3. Overall Results

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The initial assessment was successful in that it demonstrated a sitewide analysis was achievable. The results are promising and useful, provided their limitations are acknowledged.

The initial assessment met its primary objectives. The original scope of the effort was to develop and successfully test a sitewide assessment capability addressing composite risks from a suite of representative Hanford contaminants for subsurface and surface water pathways over a 1,000-year period. The stochastic capability involves a systems approach and Monte Carlo analysis of significant operational, physical, chemical, biological, and socioeconomic features of the Hanford Site and its environs. Completion of the initial assessment demonstrates that a sitewide analysis can be completed. This success has encouraged application of the SAC tool and the initial assessment results to issues facing the site. The assessment results are promising and useful, provided their current limitations are acknowledged.

The results presented in this document should not be interpreted as definitive predictions of total radiation doses or other impacts. They are representative results based on the inventory, release, transport and risk/impact models. Definitive predictions must rely on further studies to confirm that additional contaminants do not contribute appreciably to the impacts. Other issues identified in this document must also be addressed before definitive predictions about the impact of Hanford contaminants can be made.

Initial Expectations and Overall SAC Performance

SAC is a stochastic framework of new and legacy codes that produce an environmental simulation, archive environmental results, and produce risk/impact simulations. This computational split between environment and risk/impact allows multiple environmental realizations and cleanup/remedial action cases to be archived and analyzed for risk/impact. The environmental simulation is a marriage of newly generated software and legacy codes that creates a state-of-the-art capability to address sitewide issues with regard to cumulative effects from all Hanford Site waste disposals and discharges: past,

What is a conceptual model?
A conceptual model is an evolving hypothesis that identifies the important features, events, and processes that control our understanding of consequences for a particular problem. Conceptual models form the basis for investigation of field observations and laboratory data. They form the foundation for the design and development of a simulator or model.

The framework used in the initial assessment is a combination of new computer software and legacy codes that creates a state-of-the-art capability that can be applied to waste disposal issues on the Hanford Site.

present, and future. The SAC is run on a multiprocessor parallel computer designed to provide computational speed, data transfer speed, and mass storage consistent with a sitewide analysis.

Assessments completed with SAC are expected to yield information and insights on the migration and fate of Hanford Site contaminants, as well as information needed to design and create an improved assessment capability. In accordance with its design goals (Kincaid et al. 2000), the initial assessment addresses:

- A 1,000-year time period following site closure; the analysis begins at the time of site startup in 1944 and continues through 3050.
- Ten contaminants including seven representative nuclides from mobile to highly immobile classes (tritium, strontium-90, technetium-99, iodine-129, cesium-137, uranium-238, and plutonium-239/240), an organic chemical, (carbon tetrachloride), a heavy metal, (chromium) and uranium as a chemical.
- Releases from 533 locations distributed across Hanford's operational areas.
- Transient analysis of water flow and contaminant transport for the vadose zone, groundwater, and Columbia River. The spatial domain of the assessment is the groundwater from Rattlesnake Mountain to the river, and the river from Vernita Bridge to McNary Dam.
- Risk and impact analyses on four types of metrics, (human health, ecological, economic, and cultural), the first three involving multiple scenarios.
- Uncertainty through a Latin Hypercube Monte Carlo analysis – limited to 25 realizations in the initial assessment and therefore focused on the central tendency and not extreme values.

The initial assessment was run on a 128-CPU Linux cluster. Each CPU is a 1 GHz Pentium 3 processor. A controlling program was developed to distribute each of the processes (vadose zone flow, release, and transport, groundwater transport, and river transport) over this cluster. All of the results from the cluster are written to two shared 1.2 Tb SCSI disk arrays controlled by a server. This server is the central processsor with two 1.7 GHz Pentium 3 processors running Linux. During research leading to the development of this capability, SAC was initially executed on a

10 processor, MS Window®-based system that relied upon file movement across the PNNL network. The Linux cluster can complete in two weeks a problem that took over four months on the 10-processor MS Windows®-based system.

The environmental stochastic processor (controlling program within SAC) was developed to either run the total assessment in a single start-to-finish pass or stop after each process so analysts could check the interim results. The latter method was used for this assessment. The sequence of simulation steps for the assessment was as follows:

- Estimate all inventory (all sites, all modeled contaminants, all realizations).
- Estimate groundwater flow (three runs for entire simulation, with time stepping schemes appropriate to high, moderate, and low mobility contaminants).
- Estimate vadose zone flow rates using the STOMP code (all sites, all modeled contaminants, all realizations).
- Estimate release to the vadose zone (using the VADER code) and vadose zone transport (using the STOMP code) to the groundwater or river (using the VZDROP code).
- Simulate groundwater transport (using the CFEST code) to the river.
- Modify groundwater transport results to be used as boundary conditions for the river transport (using the GWDROP code).
- Estimate transport in the river (using the MASS2 code).
- Modify river transport results to be used by the river shore module and the impact codes (using the CRDROP code).
- Estimate concentrations at the river shore (using the RIPSAC code).
- Estimate risk and impact on human health (using the HUMAN code), the ecology (ECEM code), the local and regional economy (TCERM code) and the local culture (CULTURE code).

Completion of the assessment requires that each of the above steps be completed in series using the multiple-processor machine. The results of

Computer runs that took four months to simulate a year ago can now be done in less than two weeks because of continual improvements to the SAC tools and procurement of a dedicated computer system.

The results of each step of the initial assessment were checked to make sure that results were consistent. Once each step was verified, the next computational step in the sequence was started. The time to perform these checks was longer than the actual processing time. However, many techniques were developed to automate these checks and speedup the simulation.

Table 3.1. Processing time for the SAC initial assessment.

Process or Model	Number of Runs	Distributed	Processing Time
ECDA Setup	1	No	5 minutes
Inventory	1	No	2 hours
ESP – Setup	1	No	30 minutes
ESP – Vadose Zone Setup	1	No	2 hours
Vadose Zone Flow (STOMP)	18,000 (720 x 25)	Yes	3.5 hours[b]
Vadose Zone Release And Transport (VADER and STOMP)	162,000 (720 x 9 x 25)	Yes	72 hours[b]
Groundwater Transport (CFEST)	225 (9 x 25)	Yes	192 hours[b]
GWDROP Data Translator	225 (9 x 25)	Yes	12 hours[a]
River Transport (MASS2)	450 (9 x 25 x 2)	Yes	36 hours[b]
CRDROP Data Translator	450 (9 x 25 x 2)	Yes	8 hours[a]
Rivershore (RIPSAC)	2	No	50 minutes

(a) Distributed over contaminants (each contaminant is sent to a different processor, but a new realization is not distributed until all contaminant are complete for the previous realization).
(b) Assume that 128 processors are being used.
ECDA = Environmental concentration data accumulator.
ESP = Environmental stochastic processor.

each step were checked to make sure that results were consistent with the problem. Once each step or task was verified to be correct, the next computational step in the sequence was started. The time to perform these checks was longer than the actual processing time. However, many techniques were developed to automate these checks and speed up the simulation. The actual processing time for each of the environmental assessment steps is shown in the Table 3.1. Accordingly, total actual processing time (i.e., machine clock time), for the environmental components of the initial assessment was slightly in excess of 300 hours or nearly two weeks. Actual processing time for the risk and impact components of the initial assessment was on the order of minutes and inconsequential relative to that of the environmental components. Recent improvements in the CFEST code have reduced run times to about 50% of the 192 hours identified in Table 3.1. A full 1,000-year, 100-realization, 10-contaminant analysis will have a numerical simulation time of approximately one and a half months, slightly more than the original analysis time goal of SAC.

Model Performance

The overall performance of the system model becomes clear as we examine elements of history matching farther from the sources. How well do predictions match observed groundwater plumes, river water concentrations, and uptake by species? These comparisons include the cumulative influence of inventory, release, vadose zone transport, groundwater transport, river transport, and finally exposure and uptake within the food chain. This section contains a summary of overall system results with regard to inventory, environmental pathway, risk/impact and uncertainty. These topics represent a global view of the system analyzed.

What steps are taken to assess how well the models predict what will happen? In general there are two steps to establishing the credibility of a model. First, one must determine that a model, as implemented, accurately represents the developer's conceptual model and that the model accurately represents simplified cases. Second, one must determine the degree to which a model is an accurate representation of the real world by comparing model results against field observations.

Inventory. The initial assessment has assembled a complete portrait of the Hanford Site inventory for the 10 contaminants based on disposal and discharge records, estimates, and process-knowledge-based models for the entire Hanford Site. This compilation of inventory is more complete than the composite analysis (Kincaid et al. 1998) that considered only Central Plateau sites, the CRCIA Part I assessment (DOE/RL 1998) that focused on present-day risk and impact to the Columbia River, and the HEDR project (Farris et al. 1994) that examined discharges to the Columbia River and atmosphere during the major production period

Although some contaminants (e.g., technetium-99, iodine-129) do not make up a large amount of the inventory of waste at Hanford, they contribute to dose or risk because of their long half-life, high mobility, and relatively high dose or risk conversion factors.

from 1944 until 1972. By using this inventory in an assessment of contaminant migration and fate, strengths and weaknesses in the inventory are revealed when forecasts of groundwater plumes or river concentrations do or don't compare well with field observations.

Viewed simply as an inventory, metrics associated with the total inventory of individual contaminants were adopted as initial measures of our knowledge of inventory (i.e., ratios of mean value and range for two estimates of total contaminant inventory). Based on these metrics, it was determined that a satisfactory knowledge of total inventory existed. However, application of the inventory in the initial assessment has revealed weaknesses in some waste-site inventories that are susceptible to early release to the environment. In addition, it is apparent that certain contaminants with seemingly low inventories play a significant role with respect to offsite risk/impact. When viewed in the context of the complete suite of metrics including worker health, intruder health, and offsite public and ecological health, each of the contaminants included in the initial assessment can be important. However, inventory discussions that focus on offsite exposure, risk, and impact, emphasize contaminants that are relatively long-lived, mobile, and present a higher health threat. Radionuclides that are long-lived, mobile, and present a relatively high risk include technetium-99 and iodine-129.

The total inventory of radioactive and chemical contaminants at Hanford at the time of site closure depends on the quantities generated, imported, exported, and decayed or degraded. Radioactive contaminants undergo decay while chemical contaminants may be influenced by a broad range of chemical or microbiological processes. The amount of inventory at site closure will be a small fraction (i.e., less than 1%) of the generated inventory because of export and decay assuming all of the planned cleanup actions are carried out. However, the change in total inventory is largely a function of radioactive isotopes with moderate-to-short half-lives and large inventories. Examples of major contributors to inventory change are tritium and the parent-progeny pair of cesium-137/barium-137m. Iodine-129, technetium-99 and isotopes of uranium contribute relatively little to the total inventory of Hanford, and some, like iodine-129, are not exported in appreciable quantity. It is these and other relatively long-lived and mobile radioactive contaminants having relatively high dose or risk factors that define the long-term health risk and impact. Figure 3.1 shows the inventory for several contaminants from the beginning of site operations until the time of site closure.

The rate of decay, or half-life, of radionuclides varies greatly. All modules in the initial assessment took decay into account.

Tritium	*12.32 years*
Strontium-90	*28.78 years*
Cesium-137	*30.07 years*
Plutonium-239	*24,110 years*
Technetium-99	*211,100 years*
Iodine-129	*15,700,000 years*
Uranium-238	*4,468,000,000 years*

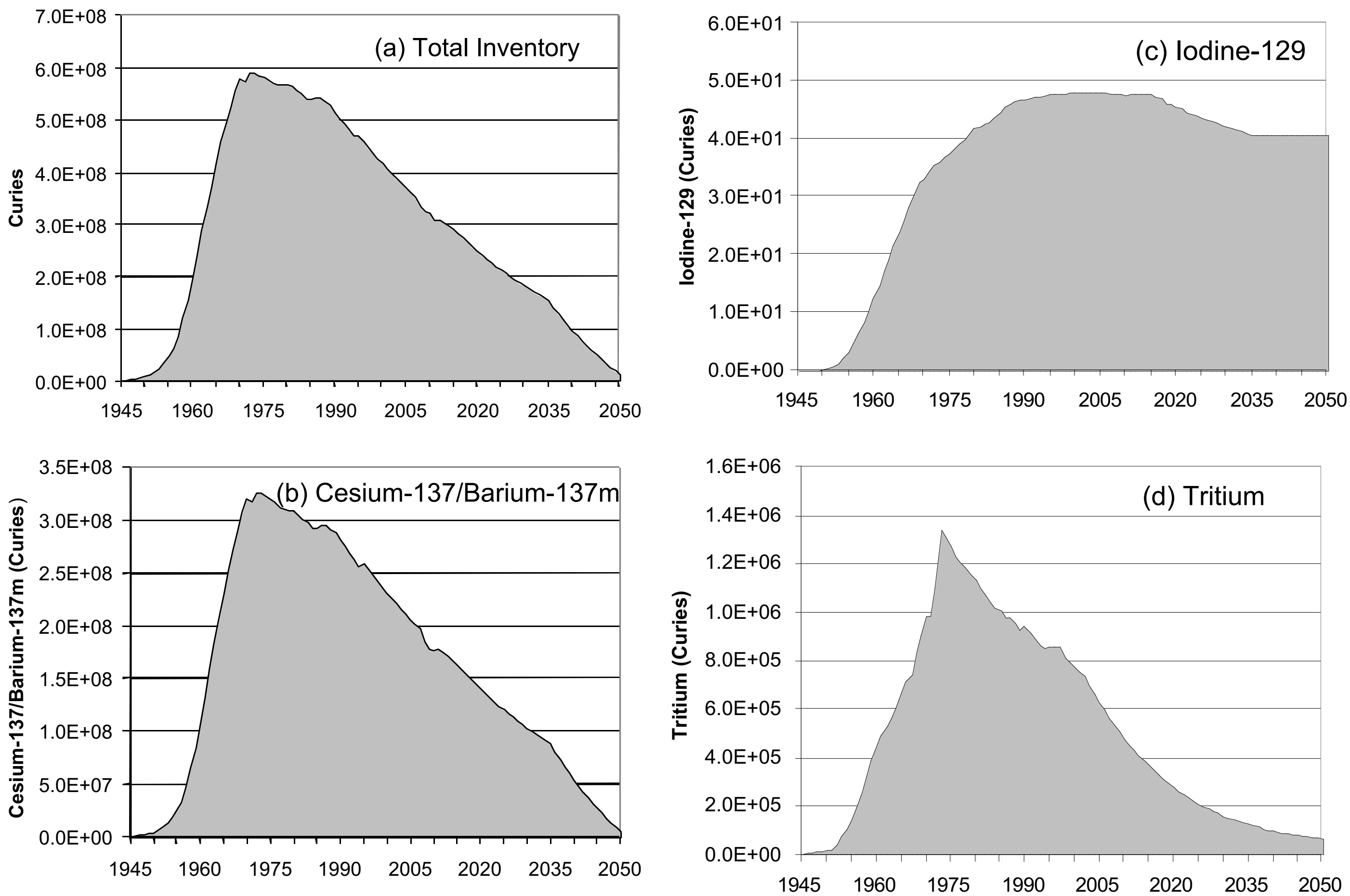

Figure 3.1. *A time history of radionuclide inventory showing generation, import, export and decay: (a) total inventory, (b) cesium-137/barium-137m, (c) iodine-129, and (d) tritium.*

Six contaminants of relatively more mobility were analyzed in the initial assessment: carbon tetrachloride, chromium, tritium, technetium-99, iodine-129, and uranium-238. The SAC model shows that some waste sites that received technetium-99, iodine-129, and uranium-238 do not result in the creation of observed groundwater plumes. Examples include the iodine-129 plume associated with Plutonium-Uranium Extraction (PUREX) cribs, and the technetium-99 and uranium-238 plumes associated with U Plant cribs. Accordingly, the performance of the overall SAC system can be improved by developing a greater correspondence between the inventory assigned to an individual crib or a suite of cribs, and the inventory estimated to reside in its associated groundwater plume. This correspondence can be achieved by performing a focused review and evaluation of

The results from the initial assessment indicate that tritium concentrations from Hanford sources are declining in the Columbia River and will continue to do so.

process knowledge, waste stream composition, discharge records, and field observations related to the specific waste sites or suite of waste sites.

Environmental Pathway. The environmental pathway is simulated using a sequence of the Release, Vadose Zone, Groundwater, River, and Riparian Zone Modules. Contaminant concentrations in each module are archived for use by the Risk/Impact Module. While there have been post mortem characterizations of select vadose zone sites, the first environment in which comprehensive data sets are available is groundwater. Field observations of the river and riparian (e.g., shoreline) environments also provide data sets, although somewhat limited ones.

A comparison of the SAC results for a contaminant such as tritium in groundwater depends on the inventory assigned to waste sites and its simulated delivery to the aquifer through the vadose zone. The current approach to groundwater simulation relies on a three-dimensional representation of the aquifer calibrated to Hanford Site groundwater monitoring water-table data collected since 1943. At this time, the groundwater model is not calibrated to the tritium concentration data set. Thus, comparison of tritium simulation results to tritium field observations represents an independent evaluation of model performance.

The initial assessment produced tritium plumes originating from several operational areas (e.g. 200 East and West Areas and several of the 100 Areas) that are generally consistent with what has been observed historically (Figure 3.2). Basically, the timing, location, and movement of simulated tritium plumes are similar to field observations of the large-scale tritium plumes originating from wastewater discharges containing tritium in selected operational areas within the Central Plateau. The largest plumes originate from 200 East Area and are attributable to historical tritium discharges associated with the PUREX Plant during the late 1950s through early 1970s and again in the mid-1980s following the PUREX Plant restart in 1984. Tritium plumes were also simulated where they have been observed in the northern part of 200 West Area near T Plant and the southern part of 200 West Area near the REDOX facility. Tritium discharges in these areas were esti-

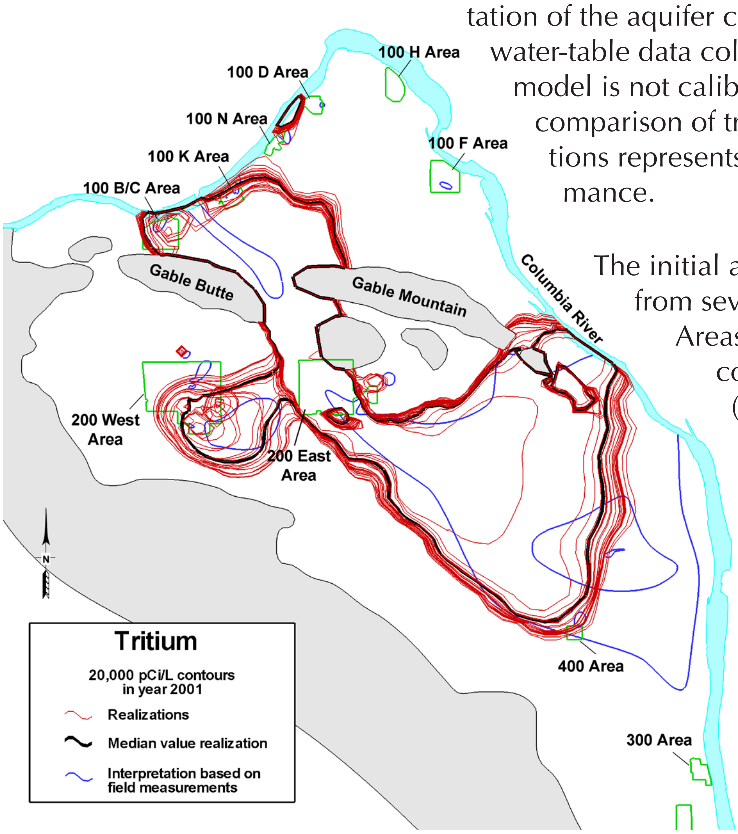

Figure 3.2. Comparison of drinking-water-standard contours for 25 realizations, median case, and field interpretations for tritium in 2001.

mated to be less than discharges in 200 East Area. Smaller local-scale plumes of tritium exceeding drinking water standards were also predicted where they have been observed in several of the 100 Areas (i.e., 100 B/C, 100 K, 100 N, and 100 D Areas).

There are inherent differences between field observations and the results of the three-dimensional groundwater model, and with that in mind, the trend and shape of the tritium plume is well represented in the initial assessment. In general, to take a field sample, groundwater is drawn from the uppermost meters of the unconfined aquifer and completely mixed as the water is drawn to the land surface. Therefore, field samples provide a two-dimensional portrait of the vertically averaged concentration of the upper aquifer layer. The simulated concentration as presented in contour plots also represents the uppermost layer of the unconfined aquifer. However, these two data sets may or may not be fully consistent depending on the precise vertical position of well screens and model layers.

More detailed evaluations were conducted to examine how well the predictions matched measured historical conditions. Figure 3.3 presents a comparison of simulated tritium concentration based on the median parameter values with measured tritium in 1995. Examination of plots for this time period and earlier ones indicates that the tritium plume originating from sources in the vicinity of the PUREX Plant and migrating east of 200 East Area generally tracked slower than historical observations. The center of mass of the plume originating from and migrating east of 200 West Area tracked similarly to the historical observed center of mass but is dispersed over a broader area. Tritium plumes simulated in the 100 Areas are, in general, consistent with the location of historical tritium plumes within these areas. However, these predictions exhibit lower concentration levels and a broader area of contamination. While matching the tritium plumes in general, the broad dispersal seen in each of these regions of the model indicate the next step is to more highly resolve the groundwater model within operational areas to more accurately depict tritium transport in the immediate vicinity of discharges.

While tritium has not been subject to pump-and-treat remedial action, other contaminants including technetium-99, uranium, carbon tetrachloride, and strontium-90 have. The initial assessment has not included pump-and-treat actions because of the problematic rules needed to start and end such operations. Consequently, contaminant maps and concentrations in the vicinity of pump-and-treat operations will not match field observations.

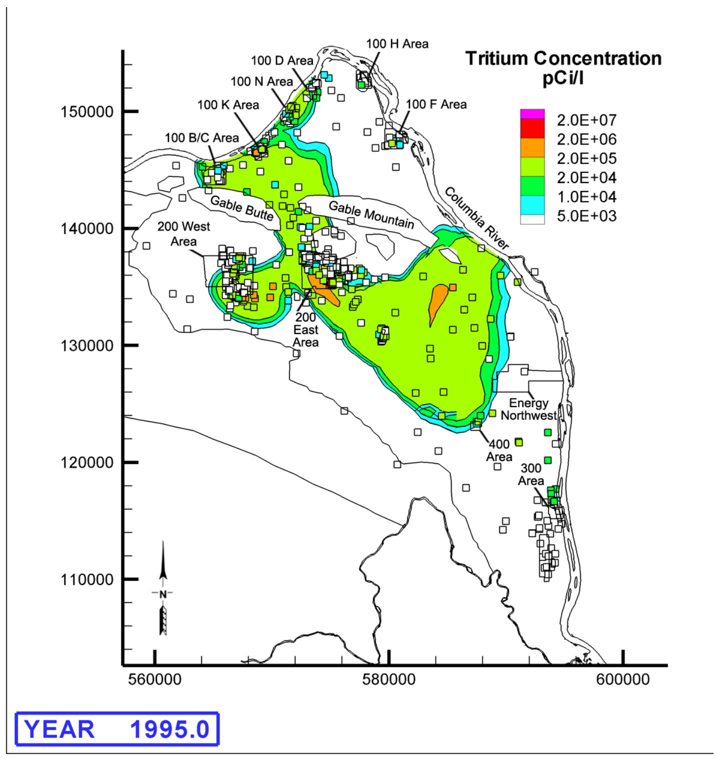

Figure 3.3. *Tritium plume median value run with tritium values measured in wells in 1995. Model result is colorized contour plot. Measured values are colorized squares at well locations.*

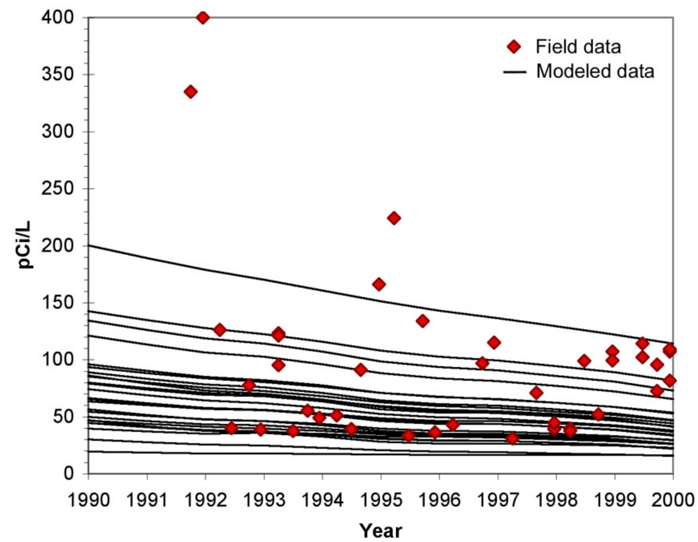

Figure 3.4. *Comparison of sampled and modeled concentrations of tritium in near-shore river water at the Richland municipal water intake. The SAC initial assessment is in general agreement with observed field data.*

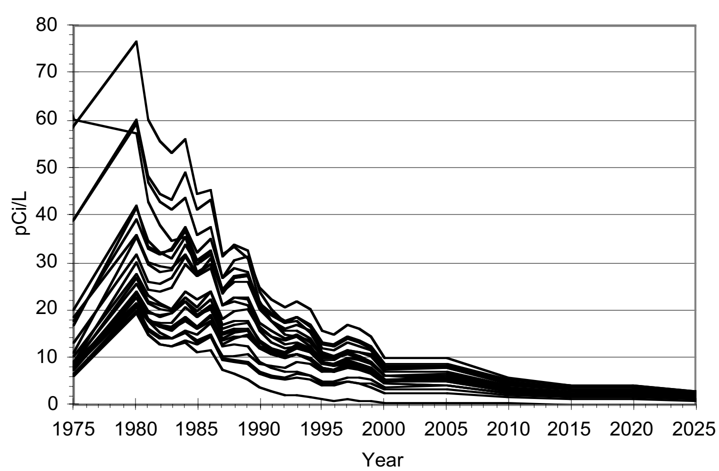

Figure 3.5. *Modeled Hanford contribution to the flow-averaged concentrations of tritium in near-shore Columbia River water at the Richland municipal water intake. The initial assessment indicated tritium concentrations are declining and will continue to do so.*

The river model accounts for hydrodynamics (water elevation and velocity) and contaminant transport in the water column and the riverbed of the Columbia River. The river model transports tritium from two sources. First, tritium enters the model at the upstream boundaries (Columbia River at the Vernita Bridge, Yakima River near Richland, and the Snake River at Ice Harbor Dam) in the form of background water concentrations, which are from tritium produced by natural processes that makes its way into the Columbia River. The natural levels in the river have been augmented by fallout from past testing of nuclear weapons. Second, tritium enters the river along the Hanford Reach as contaminated groundwater from under the site discharges into the river. Figure 3.4 shows a comparison of sampled and modeled concentrations of tritium in near-shore river water during the 1990s near the Richland municipal water intake. The sampled data, represented by red dots, are grab samples taken during a variety of low and high river flow conditions. The modeled data, shown as black lines, represent the annual time-averaged concentration results for each of the 25 realizations. The grab samples exhibit considerable variability as is expected given the variability in river discharge and stage.

The sampled data and modeled results are difficult to compare because sampled data represent point estimates and modeled results represent annual flow-averaged values. However, the response of the annual time-averaged model should lie within the range of the grab samples which experience greater extremes because of the variability of river conditions. The general structure of the declining near-shore tritium concentrations also is duplicated by the annual time-averaged model response. Accordingly, there is general agreement between these two results.

The river model is run twice for each realization. The first run models only background concentrations of tritium. The second run models background concentrations plus the influx groundwater from the site. These two runs can be differenced to obtain the concentrations due to the Hanford contribution. Figure 3.5 shows the modeled Hanford contribution to the concentrations of tritium in the near-shore Columbia River water at the Richland municipal water intake. The modeled results indicate that tritium concentrations from Hanford sources are declining in the Columbia River and will continue to do so in the future.

The drinking water standard for tritium is 20,000 pCi/L.

Risk/Impact. Impacts are estimated for four components of the environment and society: ecological health, human health, economic conditions, and cultural resources. Adverse effects result when contaminant concentrations in groundwater, soil, sediment, and/or surface water exceed certain thresholds.

Because several media may jointly influence a component of the human environment, thresholds are based on total exposure to all contaminants in all media.

The initial assessment successfully demonstrates that sitewide assessments can go beyond human health and consider the ecological health of the riparian and river environments, economic impact to the region, and cultural impacts. Impacts for these other components do not necessarily correlate strongly with the impact to human health; thus, they provide additional information on potential consequences of contaminant concentrations in the environment.

The impact to ecological health, economic conditions, and cultural resources does not necessarily correlate strongly with the impact to human health; it provides additional information on potential consequences of contamination in the environment.

The spatial coverage of the Risk/Impact Module covers those areas of the Hanford Site, the Columbia River corridor to McNary Dam, and the Tri-Cities area that have been identified as being of greatest interest to DOE, the regulators, and the public. Human health and cultural resource impact components, for example, cover all of the upland Hanford areas that are being considered for retention as buffer zones. All the risk/impact modules cover the entire Columbia River corridor from Vernita Bridge to McNary Dam.

Predictions of risk from 1944 to the present for the HUMAN (human health), ECEM (ecology), and culture models closely match monitoring data for most contaminants. One of the metrics for the cultural resource component is the total area of the Hanford Site where concentrations in groundwater exceed drinking water standards. For the year 2000, the area estimated from the SAC simulation was within 5% of the area estimated from ground-

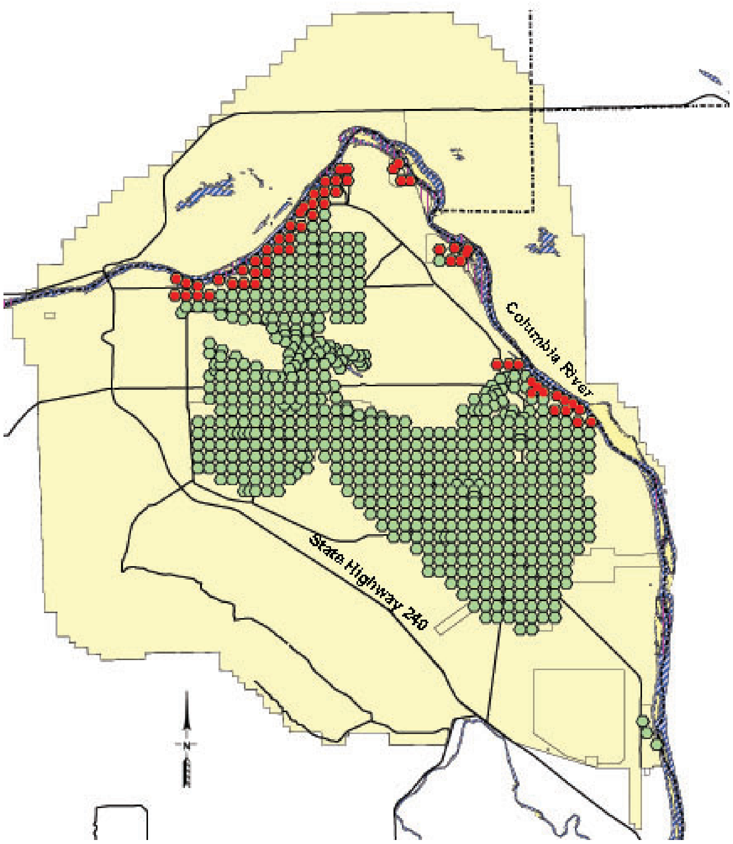

__Figure 3.6.__ Areas where the initial assessment estimated groundwater concentrations exceed drinking water standards in any year in any simulation for any contaminants (circles); those areas intersecting the Hanford Reach National Monument shown in red.

water monitoring information that year (246 square kilometers [95 square miles] predicted versus 233 square kilometers [90 square miles] observed). Figure 3.6 illustrates the area of the groundwater that exceeds drinking water standards in any year, in any realization, for any contaminant, and therefore, represents a maximally affected region. Estimated contaminant concentrations in biota of the Columbia River in the 100 and 300 Areas were within 15% of observed values for all contaminants except iodine-129, based on average values from the past decade. Estimates of human health risks based on simulations through the past two decades for upland farmers are roughly equivalent to those estimated from field monitoring data during that period.

Key findings from the risk/impact simulations include:

- Tritium dominates risks to humans in the upland farmer scenarios through the year 2050, with technetium-99 becoming dominant afterward.

- Risks from iodine-129 based on the initial assessment are significantly below those estimated from monitoring data.

- Future releases to the aquifer from waste residing in the vadose zone, (e.g., specific retention trenches, solid waste, unplanned releases including tank leaks) will not flood into the aquifer as earlier large-volume crib discharges did. Instead, they will slowly leak into the aquifer and create smaller plumes of contamination.

Figure 3.7 illustrates an overriding conclusion of the human-health simulation. Based on the set of contaminants, the period of the assessment, and the preliminary results achieved, the estimated dose to a hypothetical resident farmer from using groundwater at a location east of the Central

Plateau would decline from present day levels. During the next thousand years the uncertainty places the dose between 10 and less than 0.1 mrem per year with a median value of 4.3 mrem per year. The trend seen here is a result of the decay of tritium and the growing significance of isotopes of technetium, iodine and uranium that have longer decay half-lives and are, therefore, more persistent in the Hanford environment. An improvement in the iodine-129 inventory estimates and projections of its migration may raise risk and impact estimates somewhat.

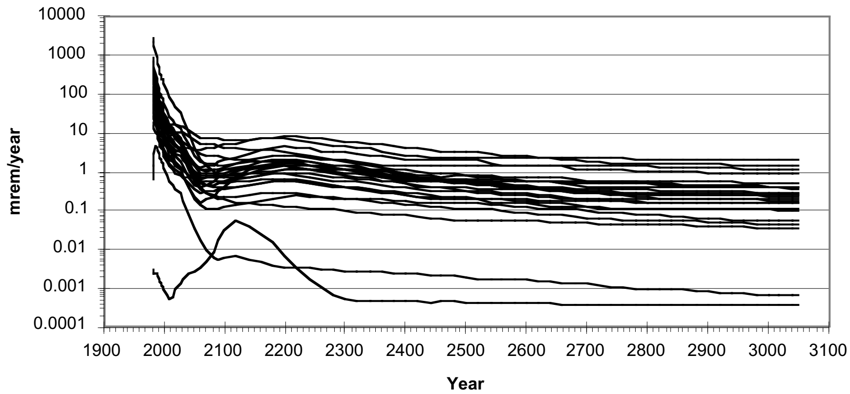

Figure 3.7. *Time series of estimated annual radiological doses to resident farmer living just east of 200 East Area.*

Uncertainty. A request of the regulator, stakeholder and Tribal Nation Community (DOE/RL 1998a) was to create a capability to quantify the uncertainty in the projections of environmental consequence and risk/impact. The SAC initial assessment meets that request by using a Latin Hypercube (Iman and Conover 1982) Monte Carlo simulation approach. This approach allows quantification of the uncertainly caused by parameter variations within the modeling system. The approach does not address model uncertainty or differentiate between uncertainty due to lack of knowledge and that due to inherent variability in the parameters. The uncertainty analysis identifies controlling sources of variability in the simulation estimates of the risk/impact measure, but not necessarily the source of the overall magnitude of the risk/impact measure. Contributions to the overall magnitude can be obtained from direct examination of the model results.

The goal of an uncertainty analysis is to determine where uncertainty in model parameters contribute the most to the variability in risk/output. The SAC models support analyses to identify the sources and origins of uncertainty.

The SAC models allow identification of the parameters having the largest contribution to the variability in any of the risk/impact measures such as radiation dose to a human, exposure of a rainbow trout in the river, or groundwater plume size. The SAC model, being a sitewide model that includes effects to the shoreline and in the river, has a large number of possible risk/impact measures. The risk/impact measures can be evaluated for many different combinations of exposure scenarios, and locations and times of interest.

The goal of an uncertainty analysis is to determine the model parameters that contribute the most to the variability in risk/impact measures. For

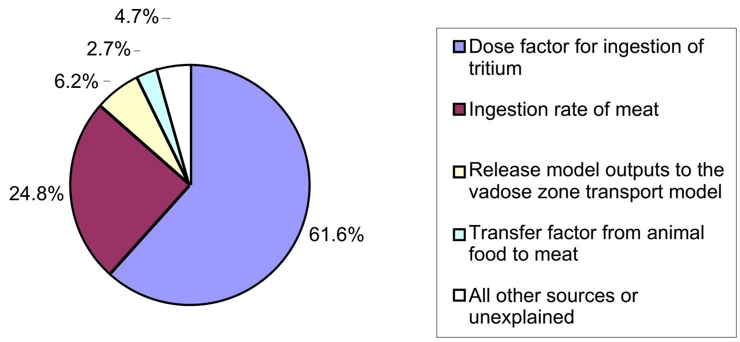

Figure 3.8. *Key parameters driving the uncertainty in the radiation dose to a residential farmer living downgradient from the 200 East Area in the year 2000.*

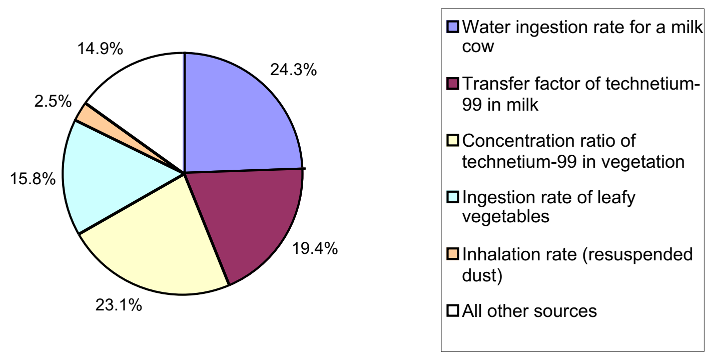

Figure 3.9. *Key parameters driving the uncertainty in the radiation dose to a residential farmer living downgradient from the 200 East Area in the year 3000.*

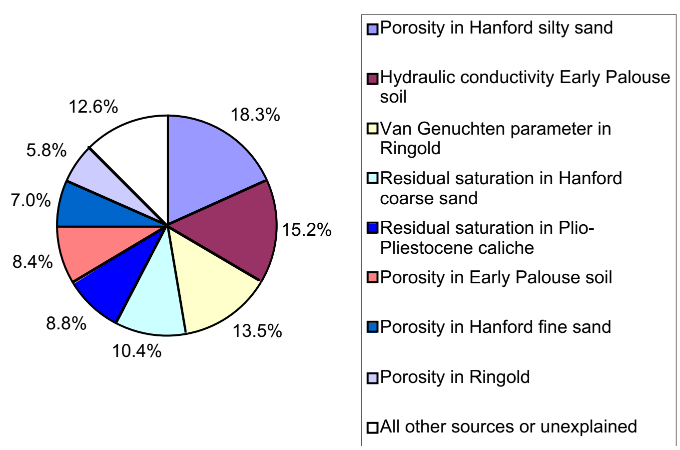

Figure 3.10. *Key sources of uncertainty in the delivery of tritium to the water table in the year 2000.*

example, the key parameters driving the uncertainty in the radiation dose to a residential farmer living down gradient from the 200 East Area in the year 2000 is provided in Figure 3.8. The variation in the dose factor for ingestion of tritium (an input to the human exposure model) explains 61.1% of the variation in the dose to the farmer. An additional 24.8% of the variability is explained by the variable ingestion rate of meat in the farmer's diet. In this particular case, 99.9% of the magnitude of the dose is due to tritium, and a small amount is due to the other eight radioactive contaminants. In this case, only about 6.2% of the variability in the farmer's dose is due to models that release and transport tritium.

The dominance of ingestion rates in determining the variability of residential farmer dose points to an issue with regulatory assessments. Assessments conducted in compliance with DOE and EPA guidance fix ingestion and uptake rates despite their known variability. Hence, results of regulatory assessments will not point to theses rates as a dominant source of uncertainty. Rather, attention will be shifted to the model elements that release and transport tritium, and other contaminants.

The leading sources of uncertainty for this exposure scenario change when a different time period is examined. For the same residential farmer scenario, 99.84% of the variability in the total dose in the year 3000 is due to the variation in the dose from technetium-99. Further examination of the variability in the technetium-99 dose identified the key sources of variability shown in Figure 3.9. In this case, essentially all the variability in the technetium-99 dose was due to parameter variability within the human exposure model, including the calculation of technetium-99 concentrations in food products, rather than in the models that produce technetium-99 concentrations in groundwater. The largest source of variability (43.7%) is due to milk pathway and another 23.1% comes from uncertainty about uptake of technetium-99 in vegetation.

Another analysis examined the sources of uncertainty in the delivery of tritium from the vadose zone to the water table. This analysis was prompted because the size of the groundwater plume where concentrations are above the drinking water standard is driven by tritium in the groundwater at the current time. Figure 3.10 identifies the variables that are key sources of uncertainty in the SAC initial assessment for delivery of tritium to the water table in 2000. For this example, the key variables are all parameters in the vadose zone water flow and contaminant transport models, and no single variable dominates the overall uncertainty.

The SAC models support uncertainty analyses to determine the sources of variation in exposure and impact results. These analyses provide insight to help guide future investigations to obtain data or update models to help reduce the overall output variability. Given the number of performance measures, time periods, and exposure scenarios of interest, it appears necessary to retain the full suite of uncertain parameters in the models at this time.

Resolving inconsistencies between old discharge records and actual field data of contaminants in the environment will help refine the assessment results.

An Alternate Case. An alternative assessment examining the importance of protective surface barriers was recently completed. The initial assessment was rerun without infiltration-reducing barriers. This action is not being considered for waste sites and was chosen only as a simple illustration of the capability. The principal difference between the initial assessment and the no-covers case is the assignment of infiltration rates following the operational period. While values of infiltration at each waste site depend on local soil, vegetation, and climate conditions, in general when a Modified RCRA Subtitle C Barrier (DOE/RL 1996b) is placed above the waste there is an infiltration rate of 0.1 millimeter (0.0039 inch) per year applied for 500 years and it thereafter increases to the pre-site infiltration rate. When no cover is applied the operational infiltration rate continues for the 500-year period, and it thereafter decreases to the pre-site infiltration rate. Typical infiltration rates during the operational period in 200 West Area are 17.3 millimeter (0.682 inch) per year for undisturbed soil without vegetation, 55.4 millimeter (2.183 inches) per year for disturbed soil without vegetation, and 104 millimeters (4.098 inches) per year for gravel surfaces. Thus, for a 500-year period the difference between covers and no-covers can be between a 200 and 1,000 fold difference in infiltration rate.

The initial assessment performed reasonably well when compared to historical and field data.

This no-cover assessment illustrates how alternatives at Hanford can be modeled with SAC by examining a critical design function of planned protective barriers, i.e., the reduction of infiltration rate into the vadose zone, and, hence, the recharge rate into the aquifer. The lower infiltration and recharge rates imply slower waste migration through the vadose zone and into the aquifer.

In general terms, for the no-cover assessment, the releases to the aquifer and the associated risk/impact nearly double for uranium and quadruple for technetium-99 during the 1,000-year period of the initial assessment. The no-cover alternative demonstrates clearly the importance of protective barriers to control the future release rates of contaminants, especially more mobile contaminants like technetium-99 that may significantly contribute to human dose and other risks and impacts.

Conclusions

Cumulative, sitewide assessments will influence the decision to allow continued disposal of low-level waste at the Hanford Site. The composite analysis required by DOE Order 435.1 is a direct input to this decision and it influences the disposals of low-level waste in solid waste burial grounds, immobilized low-activity waste and melter components from the waste treatment facility in their disposal facilities, and CERCLA waste in the environmental restoration disposal facility. Site-specific decisions by DOE on the priority and acceptable levels of cleanup and remedial action will rely on this assessment capability to provide the sitewide context for decisions. These actions will include the final decisions for groundwater remediation for both 100 Areas along the river corridor and the 200 Areas on the Central Plateau. Decisions on the safe closure of single- and double-shell tanks also will use this capability to provide the sitewide context for specific tank and tank farm decisions. It is envisioned that all decisions requiring consideration of the cumulative, sitewide, long-term risk and impact will rely on the SAC and its future revisions.

The SAC also can be used to examine many of the Hanford Site's assumptions about the inventory of chemicals and radionuclides in Hanford waste, how chemical and radionuclides release from the various types of waste, and how those materials move through the environment. For example, current inventory records and chemical process knowledge used to estimate inventory where records do not exist can, for some contaminants, be inconsistent with field observations of vadose zone and groundwater plumes. A consistent and holistic inventory will result from further resolution of inconsistencies among process knowledge and measured waste composition, discharge records and estimates, and field observations of contaminants in the environment, (e.g., iodine-129 releases to the atmosphere and vadose zone from the PUREX Plant, and technetium-99 releases from U Plant). Given that total inventory is relatively well known, as we become more confident about past disposal and leak inventories, we become more certain about the inventories remaining in tanks awaiting treatment and disposal. Also, the past use of specific retention trenches to dispose of scavenged uranium metal waste can be compared to past tank leak behavior. The radionuclides in the waste leaked from tanks are known to have reached the water table in some instances, and the comparison of these two types of events can provide insight into the potential significance of accelerating the placement of covers on sites that have not yet released to groundwater. SAC predictions can guide field investigations targeted to discriminate among alternate concepts of where this material is and how it is moving.

Using a variety of risk/impact metrics that represent public values, this capability can provide decision makers with an estimate of incremental risk from alternate remedial action and waste disposal options at points between the Central Plateau and the Columbia River. The SAC is a stochastic analysis with an option to perform a single deterministic simulation, and has resulted in the assemblage of parameter distribution information. Accordingly, SAC can provide stochastic assessments illustrating the uncertainty of options, or median valued assessments of various options. Such analyses can reveal whether proposed remedial actions reduce risk, delay an ultimate risk, or have virtually no impact on risk because cumulative risk is governed by other releases.

Site-specific decisions by DOE on the priority and acceptable levels of cleanup and remedial action will rely on this sitewide assessment capability to provide the context for decisions.

In the broad context of a sitewide assessment, SAC is a tool currently available at Hanford that can be used to evaluate the influence of features, events, and processes related to waste site cleanup, contaminant transport, and risk/impact to public health and the environment. Through a better understanding of the sources of uncertainty, this capability allows DOE and regulators to prioritize research (e.g., vadose zone hydraulics in the case of tritium plume and near-term dose) and site surveillance and monitoring activities (e.g., monitoring and characterization of BC cribs and trenches).

The SAC model, as demonstrated through the initial assessment, has done well compared to success criteria developed prior to the assessment. The capability was to be able to simulate:

- Up to 10 radioactive and chemical contaminants.
- A 1,000-year post-closure period.
- Waste deposits from the operational areas in the river corridor and Central Plateau.
- An uncertain environment and risk/impact setting.
- A suite of metrics and exposure scenarios evaluating risk and impacts to human health, ecology, economics, and culture.

In addition, SAC performs reasonably well when compared to success criteria associated with matching historical observations. This initial assessment has duplicated the historical events and processes that created the major groundwater plumes of the mobile contaminant tritium. Most of the major deviations with regard to contaminant plumes arise from discrepancies in waste-site-specific inventory and conceptual models of vadose zone transport. This means the capability can provide the needed analyses when data gaps are filled and alternate conceptualizations are evaluated and incorporated to achieve better agreement with field data.

As SAC moves from a demonstration mode to an application mode, additional data and model improvements will be important to obtaining more credible results.

Recommendations

A major purpose of the initial assessment was to demonstrate the capability to conduct a sitewide assessment while providing uncertainty estimates for a wide group of performance measures. The computational tools to perform these analyses have been developed and demonstrated. However, as SAC moves from a demonstration mode to an application mode, additional data and model improvements will be important to obtaining more credible results.

Performing an assessment always requires making assumptions and modeling choices that limit the applicability of the results. In addition, site-specific data to run the models are often unavailable, thus, completion of an analysis relies on surrogate data. The following recommendations for future assessments address some of the data limitations of the SAC initial assessment:

- Improve the inventory estimates for a number of sites using process knowledge or field observations. Examples include technetium-99 discharges at U Plant, technetium-99 export and import with reprocessed uranium, iodine-129 liquid discharges at the PUREX and REDOX Plants, chromium releases near the D Reactor, uranium in the 300 Areas, and tritium at some of the 618-11 solid waste burial site.

- Improve the accuracy of the release and vadose zone transport models through site-specific data collection. The release model data needs include solubility limits and dissolution rate data for a number of waste forms. The vadose zone model can be improved with better information on soil and hydraulic properties, as well as site-specific geologic profile information for many sites. Also needed are soil/water partition coefficients specific to a suite of chemical and water flow regimes.

- Improve the accuracy of the groundwater transport model. Improvements include a more finely resolved grid, calibration against observed plume movements, and additional site-specific data on soil/water partition coefficients.

- Obtain better data to describe the inflow boundary conditions for sediment and background contaminants at the Vernita Bridge, and the Yakima, Snake, and Walla Walla Rivers and at the effluent boundary of McNary Dam.

- Obtain more species and contaminant specific data for the uptake of contaminants in the ecological food-web model.

SAC is scheduled to provide primary or supporting calculations for a number of projects over the next few years.

At present, SAC is scheduled to provide primary or supporting calculations for a number of projects over the next few years. The combined analysis needs for the composite analysis, the Tank Farm Accelerated Closure Demonstration Project, groundwater remedial actions, and environmental impact statements have a number of implications for the requirements of the tool in the future. The major implications are the following:

- An air pathway model must be added to allow the all pathway analysis called for in the composite analysis to be performed. This new model has requirement implications for the source term, release, air transport, soil concentration, and impacts modules.

- Models for releases from a glass waste form, release of carbon-14 and chlorine-36 from buried graphite reactor cores, and releases from buried naval reactor compartments are needed.

- A multiple-phase model is needed to more accurately track the movement of carbon tetrachloride in the vadose zone.

- The capability to run 10,000-year or longer analyses is needed.

- The capability to more closely match modeling results from other projects requires incorporation of a two-dimensional or three-dimensional vadose zone transport model and the ability to accept results produced by others for specific waste sites.

- The ecological model needs to calculate upland animal and food crop concentrations, in part to support human risk estimates utilizing food crops and animal products.

Simulations for the initial assessment yielded information and insights about the migration and fate of Hanford Site contaminants of interest. They also provided needed information on the design and performance of a system that will contribute to an improved assessment capability in the next year. With further refinement using improved conceptualizations of contaminant transport and greater consistency between inventory discharges and field observations, SAC will become an integral part of the decision process for cleanup and closure.