CALCULATING ECONOMIC RISK AFTER HANFORD CLEANUP

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ABSTRACT

Since late 1997, researchers at the Hanford Site have been engaged in the Groundwater Protection Project (formerly, the Groundwater/Vadose Zone Project), developing a suite of integrated physical and environmental models and supporting data to trace the complex path of Hanford legacy contaminants through the environment for the next thousand years, and to estimate corresponding environmental, human health, economic, and cultural risks. The linked set of models and data is called the System Assessment Capability (SAC). The risk mechanism for economics consists of "impact triggers" (sequences of physical and human behavior changes in response to, or resulting from, human health or ecological risks), and processes by which particular trigger mechanisms induce impacts. Economic impacts stimulated by the trigger mechanisms may take a variety of forms, including changes in either costs or revenues for economic sectors associated with the affected resource or activity. An existing local economic impact model was adapted to calculate the resulting impacts on output, employment, and labor income in the local economy (the Tri-Cities Economic Risk Model or TCERM). The SAC researchers ran a test suite of 25 realization scenarios for future contamination of the Columbia River after site closure for a small subset of the radionuclides and hazardous chemicals known to be present in the environment at the Hanford Site. These scenarios of potential future river contamination were analyzed in TCERM. Although the TCERM model is sensitive to river contamination under a reasonable set of assumptions concerning reactions of the authorities and the public, the scenarios show low enough future contamination that the impacts on the local economy are small.

INTRODUCTION

Since late 1997, researchers at the Hanford Site have been engaged in the Groundwater Protection Project (formerly, the Groundwater/Vadose Zone Project), developing a suite of integrated physical and environmental models and supporting data to trace the complex path of Hanford legacy contaminants through the environment for the next thousand years, and to estimate corresponding environmental, human health, economic, and cultural risks. The linked set of models and data is called the System Assessment Capability (SAC) (1). The economic and cultural risk components of the SAC primarily arose out of stakeholder concerns that the analysis of risk of Hanford-derived materials and contaminants reach beyond the usual analysis of effects on human health and ecosystems to encompass effects on the economy and culture. From time to time, stakeholder groups have worried in particular that avoidance of agricultural products and recreation might have considerable adverse impact on the local economy. As used in the project, the term "economic risk" emphasizes *potential offsite consequences or impacts* of contamination on economic activity and value rather than, for example, the lifecycle cost of building and operating barriers to prevent, contain, or clean up contamination. The stakeholders articulated this view in Part II of the Columbia River Comprehensive Impact Analysis (CRCIA) in 1998 (2).

To address economic risk, an economic model was developed that contains an appropriate risk mechanism that consists of "impact triggers" (sequences of physical and human behavior changes in response to, or resulting from, human health or ecological risks), and processes by which particular impact triggers induce impacts. This component consists of both 1) economic market effects and changes in resource or activity values that are directly generated, and 2) indirect regional economic impacts that occur through "ripple effects" from the direct impacts. Both components are driven by information inputs from the human health and ecological risk assessments. The trigger mechanisms include both protective actions by regulatory authorities and the avoidance responses of consumers or visitors to the river (boaters, swimmers, fishermen, etc.—which we will describe as "visitors") in response to perceived risk.

Protective actions could involve government proscription of any use of a resource or location to protect the public health from perceived risk, and may involve health advisories as well. Projecting the potential for protective action is complicated by the fact that available information may or may not accurately portray physical risks. Regardless of their relation to health risk estimates, protective actions of almost any type are likely to lead to some economic impact. The magnitude of economic impacts induced in this manner depends on the type and duration of the protective action, the geographical scope and types of resources affected, and the extent of public involvement. Losses could occur in the local agricultural sector, either because local crops and other agricultural products could not be grown using contaminated water sources, or because they could they could not be sold if they were perceived as contaminated. Visitors may reduce the amount of their activity on the Columbia River as a result of perceived risk, regardless of government action.

Economic impacts stimulated by the trigger mechanisms may take a variety of forms, some of which involve well-defined markets for which data are available, but some of which are non-market in nature. Within the category of market effects, impacts may take the form of changes in either costs or revenues for economic sectors associated with the affected resource or activity. Impacts are measured as the net change from the baseline value of activity costs and revenues for the sectors affected (as measured by income or employment, for example).

A search was conducted of literature and secondary data sources in the summer of 2000 to see if good counts/estimates exist of consumer/recreator avoidance of environmental contamination. In several cases, the situation involved a relatively long-term controversy regarding health risks. During July and August, 2001, DOE also commissioned a survey of Columbia River visitors, which was used to supplement secondary data sources. An existing local economic impact model was adapted to conduct the analyses in this report. The adapted code is called the Tri-Cities Economic Risk Model (TCERM). The model was derived from IMPLAN (IMpact analysis for PLANning), a regional economic modeling system that was originally developed by the U.S. Forest Service, in cooperation with the Federal Emergency Management Agency. TCERM provides a framework for analyzing the economic impacts (changes in employment, output, income, etc.) from any number of economic shock scenarios.

TCERM accepts direct effects such as changing levels of local recreation spending or changed sales of agricultural products as inputs, and then estimates the subsequent indirect economic activity that results when local businesses increase or reduce expenditures to meet the changes in demand, as well as the induced economic activity caused by the employed workers spending their salaries and benefits. The total of these direct, indirect, and induced effects have been estimated for the value of regional economic output, employment, and labor income in the Tri-Cities. The SAC researchers ran a test suite of 25 realization scenarios for future contamination of the Columbia River after site closure for a small subset of the radionuclides and hazardous chemicals known to be present in the environment at the Hanford Site. These scenarios of potential future river contamination were analyzed in TCERM. Although the TCERM model is sensitive to river contamination under a reasonable set of assumptions concerning reactions of the authorities and the public, the scenarios show only small impacts on the local economy.

The results shown in this paper should not be interpreted as definitive predictions of total radiation doses or other impacts. They are representative results based on a limited number of contaminants moving through release and transport models. Definitive predictions must rely on further studies to confirm that additional contaminants do not contribute appreciably to the impacts. In addition, numerous inventory and transport issues must be addressed before definitive predictions can be performed (1, 3).

METHODS

The conceptual economic model is illustrated in Figure 1. A more complete discussion is included in (4, 5, and 6). Components implemented in the initial assessment are shown in white boxes, or, where only part of the component was implemented, in italics. The remaining portions are in gray. There are two major conceptual impact pathways (health risk and ecological risk) and two major model components (trigger mechanisms and impact). As illustrated, 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 white diamond-shaped boxes. The trigger mechanisms are assumed sequences of regulatory or consumer behavioral changes in response to, or resulting from, human health or ecological risks. Examples include regulators’ closing potions of the river, some fishermen and water skiers avoiding the river, or consumers avoiding crops grown with contaminated river water. The second component is impacts, with the sections implemented for the initial assessment shown in italics. 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. It also includes indirect regional economic impacts that occur through "ripple effects" from the direct impacts. Risk characterization, shown in the final box, 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 parts of the conceptual model related to human health risks are implemented in the initial assessment.

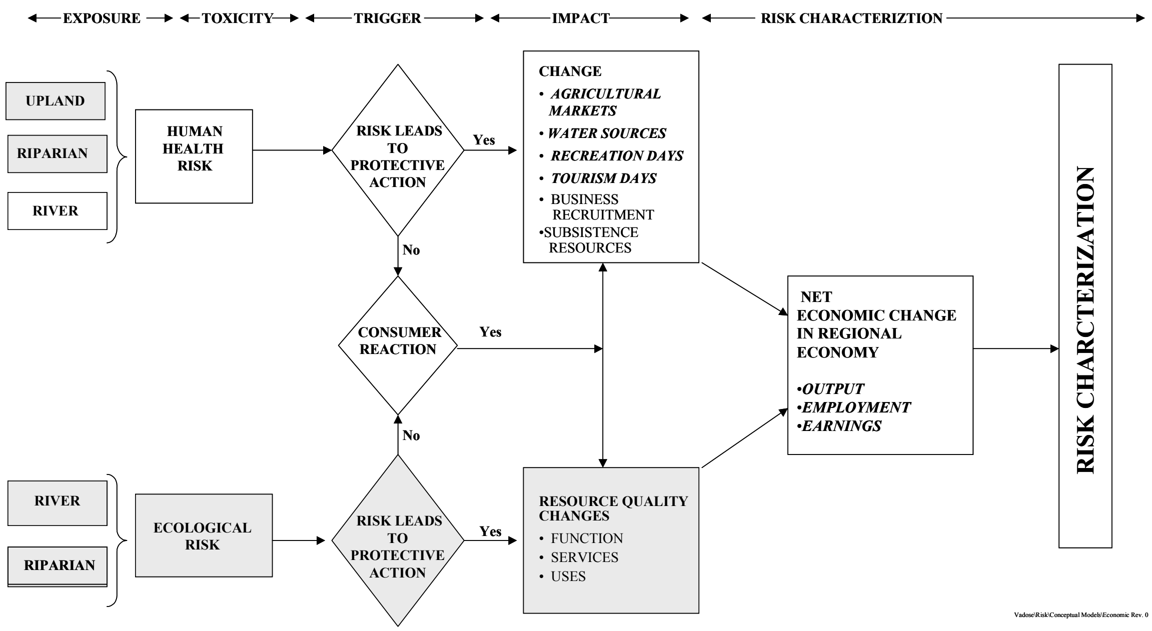

Fig. 1. Conceptual economic risk model showing those components in that were implemented in the initial assessment (Implemented components are shown in white boxes. Where entire component was not implemented, the implemented portion is shown in italics.)

As with the other impact modules of SAC, 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 concentrations of contaminants in fish 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.

Accurate data concerning economic impact triggers for the Tri-Cities economy is not available. For the purposes of this analysis, triggers were estimated from data on other areas reported in the literature, and may not accurately reflect Tri-Cities conditions. Based on values in the literature, contamination trigger values based on drinking water standards were used for regulatory actions to proscribe sales of crops, or ban non-fishing water-based recreation. For fishing, concentrations in fish were also used. Based on the literature, these bans were assumed to be less than 100 percent successful. Consumers and river visitors were also assumed to begin to avoid crops or the river at levels of contamination generally lower than the trigger values used by the regulatory authorities. Using these triggers, reduction in recreational fishing was the largest contributor to the decrease in the local economic activity.

The risk/impact described here illustrates the sensitivity of the economic model to preliminary projected changes in the levels of ten contaminants in the Columbia River at four representative locations. If the levels of contaminants were high enough in surface water or fish, regulatory authorities likely would take measures to protect public health. Independently, the public might also take action to reduce their exposure.

It is very difficult to tell how people actually would react and how adverse the reaction might be. Partly this will turn on how responsible the press and public policy discussion turns out to be if there is any future contamination. . For example, consider the concept of genetically-modified plants and very different social and political reactions to them in Europe and the United States (7).

Consumer behavior in the model was calibrated from a literature survey of historical food contamination episodes and fishing advisories, where the researchers reconstructed consumer and recreator reactions to alleged contamination of foodstuffs and water bodies. (See the Appendix for a list of the key studies. Virtually no studies were found on non-fishing water-contact recreation, so inferences were made from fishing behavior.) All but one of the food studies reviewed dealt with pesticide residues from pesticide application practices rather than accidental contamination. In several cases, the situation involved a relatively long-term controversy regarding health risks. In most cases, consumer confidence was restored through removal of contaminated products from the market, regardless of how low the risks might actually be. This was not the case for apples in the New York market area, where substantial avoidance persisted for more than 5 years. This was also the case with the milk avoidance example associated with the Three Mile Island accident, although milk was not found to be contaminated.

Of particular note was a series of fishing advisories. Researchers interviewed hundreds of sport fishermen to find out how they react to advisories from health authorities that certain water bodies are contaminated and that certain actions should be taken with respect to fishing (avoid fishing, don't eat the fish, etc.). Fifteen key studies were reviewed for this project. A majority of the individuals interviewed in the fisheries studies cited two methods for determining the rates at which they consumed sport-caught fish: the limits recommended by the advisories and their *personal* assessment of the health of the fish. Those that exceeded the recommended limits usually relied on their own senses to determine whether a fish was safe to eat. In fact, in many cases people relied on their own abilities and completely ignored the advisories. Most relied on the appearance and smell of the fish, though the contaminants did not leave any evidence that the fish were unhealthy. Also, people relied on the fact that they had seen no immediate negative health effects in people that had consumed the sport-caught fish. This approach totally ignores the effects of chronic exposure to the contaminants. In response to an advisory, many individuals did a more thorough job of cleaning the fish and removing the fat. This was especially true when the advisory mentioned cleaning and cooking techniques. For the most part, those individuals that knew of the advisory and recommended cooking techniques followed them. Another response was to simply stop eating sport-caught fish, but this was not as common as changing cooking habits. And finally, some people chose to make no changes, even if it meant they were exceeding the recommended limit.

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, the survey of the environmental economics literature suggested that drinking water standards may help orient both. (Table 1 shows the standards for contaminants in water and fish used as thresholds in this study.) 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 ranges of 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.

RESULTS

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.

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Table 1. Key threshold values for regulatory action (recreation and food avoidance begins 1% of the level shown, except for carbon tetrachloride, where avoidance begins at the detection limit of 0.25 µg/L in water)

Analyte	Concentration in Drinking and Contact Water	Concentration in Fish
H-3	20,000 pCi/L[a]	34,000 pCi/kg[i]
Tc-99	800 pCi/L[b]	34,000 pCi/kg[i]
I-129	0.5 pCi/L[b]	1,500 pCi/kg[g]
U-235/238 as radionuclide	15 pCi/L[c]	1,500 pCi/kg[g]
U238 as chemical	45 µg/L[k]	4.5 mg/kg[k]
Sr-90	8 pCi/L[d]	2,700 pCi/kg[j]
Cs-137	160 pCi/L[b]	27,000 pCi/kg[j]
Pu-239/240	13 pCi/L[b]	27 pCi/kg[j]
CCl_4	0.25 µg/L[e]	82 µg/kg[l]
Cr	11 µg/L[f]	350 µg/kg[l]

[a] National Interim Primary Drinking Water Standards 40 CFR 141, explicitly called out.
[b] National Interim Primary Drinking Water Standards 40 CFR 141, 4 mrem/year criterion using NBS-69 process.
[c] National Interim Primary Drinking Water Standards 40 CFR 141, alpha criterion.
[d] National Interim Primary Drinking Water Standards 40 CFR 141, explicitly called out.
[e] National Recommended Water Quality Criteria for Priority Toxic Pollutants FR 63, 68357; human health water plus organisms, also 62 FR 42160.
[f] National Recommended Water Quality Criteria for Priority Toxic Pollutants FR 63, 68357; freshwater CCC, also 57 FR 60848
[g] Derived using FDA approach.
[h] Explicit in FDA approach "Accidental Radioactive Contamination of Human Food and Animal Feeds: Recommendations for State and Local Agencies."
[i] CODE Allimentarius Commission guideline levels for radionuclides in food moving in international trade.
[j] Derived Intervention Levels for Radionuclides in Foods - Guidelines for Application after widespread radioactive contamination resulting from a Major Radiation Accident
[k] U-238 activity concentrations converted into mass units.
[l] No regulatory threshold exists. These values were derived from the EPA Reference Doses (RfD) from the IRIS database (http://www.epa.gov/ngispgm3/iris; August 2000).

Figure 2 summarizes the estimated impact on employment in the Tri-Cities of actions taken by regulators, visitors, and consumers of crops reacting to 25 projected levels of contamination. Today's economy was used as baseline for the future impacts. Job losses are shown as a percentage of jobs lost in the regional economy. The 25 realizations show a loss of from 0.04 percent to 0.07 percent 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 percent to 0.04 percent of total regional employment. The low overall impact on employment comes from three sources.

- The review of the literature showed that people often don't panic when faced with contamination. To the contrary, they frequently ignore the warnings.

- The current level of contamination is extremely low (indeed, a lot of it is from background sources above Hanford), and forecasted changes are either very small increases or even decreases, making future contamination a matter of mostly declining importance.

- Even though the area is agricultural and recreation is relatively important compared with some regions, the estimated reductions in local fishing and losses in crop sales would have a very small percentage impact on the much-larger local economy. In 1999, for perspective, *all* of local agriculture directly accounted for 15% of local jobs and 10% of local income. The "visitor" industry (most of which is not dependent on fishing) accounted for about 7% of jobs and 5% of income. Small changes to these sectors would have smaller impact still.

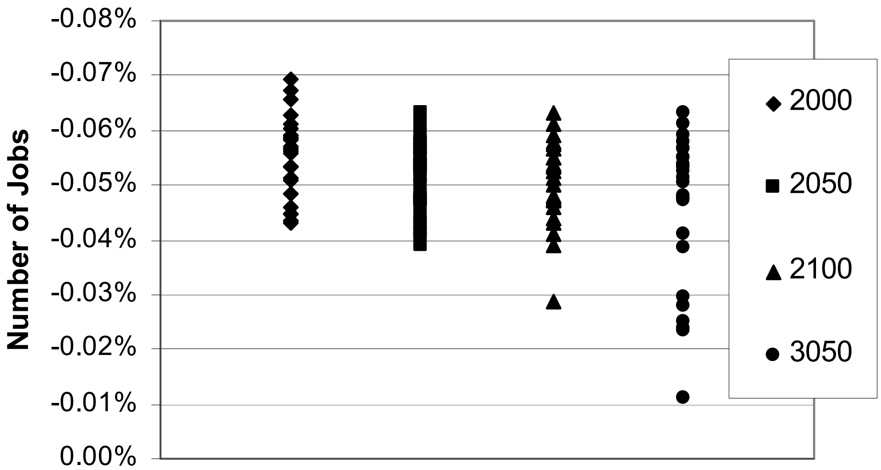

Fig. 2. Reduction in total employment from the baseline economy for Benton and Franklin Counties. Results from 25 model realizations for the years 2000, 2050, 2100, and 3050.

A considerable amount of the variation in impact estimates is due to uncertainty in the estimated contaminant concentrations. 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 as concentrations of contaminants decline. 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 in the Hanford Reach.

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. That is, there is very little (if any) discernible avoidance of the Columbia River sports fishery or local agricultural crops due to current levels of contamination, and the overall economy is not very dependent on fishing-related activity or agricultural crops irrigated from the Columbia River below Hanford. (Most local crops are grown with water originating above Hanford or from the Yakima and Snake Rivers.) 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.

UNCERTAINTIES

All modules of SAC (inventory, release, vadose zone transport, groundwater transport, river transport, riparian zone, and risk/impact) are stochastic and are analyzed by Monte Carlo methods, with efficiencies improved by the use of Latin Hypercube sampling (8). Even with the limited analysis of risk and impact that has been performed thus far with SAC, it has been possible to begin to learn “what matters” for impact. This analysis addresses the role of uncertainty as caused by the variation of parameters within the modeling system. It does not address causes of errors between the modeled and observed data, and it does not address uncertainty due to the use of different models. In addition, the analysis presented here does not differentiate between uncertainty due to lack of knowledge and uncertainty due to inherent variability in the parameters.

To locate the most influential parameters in the uncertainty of final impact estimates, a top-down hierarchical analysis was performed. This approach is similar to that used for the Hanford Environmental Dose Reconstruction Project (9). In this approach, the first tier of analysis considered the major contributing inputs to the performance measure being evaluated. Sometimes the inputs to the specific impact model were derived values, such as the concentration of tritium in groundwater, rather than values of a sampled parameter. If the uncertainty in the performance measure was sensitive to one or more of the derived (previously modeled) parameters going into the equation, then the uncertainty analysis proceeded to the second tier and examined the uncertainty in the derived parameters. A relatively small number of input parameters determine most of the variability in the calculated performance measures. Interestingly, when the performance measure is human dose, variability with regard to individual behavior and exposure affects uncertainty in the estimated dose more than does variability in inventory, release, or environmental transport of the contaminant. The same observation was made in the Hanford Environmental Dose Reconstruction Project.

Table 2 describes qualitatively which parameters contributed the most to the uncertainty in some of the key risks discussed in the paper. In each case, a stepwise linear regression analysis was performed using the output results and input parameters. Percentages in Table 2 refer to the additional percentage of the coefficient of multiple determination (R^2) explained as the additional variable is added to the regression model. For details of the analysis, the reader is referred to chapter 11 of (1). Much of the uncertainty is driven by uncertainty in parameters within the Risk/Impact Module; that is, while the amount of contamination exposure is important, factors internal to the exposed system are often equally important or more important.

Table 2. Parameters controlling variability in the loss of employment (number of jobs) due to tritium contamination in the year 2000.

1st Tier Major Explanatory Variable(s	Percentage of Variability Explained (R^2)	2nd Tier Major Explanatory Variable(s) and Percentage of Variability Explained
Rate of voluntary avoidance of winter wheat	42.4%	None
Concentration of tritium in water for drinking,	15.8%	None
Concentration of tritium in water for irrigation	15.5%	None
Rate of voluntary avoidance of swimming	10.0%	None
Rate of voluntary avoidance of fishing	4.2%	None
Source: Adapted from Bryce et al. (2002) (Reference 1).		

CONCLUSIONS

The preliminary ecological, human health, cultural, and economic risks described in the previous section show that contamination from the combined operations of Hanford Site poses some small long term risk to the environment. However, in most of the realizations this risk declines with time, particularly as tritium decays and leaves the system. Tritium decays faster than the other nuclides, so within about 40 years technetium-99 becomes the largest contributor to human risk. The very small risk to the local economy is driven by reductions in the level of fishing in the Hanford Reach, due mostly to very sensitive threshold values for recreational avoidance relative to the background levels of contamination predicted for fish, but the major uncertainties between cases are driven by uncertainties regarding avoidance of agricultural products.

For the successful use of TCERM in forecasting the economic impact of future contamination of the Columbia River, the most fundamental issue is that very little is known about how consumers and visitors actually would react to the knowledge that the Columbia River was contaminated. More work needs to be done to develop reliable characterizations of these trigger mechanisms, including appropriate thresholds.

The initial assessment has successfully demonstrated that sitewide assessments can go beyond the traditional area of human health, and even include economic impact. The analysis has demonstrated that SAC also can be used to gain insight into the underlying causes of impact and uncertainty, which will help both to direct future research to reduce the uncertainty and to prioritize individual cleanup actions and monitoring and characterization. Once it is further refined, SAC will become an integral part of the decision process for site cleanup and closure at Hanford and a model tool for other sites.

APPENDIX: KEY STUDIES REVIEWED FOR CONSUMER REACTIONS TO CONTAMINATION

Key Food Contamination Studies

BROWN, J.D. 1969. “Effect of a Health Hazard “Scare” on Consumer Demand,” *American Journal of Agricultural Economics*, 51(3):676-678.

DOHERTY, L.E. 1964. “Tuna’s Time of Trouble,” *Food Business*, January, pp. 28-34.

JOHNSON, F.R. 1988. “Economic Costs of Misinforming About Risk: The EDB Scare and the Media,” *Risk Analysis*, 8(2):261-269.

PENNSYLVANIA DEPARTMENT of AGRICULTURE. 1980. “Three Mile Island Socio-economic Impact Study: A Final Report on Work Element 3,” Harrisburg, PA.

SMITH, M.D., E. O. VAN RAVENSWAAY, and S.R. THOMPSON. 1988. “Sales Loss Determination in Food Contamination Incidents: An Application to Milk Bans in Hawaii,” *American Journal of Agricultural Economics*, 70(3):513-520.

VAN RAVENSWAAY, E.O. and J.P HOEHN. 1991. “The Impact of Health Risk on Food Demand: A Case Study of Alar and Apples,” in *Economics of Food Safety*, ed. J.A. Caswell, 155-174, Elsevier Science Publishing Co, New York, NY.

Key Fisheries Studies

BALES, C.W. and R.L SELF.1993. “Evaluation of Angler Fish Consumption After a Health Advisory on Lake Hartwell, Georgia and South Carolina,” *1993 Proceedings of the Annual Conference,* Southeastern Association of Fish and Wildlife Agencies, 47:650-656.

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CONNELLY, N. and B. KNUTH. 1993. Great Lakes Fish Consumption Health Advisories: Angler Response to Advisories and Evaluation of Communication Techniques, HDRU Pub. 93-3, Department of Natural Resources, New York State College of Agriculture and Life Sciences, Ithaca, NY.

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DIANA, S., C. BISOGNI, and K. GALL. 1993. ”Understanding Anglers' Practices Related to Health Advisories for Sport-Caught Fish,” Journal of Nutrition Education, 25(6):320-328.

JAKUS, P., M. DOWNING, M. BEVELHIMER, and M. FLY. 1997. “Do Sportfish Consumption Advisories Affect Reservoir Anglers' Site Choices?” Agricultural and Resource Economics Review, 26(2):196-204.

KNUTH, B. 1996. “Who Heeds Fish Consumption Advisories?” *The Information Exchange*, 5(1):1-5.

KNUTH, B., N. CONNELLY, and M. SHAPIRO. 1993. Angler Attitudes and Behavior Associated with Ohio River Health Advisories, Cornell University, Human Dimensions Research Unit.

LEVINE, K.J., et al. 1999. “Anglers' Attitudes, Beliefs, and Behaviors as Impacted by the Michigan Fish Consumption Advisory,” Journal of Public Health Management Practice, 5(6):18-28.

MACDONALD, H.F. and K.J. BOYLE. 1997. “Effect of a Statewide Sport Fish Consumption Advisory on Open-Water Fishing in Maine,” North American Journal of Fisheries Management, 17:687-695.

MAY, H. and J. BURGER. 1996. “Fishing in a Polluted Estuary: Fishing Behavior, Fish Consumption and Potential Risk,” Risk Analysis, 16(4): 459-471.

TILDEN, J., L.P. HANRAHAN, H. ANDERSON, C. PALIT, J. OLSON, and W.M. KENZIE. 1997. “Health Advisories for Consumers of Great Lakes Sport Fish: Is The Message Being Received?” Environmental Health Perspectives, 105(12):1360-1365.

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