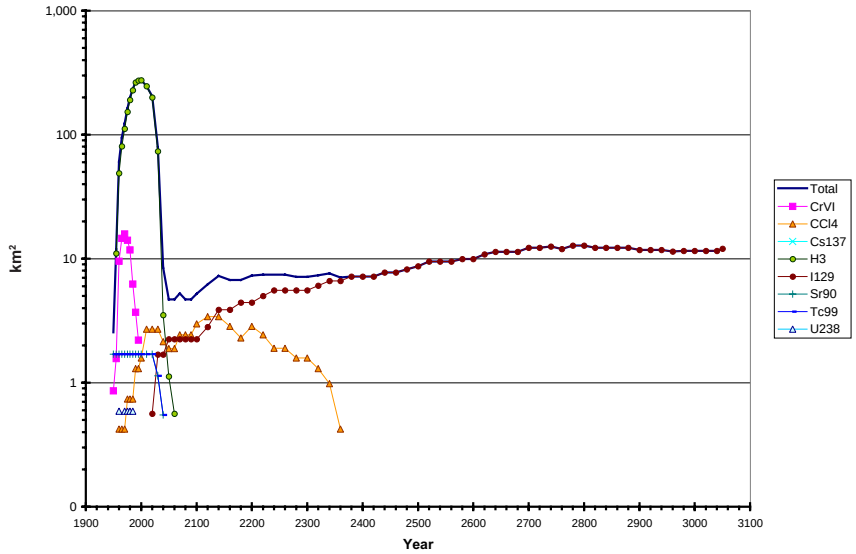

Figure 10.14. *Area of the Hanford Site where contaminants in groundwater exceed drinking water standards, realization 19.*

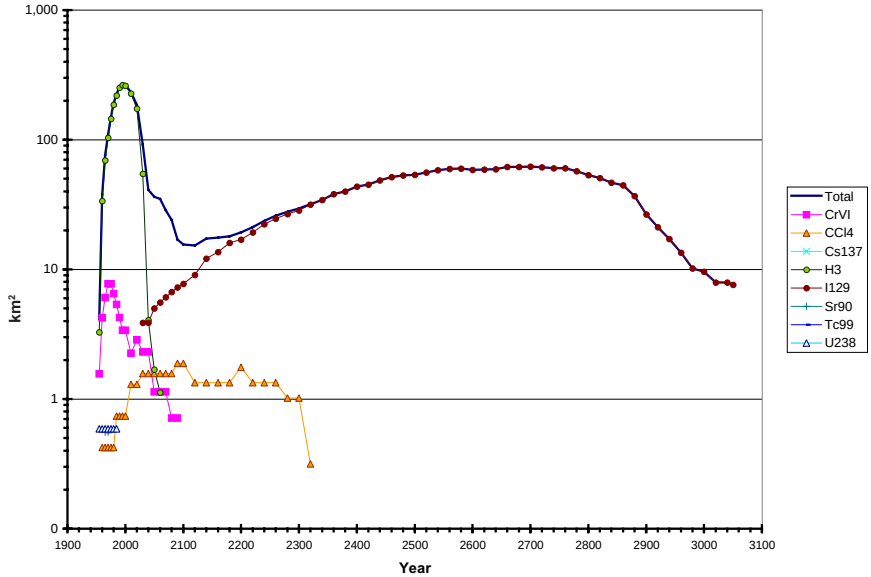

Figure 10.15. *Area of the Hanford Site where contaminants in groundwater exceed drinking water standards, realization 5.*

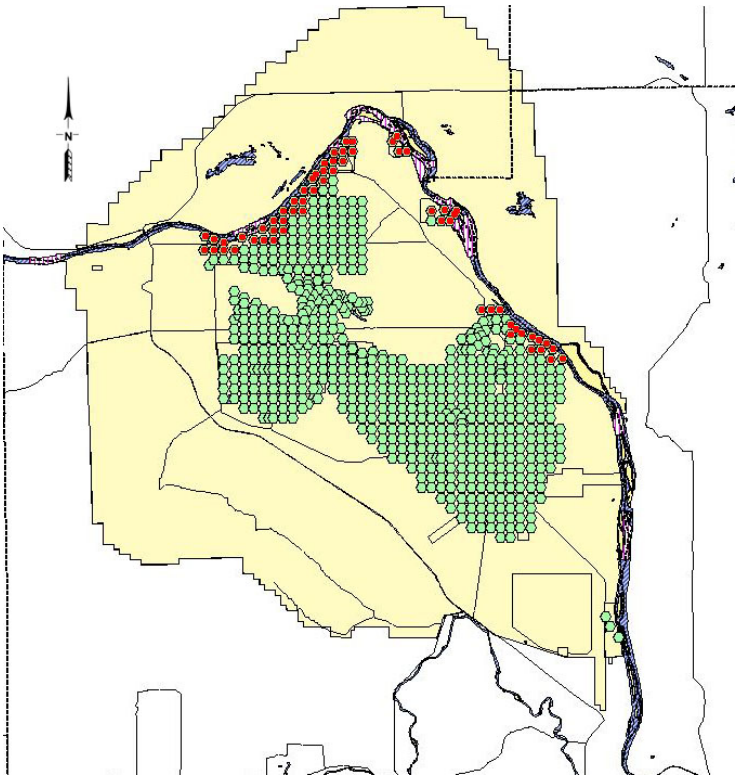

Figure 10.16. Areas where any contaminant exceeded drinking water standards at any time during the analysis in at least 1 of 25 stochastic simulations (colored dots). Red dots show where these occur within the Hanford Reach National Monument.

Conceptual/Implementation Model

The cultural model (CULTURE) addresses risk/impact on the social and cultural resources of cultural groups affiliated with Hanford (referred to as affected populations and defined as people who live, work, or use the area that is in proximity to the Hanford Site). Hanford's affected populations may interact with the environment in culturally specific ways and have specific concerns about distinct socio-cultural entities that would not be identified within the framework of traditional risk assessment. The objective of cultural impact assessment is to determine whether the social and cultural systems of affected populations are affected by the presence of contamination. This is distinct from monetary or health-related impacts, which are addressed by the other components of the Risk/Impact Module.

Cultural impacts result when the presence of contamination reduces the perceived cultural value, function, or use of the entity for the affected cultural group. Cultural impacts can arise directly from the presence of contamination in abiotic media, or indirectly through ecological or human health-related effects (Figure 10.17). For the model's operation, information about the concentrations of contaminants in various environmental media are inputs to the CULTURE model. If contaminant concentrations exceed the cultural threshold, then a variety of consequences could result.

The CULTURE model does not predict how cultures will respond to concentrations in excess of a cultural threshold, but it does provide the input to such an analysis. The threshold for impact in the initial assessment is federal drinking water standards; obtaining different thresholds from cultural groups would alter the specifics regarding affected areas. Using one cultural threshold for all areas also assumes that the entire Hanford Site is equally important culturally. A refined spatial definition of culturally significant entities, and the relevant contaminant thresholds for those entities, allows this model to provide a more accurate depiction of cultural impacts.

The results of the CULTURE model, for areas above drinking water standards, matches well with observational data. According to the 2000 groundwater monitoring report (Hartman et al. 2002), the median groundwater results for tritium are within 5% of that observed in 2000 (246 square kilometers [95 square miles] predicted versus 233 square kilometers [90 square miles] observed). Iodine-129 concentrations are not consistent with observed data, largely because the groundwater model does not include source inputs from the PUREX or REDOX facilities.

Within the CULTURE code, there are no stochastic variables. Therefore, 100% of the variability in the CULTURE output is due to the variability in the other modules that are treated stochastically.

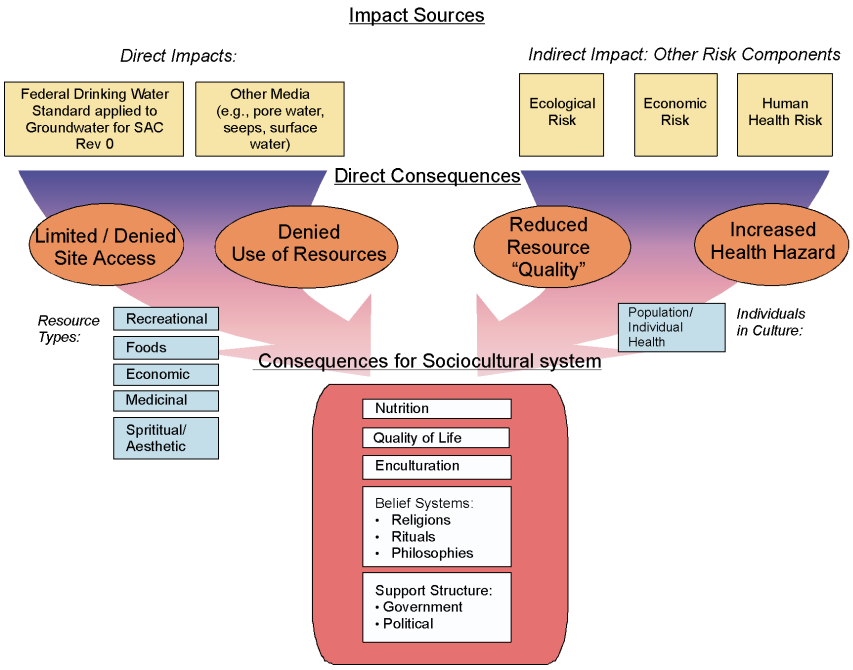

Figure 10.17. *The conceptual cultural risk model. The initial assessment implements only the groundwater portion.*

Economic Component

Concentrations of contaminants in the environment can affect the local economy in several ways. Concentrations above certain levels may trigger actions by the authorities to protect public health such as closing access to the river for some forms of recreation and/or limiting water use for drinking or irrigation. Even without such restrictions, people might avoid water-based recreation on the Columbia River or avoid agricultural commodities that might have been produced with contaminated water. Figure 10.18 shows the locations where concentrations of contaminants in water or fish from the Columbia River were used to estimate economic impacts.

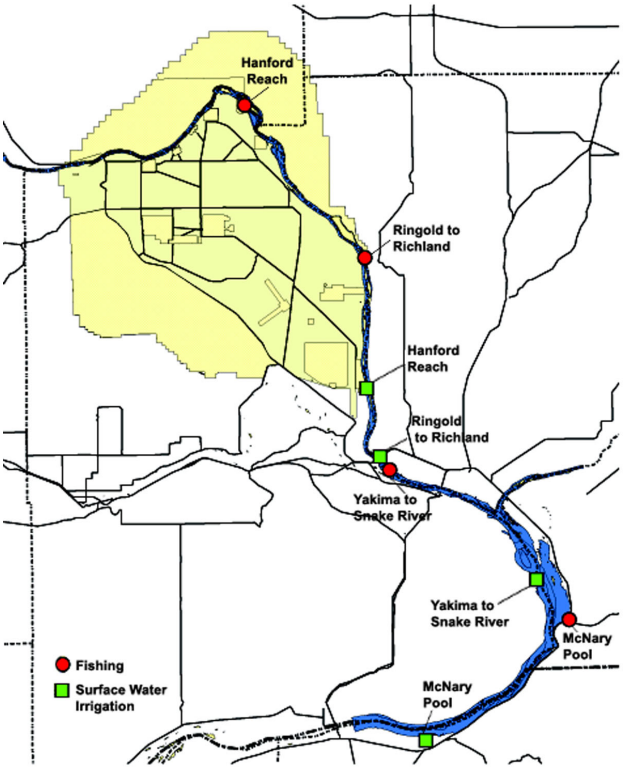

Figure 10.18. *Locations where water (green squares) or fish tissue (red circles) concentrations of contaminants were used as input to the TCERM economic impacts module.*

Results

Figure 10.19 shows the estimated impact on employment in the Tri-Cities as a percentage of jobs lost in the regional economy. The 25 realizations show a loss of from 0.04% to 0.07% of the region's jobs in the year 2000. The range in absolute numbers is from 45 to 72 jobs in an economy that currently (2002) employs about 103,200 people. The difference in jobs lost between the background only case and the Hanford plus background case varies from 0 to 38 jobs, or 0% to 0.04% of total regional employment. All of the job loss is due to estimates of background water concentrations, except at the Hanford Reach location where contaminants from Hanford influence the outcomes.

Accurate data of economic impact triggers for the Tri-Cities economy are not available. For the purposes of this analysis, triggers were estimated from other areas and may not reflect actual conditions. Using these triggers, reduction in recreational fishing is the largest contributor to the decrease in the regional economy. A considerable variation in impact estimates is due to uncertainty in the estimated contaminant concentrations and uncertainty in response. Fishing was estimated to be depressed in the Hanford Reach relative to the McNary pool. Impacts within the Hanford Reach decline after the year 2000. In the model results, the contaminant most responsible for fishing reduction is uranium. The fishing reduction fractions differ from the background-only case for regulatory reduction only at the Hanford Reach location.

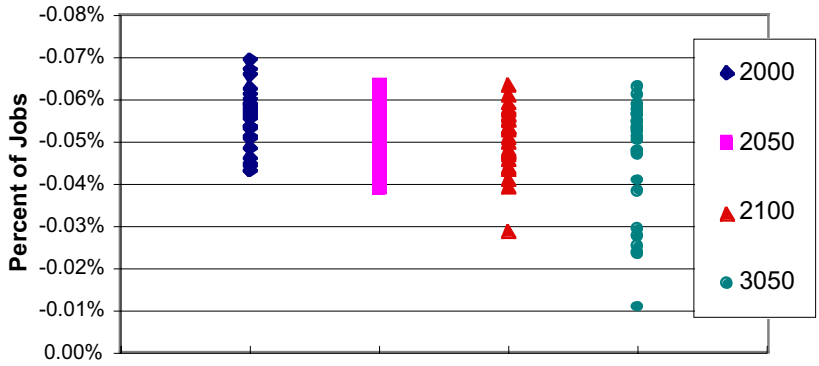

Figure 10.19. *Reduction in total employment from the baseline economy for Benton and Franklin Counties.*

Given the small magnitude of the change in employment estimated for the year 2000 (a few hundredths of a percent change in the regional

economy), the model adequately reflects the present day economy. The predominant effects in recreation come from the sensitivity of the fishing avoidance trigger mechanism. If the estimated surface water concentration at a fishing location is within one percent of the threshold (currently the federal drinking water standard), then a reduction fraction is applied to recreational fishing. Further research is necessary to develop more realistic trigger mechanisms. The economic component also relies on the ecological model to produce estimates of the fish concentrations that are used to estimate reduction in fishing due to regulatory restrictions. The major contributor to regulatory reduction in fishing is uranium-238, and the fish body burden threshold is exceeded for most realizations in the background-only simulations for this contaminant. Either the input parameters to the ecological model or the background water concentrations that contribute to the fish concentrations may need to be adjusted to produce more realistic uranium-238 concentrations in the fish.

The Economic Module estimates the impact in the economy to be less than 0.1% of today's jobs.

Conceptual/Implementation Model

The conceptual economic model is illustrated in Figure 10.20. Components implemented in the initial assessment are shaded and in bold. There are two major conceptual impact pathways (health risk and ecological risk) and two major model components (trigger mechanisms and impact). As illustrated in blue, the model accepts estimates of contaminant concentrations in fish and water, which are compared with literature-based estimates of levels likely to result in human health risk. The model then feeds the values to its first major component, the "trigger mechanisms" shown in yellow. The trigger mechanisms are sequences of regulatory or consumer behavioral changes in response to, or resulting from, human health or ecological risks. Parameters for these mechanisms are based on a literature review conducted in summer 2000. The second component, impacts, is shown in green, with the sections implemented for the initial assessment shown in red bold type. The impact component contains the processes by which particular trigger mechanisms induce impacts. This component consists conceptually of both direct effects to economic markets and changes in resource or activity values.

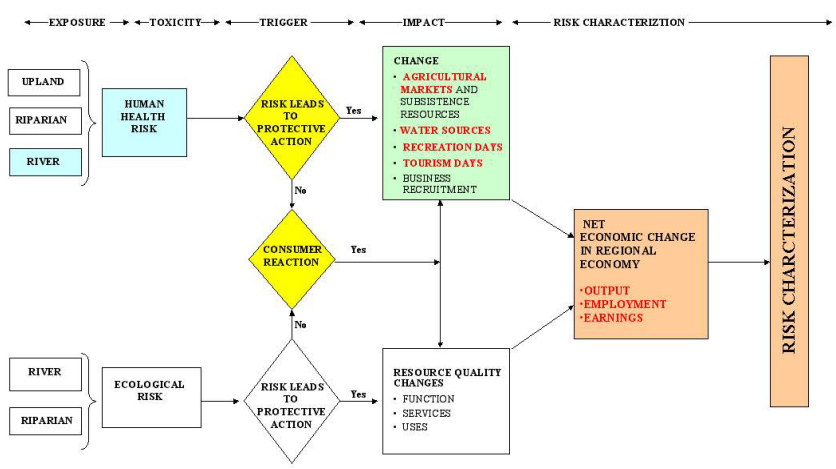

Figure 10.20. *The conceptual economic risk model showing those portions in color that were implemented in initial assessment.*

It also includes indirect regional economic impacts that occur through "ripple effects" from the direct impacts. Risk characterization, shown in orange, is implemented in the initial assessment as the distributions of output, employment, and earnings impacts. Conceptually, the analysis is driven by information inputs from the human health and ecological risk assessments. Only the portion of the conceptual model related to human health risks is implemented in the initial assessment.

As with the other impact modules, the economic risk conceptual model relies on the various transport modules to provide contaminant concentrations in groundwater and surface water at the various locations where impacts are estimated. In addition, the economic model uses fish concentrations computed in the ecological module at locations where fishing reduction results are to be estimated. Using these location-specific concentrations, the economic risk model estimates the likelihood and severity of economic reaction to radiological and chemical contaminants.

The risk/impact described here illustrates the sensitivity of the economic model to changes in the levels of 10 contaminants in the Columbia River at four representative locations. If the levels of contaminants were high enough in surface water or fish, regulatory authorities would likely take measures to protect public health. Independently, the public might also take action to reduce their exposure. The impacts discussed here are plausible, based on the literature, but the degree of uncertainty is actually very large and should be investigated further. Several of the realizations show significant recreational avoidance, but the level of avoidance drops over time. Some level of avoidance and impact also occurs at modeled background concentration levels in the Columbia River.

Although the specific reactions of authorities and consumers cannot be known, a survey of the environmental economics literature suggested that drinking water standards may help orient both. The survey also suggested that bans on recreation or consumption of agricultural products and avoidance of water-based recreation and agricultural products would be less than 100% effective. The literature suggests values for thresholds of sensitivity and levels of avoidance, given that a threshold is crossed. Thus, the estimates provided here are illustrative or plausible rather than definitive: too much is still unknown about the real response at low levels of concentrations.