ALTERNATE TECHNICAL STRATEGIES TO SUPPORT THE CHARACTERIZATION AND MANAGEMENT OF GROUNDWATER CONTAMINATION AT THE NEVADA TEST SITE

by
Earle C. Dixon
Technical Advisor NTS CAB
Greenspun College of Urban Affairs
University of Nevada, Las Vegas
and
Dennis Weber
Harry Reid Center for Environmental Studies
University of Nevada, Las Vegas

ABSTRACT

Beginning in the late 1950's, the Nevada Test Site (NTS) was the scene of 828 subsurface nuclear weapons tests, 160 of which probably have created contamination plumes in the groundwater. The Department of Energy (DOE) is faced with the unique challenge of understanding the extent and magnitude of underground contamination. The technical task is complicated by the variability of nuclear device types and sizes, the NTS hydrogeology, the depth of tests, and the paucity of data for such large regions. The regulatory driver is complicated by economics and constraints that impose a goal and a loosely defined generic strategy to achieve the goal. The goal is to accurately define for a 1000 year period a contaminant boundary around the nuclear test areas for which a person drinking the groundwater would not accumulate a dose of more than 4 mrem/year. To date the DOE strategy to estimate contaminant boundaries has not been found realistic enough to be acceptable. The strategy is: 1) create a numerical groundwater model of the regional hydrologic system (9,000 sq. mi.) surrounding the NTS (1,350 sq. mi.); and 2) create local scale (100 sq. mi.) numerical groundwater models to predict the 4 mrem/yr boundary for each NTS area. Since data are limited at both modeling scales, boundary conditions for the local scale model are derived from the regional model. The strategy places more emphasis on complex, sophisticated modeling over field data acquisition and local problem identification. Paucity of data and procedural flaws have plagued this approach, which unfortunately has lead to very little new understanding of the contamination and groundwater flow. The authors, deriving ideas partly from external peer reviews of the DOE's program, believe that such a large and complex project such as this one requires a different approach based on an iterative process of problem identification, small-scale probablistic modeling and limited field data acquisition. In this manner, some problems become understood and possibly eliminated, hence gradually narrowing the focus and scope of the project to a more credible, manageable, and regulatorally acceptable level.

INTRODUCTION

The overall goal of the Department of Energy's (DOE) Underground Test Area Program (UGTA) is to understand the migration and strength of radioactive contamination in the groundwater

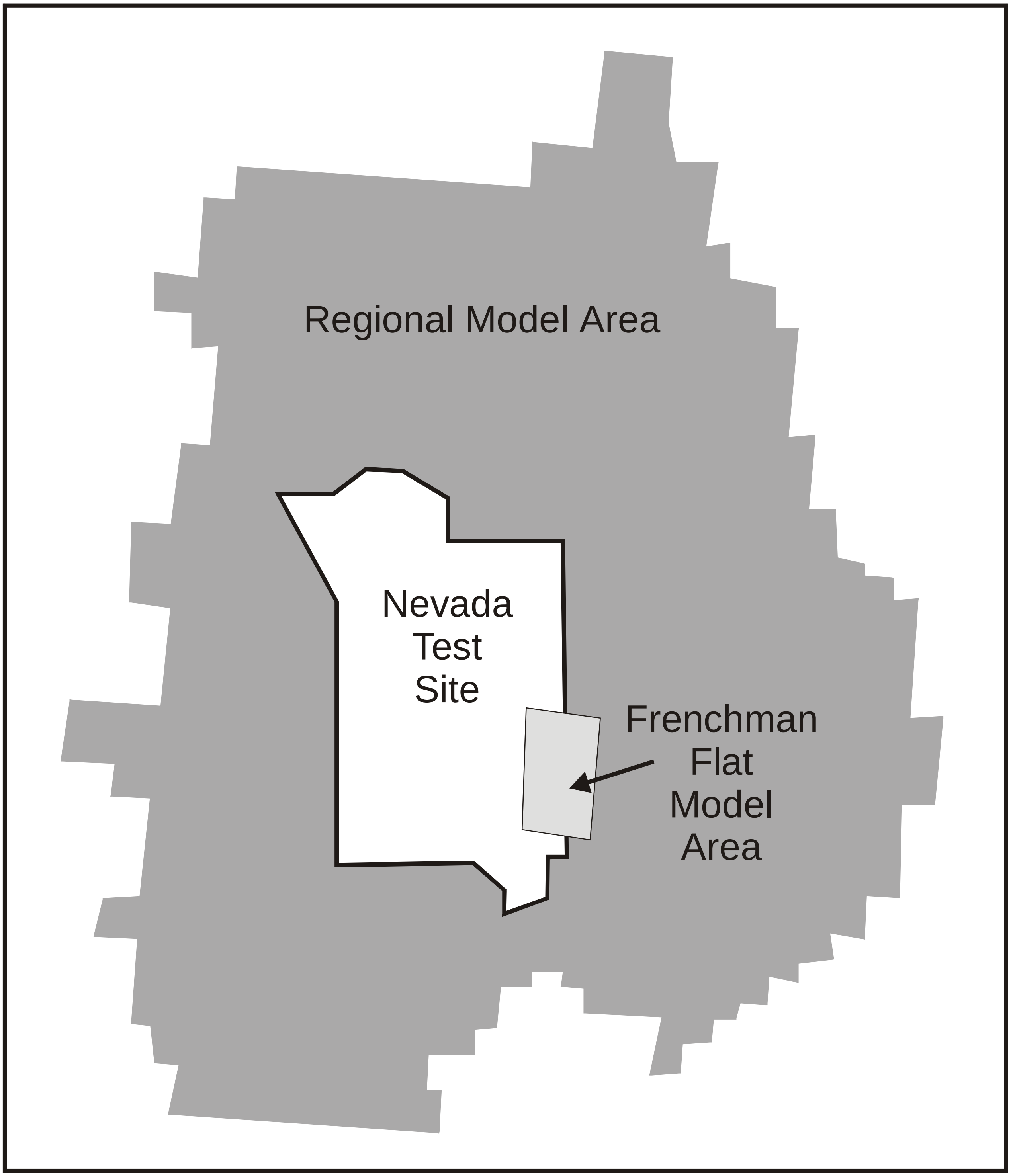

Figure 1. Regional Groundwater Modeling Area, NTS Area, and Frenchman Flat Model Area.

beneath the Nevada Test Site (NTS) caused by subsurface detonation of over 900 nuclear devices during the years 1961-1992 (Figure 1). The goal of UGTA is driven by a 1996 regulatory agreement between the DOE and the Nevada Department of Environmental Protection (NDEP) that requires determination of the extent of contaminated groundwater unsafe for public use **(1)**. The original agreement maintained that sufficient hydrologic and radiological source term data already existed to predict (by using models) the contaminant boundary for a 1000-year period within a 95% level of certainty**. Almost an exclusive use of predictive models (as opposed to a balance of modeling and data acquisition) was preferred as a reliable and cost-effective strategy. The more conventional approach would rely more heavily on drilling and testing monitor wells to characterize groundwater flow and contaminant plumes near known detonation cavities**. The depth of contamination, the huge areal extent of the NTS groundwater system, and limited financial resources drove the DOE to heavier reliance on models that used existing but inadequate data.

About 260 nuclear weapons tests detonated near or beneath the water table contaminated large volumes of material and groundwater with radionuclides (radiological source terms, which are the original inventories of radionuclides produced by the bombs) that can be transported by the groundwater. The yield (the energy expended) of the nuclear weapons ranges from less than one kiloton to about 1.3 megatons, but since each device was designed differently, it is unreliable to relate directly the production of Curies from individual radionuclides to the yield. Consequently, it is impossible without access to classified information to calculate realistically the abundance of each radionuclide from a given detonation. **Because the radiological source term is classified, and the present DOE policy is to not characterize (*or chase*) the contamination that leaves the cavities by groundwater transport (the contaminant plume, or the hydrological source term), very little is known about the groundwater contamination**. There are possibly 260 contaminant plumes that have been migrating for up to 40 years with the groundwater flow, but there are no data to reveal their constituents, concentrations, sizes, and locations.

HISTORICAL BACKGROUND OF UGTA

In 1989, the DOE undertook a project to understand the underground contamination at the NTS. The program, originally the Groundwater Characterization Project (GCP), consisted of a two-phase approach **(2).**

Phase I involved the creation of a huge regional model of the Death Valley Aquifer, which encompassed an area of 9,000 square miles and included the 1,350 square mile area of the NTS. Some areas spanned by the regional model have adequate data, but hundreds of square miles in southern Nevada have no hydrogeologic information. Even though the database was sparse and scattered, the GCP's long-range plan was structured to link its regional flow model with local-scale models to help predict contaminant boundaries. Consequently, rather than focusing on the local scale to characterize local contamination and groundwater flow, the DOE created a regional model, which neither fulfilled regulatory requirements nor added significantly to the knowledge base. The regional model suffered from a range of deficiencies inherent in such a large, scale effort for a complex and data sparse area. In 1997, an external peer review found major deficiencies with the model and emphasized that results obtained from the model had uncertainties that were unacceptably high **(3)**.

Phase II was based on a concept that around 100 deep monitoring wells would be installed at the local scale over a ten-year period for all of the underground test areas. The GCP monitoring well program was a scaled-down approach compared to the hazardous waste industry's one up gradient, two down gradient, approach for hazardous waste site characterization**. However, if the conventional approach for hazardous waste site characterization were applied to the 260 test sites in or near the water table, then approximately 780 wells would be needed at the NTS.** If the conventional characterization approach were applied to *all* NTS underground test sites, the total number of monitor wells would be several thousand, which is cost prohibitive. It is also particularly noteworthy that many NTS groundwater characterization wells are quite deep (up to 5000 feet), whereas, most hazardous waste site monitor wells are less than several hundred feet deep.

However, the two-phase GCP approach changed officially in 1996 (as did the name to UGTA) when the DOE and the Nevada Department of Environmental Protection (NDEP) came to a legal agreement over the environmental clean up of the NTS. This agreement is the Federal Facility Agreement and Consent Order (FFACO.) Apparently, both agencies wanted to keep the NTS off of the Comprehensive Environmental Reclamation Compensation Liability Act (CERCLA) National Priority List (NPL) for very good reasons. Placement of the NTS on the NPL or Superfund List was viewed as a time-consuming, resource intensive, and complicated regulatory process that would result in precious funds expended more on bureaucracy than on actual environmental fieldwork. **Moreover, it is widely believed that Nevada resources were made available to support the defense testing mission, and environmental management funds are simply not available to clean up NTS areas when the risks to the public are assumed to be very low.** Consequently, the agencies negotiated a CERCLA-like agreement to address NTS underground contamination that involved only the DOE and the NDEP with no formal third party oversight like the Environmental Protection Agency (EPA) or the Nuclear Regulatory Commission (NRC).

Federal Facility Agreement and Consent Order

In 1996 the DOE and the NDEP officially signed the FFACO, which formally requires the DOE to investigate the severity of underground contamination at the NTS as part of its responsibility to protect public health and the environment. Since the total area of underground contamination at the NTS is so large (300 square miles), the approximately 900 below surface detonations were divided into six administrative groups called Corrective Action Units (CAUs) based on their geographic locations. The FFACO provides a generic corrective-action process to address underground contamination and to predict a 4 mrem/yr contaminant boundary (CB) around each CAU valid for a 1000 year period at a proposed 95% confidence interval (Figure 2). The boundary is the imaginary line around a CAU, beyond which a resident can drill a well and consume the groundwater without exceeding a dose of 4 mrem/year. The UGTA project is charged with implementation of the strategy to predict the 4 mrem/yr contaminant boundary.

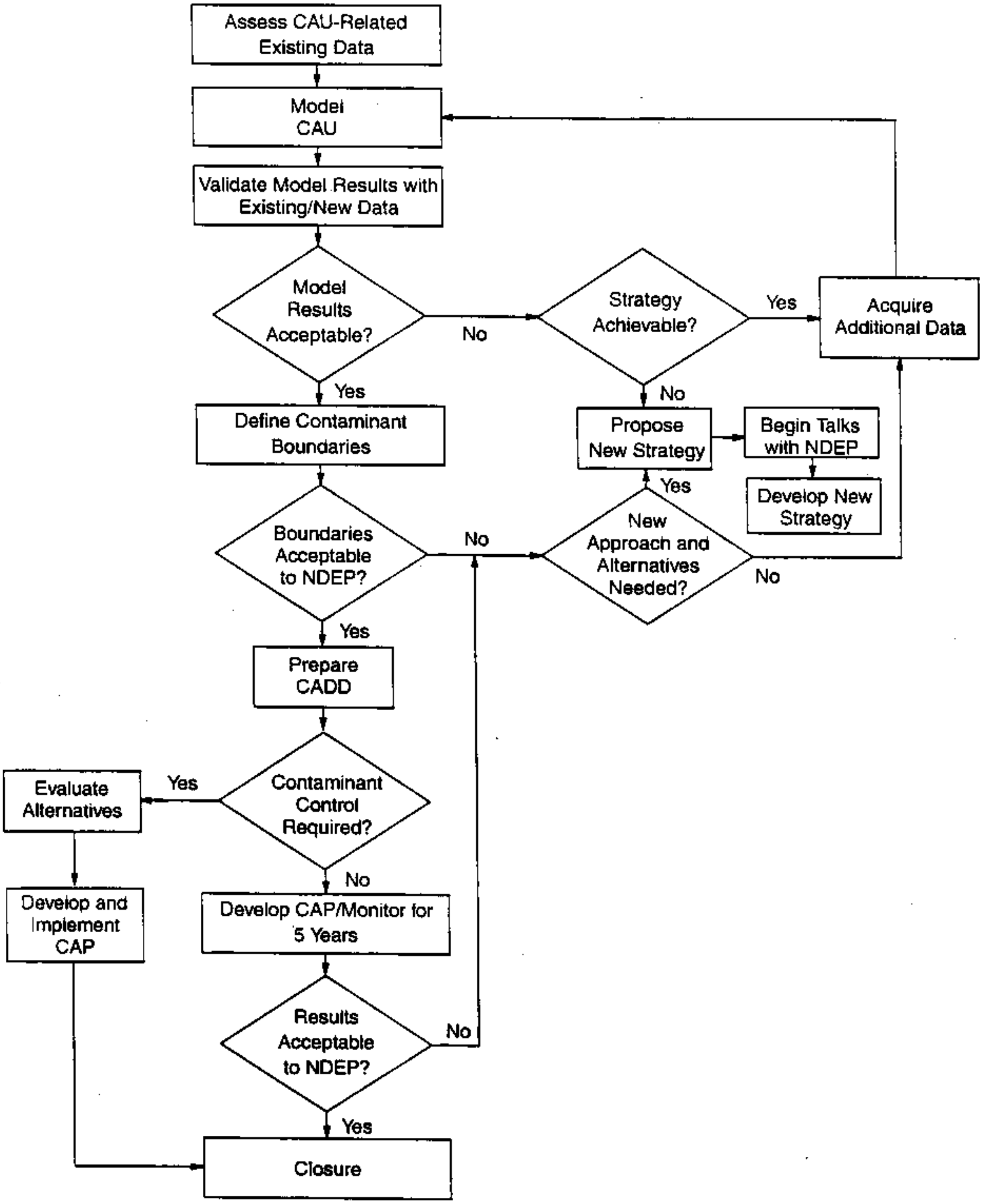

Figure 2. Process Flow Diagram for Underground Test Area Corrective Action Units.

When the FFACO became the official regulatory driver for the UGTA project, a new strategy was adopted. Appendix IV of the FFACO states that the second phase will use only existing data to model (predict) the CB around each CAU, and the 100-well program to acquire new data was dropped from the new strategy. To some local experts, this was unacceptable because there were already too few hydrogeologic data, and credible prediction of the CB prediction would require additional data at the CAU scale. They were right! **The new FFACO strategy compounded the fundamental UGTA problem and it encouraged or forced a preference (or over reliance) on modeling at the expense of acquiring data**. Nevertheless, the DOE moved forward with the implementation of its strategy to link local-scale modeling with the regional-scale flow model. The Frenchman Flat area was selected as the first CAU to demonstrate a successful modeling strategy to predict the CB, and to establish a transferable template for other CAUs.

Frenchman Flat CAU

In 1996 the DOE began its effort to model and predict the CB for the Frenchman Flat CAU using only existing data **(4)**. The FF-CAU is understood to be the most innocuous CAU because it contained only 10 detonations, none of which exceeded 20 kilotons of yield. All ten underground tests were conducted in the (upper) alluvial aquifer system, which lies above the lower carbonate aquifer (LCA). The LCA could possibly carry radioactive contamination off site to down gradient, residential communities. An aquitard separates the two aquifers, but heavy faulting might create pathways between them such that alluvial contaminants might be transported along faults to the lower carbonate system and then off site.

The DOE's strategy to predict the contaminant boundary at the FF-CAU can be lumped into four basic components (Figure 3). One component is the conceptual model, i.e., the geologic structure, the stratigraphy, the hydraulic characteristics, and the groundwater system behavior. A second component is a theoretical model created to predict the hydrological source term from the classified radiological source term. This second component is needed because the DOE prefers not characterize the hydraulic source term by drilling. The third component was a local-scale finite-difference groundwater flow and transport model of the FF area. The fourth component was the linking of the regional model to provide boundary conditions (flow and hydraulic head conditions) and a method to deal with parameter uncertainty.

In 1998, a Value of Information Analysis (VOIA) for the FF-CAU stated that there was insufficient information to determine if there is leakage from the alluvial aquifer into the lower carbonate aquifer or to determine the direction and speed of lateral flow. Furthermore, vertical flow would be the most threatening pathway**.** In spite of this knowledge, the DOE surprisingly decided that additional data were unnecessary and the new FFACO strategy would prevail. **Subsequently, a conceptual model was decided upon that neglected vertical flow, and also surprising is the fact that the flow direction in the conceptual model disagreed with the direction predicted by the regional model in the same aquifer**. This disagreement meant that the regional model had to be recalibrated before it could be linked up with the local model for FF. Remember that the regional model was considered to provide input into the FF model!

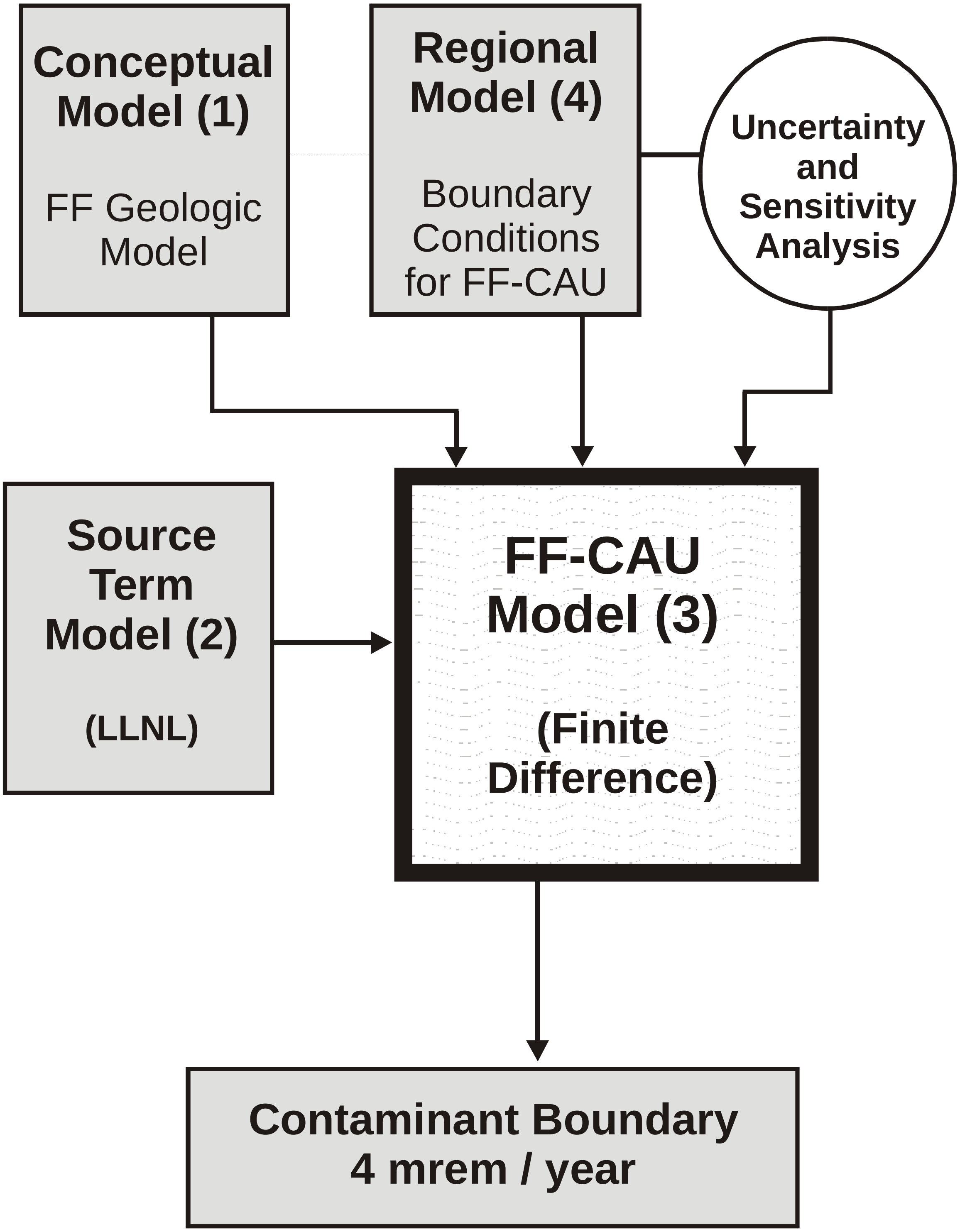

Figure 3. Frenchman Flat Modeling Process to Predict the Contaminant Boundary.

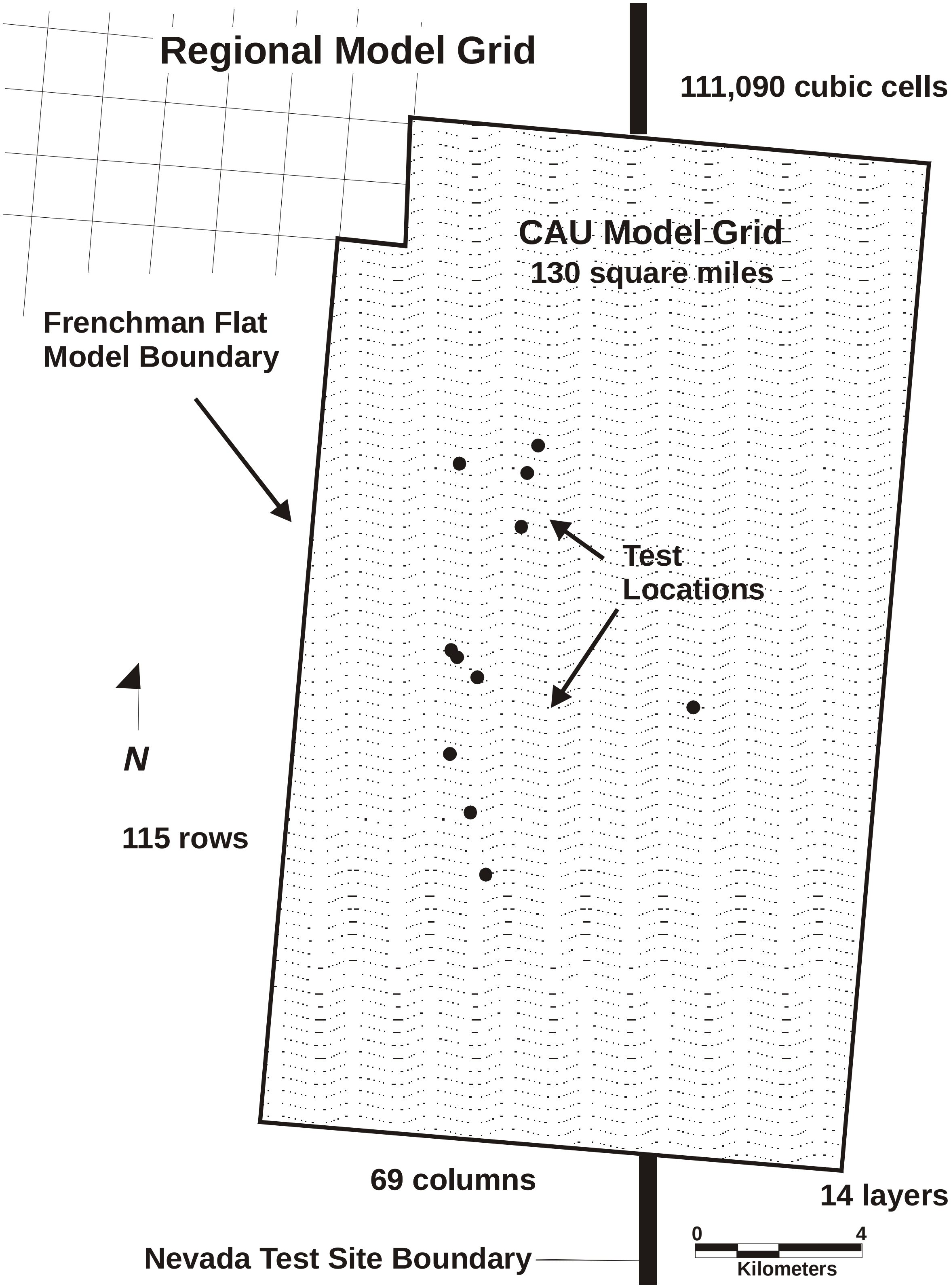

Figure 4. Frenchman Flat Local Scale Modeling Grid and Data Points.

The DOE chose finite-difference model (SWIFT) as their local-scale flow and contaminant transport model. SWIFT is an outdated, slow model, and because it uses finite difference, it was not able to fit the faulted irregular blocks and layers comprising the aquitard between the alluvial and lower carbonate aquifers as described by the conceptual model. In addition, constraints on gridding caused dilution of the contaminant source term. The SWIFT flow and transport model covered 135 square miles of area and was comprised of about 111,000 rectangular cells. Data support for this model, however, was based on a scant line of about ten monitoring wells (Figure 4). SWIFT was coupled with the regional model (after recalibrating the regional model) as planned in order to use regional model boundary conditions in the SWIFT model, and to form a loop with the two models to use for Monte Carlo simulations to obtain uncertainty information. Although predictions were made of the CB for the FF-CAU with this modeling system, SWIFT model was too slow (one run took about 90 minutes) to use in a Monte Carlo mode, and the cumbersome linkage with the regional model did not produce scenarios that were within calibration.

The External Peer Review Group Report

In May of 1999, the DOE commissioned a blue ribbon external peer review group (EPRG) to perform a wide-reaching review of the draft data and modeling of the Frenchman Flat CAU **(4)**. It was charged to review the strategies and methods employed during data collection, and to review and evaluate the proposed geologic and hydrologic conceptual models, and the results of the groundwater modeling efforts. The EPRG was tasked to provide comments about significant omissions, shortcomings, errors, or ineffective strategies used in the preparation of the data analysis and modeling work products. In addition, the group was asked to comment on the transferability of the Frenchman Flat modeling approach. The EPRG was comprised of five internationally recognized preeminent scientists in the fields of groundwater modeling, hydrology, and geochemistry. A sixth member was a local expert in groundwater modeling and spatial statistics who was appointed by the NTS Community Advisory Board to represent the Nevada public.

The EPRG's final report (September 1999) was scathing. The DOE failed to produce an acceptable strategy for Frenchman Flat, and certainly did not produce one that is transferable to other CAUs. Briefly concerning the four components of the strategy, the EPRG found the theoretical model to predict the hydrological source term interesting, but not useful without validation. Validation requires the same data that would be required for the source term in the first place. The conceptual model was plausible, but it did not represent the best choice of alternatives since it required recalibration of the regional model, and it did not account for the possibility of vertical leakage. Concerning the regional model, the EPRG could see no reason to trust this relatively crude model, with its sparse data, as capable of providing reliable quantitative inputs into the FF model, or descriptions of flow and transport on the CAU-scale. The flow and transport model (SWIFT) was inappropriate, too slow, too large in areal extent, and there were too few data to calibrate or validate it. Finally, the linkage between the regional and local models was cumbersome and did not produce credible results. **In summary, the DOE strategy for prediction of the CB in the FF-CAU was not credible, and resulted in several years of time and millions of dollars spent ineffectively**. What went wrong? Is there a better strategy?

According to the EPRG, there are better ways to approach the problem and achieve a credible strategy that optimizes limited resources to address such a complex situation. How can the DOE be encouraged to adopt these better ways?

In our opinion, the greatest weakness of the DOE strategy for the FF-CAU was the absence of problem identification, i.e., identifying the potential scenarios having a high probability of creating risk to the public. These potential scenarios are also called failure scenarios. An example is a leak in an aquitard that allows vertical leakage between aquifers. Although the VOIA stated that the greatest chance of contamination escaping from the FF area was from vertical flow to the underlying carbonate aquifer, DOE made no attempt to check for this possibility in its strategy, i.e., there was no evaluation of that failure scenario. Consequently, no well(s) was drilled, no data were acquired, and the question was not answered. The new FFACO strategy apparently was for the DOE to model its way out of the problem. The obvious imbalance of modeling and data acquisition, and the ignoring of potential failure scenarios seemed to have doomed this program.

NTS ADVISORY BOARD AND EPRG: ALTERNATE STRATEGIES

The NTS Community Advisory Board (the CAB) is the local site board that provides advice and recommendations to the DOE and the NDEP about environmental restoration and waste management issues at the NTS. Stakeholder representation on the CAB is broad and consists of local citizens, NTS workers, interest groups, and ex officio members from state and local governments. Since the creation of the FFACO and the UGTA project, the CAB has endeavored to understand the UGTA strategy, however, it has found the ongoing program confusing and complicated. During 1999, the CAB focused the work of a single committee of volunteers to study the UGTA strategy.

The DOE offered the CAB a seat on the FF-EPRG as a possible mechanism for greater understanding of the FFACO strategy. The CAB appointed a representative of their choice (noted above), who was tasked to: 1) participate in the review; 2) report back to the CAB; 3) present the results of the review to the CAB and the public at a monthly meeting; and 4) assist the CAB in making a recommendation to the DOE on the overall FFACO strategy based on the results of Frenchman Flat.

In addition to the formal review and comments on transferability, the EPRG report contained a section on Recommended Actions. It suggested alternative approaches that might lead to a more defensible prediction of the 4 mrem/yr contaminant boundary. These recommended actions formed the basis for the CAB's recommendations to the DOE **(5)**. The CAB's recommendations, however, were tempered by its members' knowledge of, and social responsibility to Nevadans, and by their knowledge gained from the EPRG presentations and discussions with the authors. The results are summarized in the following technical suggestions to the DOE to help improve the UGTA strategy.

1) Utilize problem identification as the first step in a phased approach for addressing groundwater contamination at the NTS. If the DOE were to identify the problem of whether or not the contaminants can reach the carbonate system beneath Frenchman Flat, it may not be necessary to continue with large-scale deterministic modeling to predict the CB. In that case, very little characterization work and modeling would be needed to predict the CB, and precious resources could be diverted for problem identification and data collection at other CAUs.

2) - Utilize probabilistic modeling techniques to address the large range of uncertainty inherent in the non-verifiable, deterministic numerical models currently used at the regional and local scales.

3) - Revisit and peer review the FFACO UGTA strategy in a manner that includes professionals with specialization and experience in technical and regulatory areas commonly found at Superfund sites across the nation. The report of the FF-EPRG is of tremendous benefit to the UGTA program. Likewise, a peer review of the FFACO UGTA strategy could greatly benefit all parties and lend more credibility to future work and budget accountability. It may also help to define possible regulatory endpoints for decision makers on the management of NTS groundwater resources.

4) - Reduce the effort on the regional groundwater flow model, because this deterministic modeling effort is non-verifiable, unreliable, and unacceptable to the public. Modeling efforts (and data acquisition) should be shifted away from the regional scale and toward the CAU scale where contaminant migration is more relevant to nuclear test cavity sites than to the surrounding region.

DISCUSSION

Unfortunately, the success rate of government agencies like the DOE to address complex problems similar to the UGTA is often quite low. Large, complex problems where resources are limited and data are scarce require a different strategy than smaller problems where an entire area can be modeled with a relatively, easy to calibrate model**. The historical development above was intended not to denigrate the DOE, but rather to show that the preference for large-scale modeling is misguided, and that it produces unacceptable predictions and very little new information**. A complex problem such as the UGTA cannot be solved in a few years, and it will drag on until the problem is solved to the satisfaction of regulators and the public. At the current rate of progress, this may never happen and eventually lead the parties to litigation. Therefore, the authors of this paper are suggesting that past performance of the DOE UGTA effort, plus the recommendations of five of the most preeminent scientists in the field of hydrology are sufficient to give weight to the suggestions of an alternate type of strategy. That strategy is simpler than the DOE's existing methodology. An alternate strategy based on problem identification and limited data collection will lead to an increase in knowledge, an eventual reduction of the scale of the problem, and to an increase in performance of the UGTA program.

This suggestion also by no means neglects the managerial aspect of the problem. The authors are aware of the difficult task of managing seven different contractors simultaneously, but are confident that our suggestions would lead to different management, not necessarily more difficult problems.

An estimated $176 million has been spent since 1989 to develop a regional model, collect data from multiple locations on and off the NTS area, and to simultaneously analyze data and develop models for each CAU **(6)**. The FFACO requires that the DOE simultaneously perform work on all CAUs as part of the schedule to reach regulatory closure for the UGTA program in the year 2014. **Estimated to have a life cycle cost of $260 million in 1996, the UGTA strategy appears to be heading on a course that will require more funding and field work to utilize predictive, non-verifiable models to estimate contaminant boundaries**.

The first CAU effort to demonstrate the UGTA strategy using existing data was reviewed by the EPRG and the NDEP. Neither entity found the FF data analysis and model acceptable due mainly to the imbalance of modeling to data (the preference for modeling.) In their September 1999 letter, the NDEP approved the Draft Investigation Plan for the FF-CAU with 41 comments **(7)**. In a November 1999 follow-up letter the NDEP set enforceable deadlines for the DOE to include an addendum to the Plan proposing how data insufficiencies are going to be addressed in FF **(8)**. The DOE is presently drafting a work plan that will include drilling two wells, collection of data, and revision of predictive models to include a better site scale model. Rebaselining of funds and work in the entire UGTA program is ongoing to support the additional work expected to satisfy EPRG recommendations and the NDEP acceptance criteria.

CONCLUSIONS

The characterization of the impact of underground nuclear weapons testing on the subsurface and water resources of southern Nevada is a complicated task. The evolution of the strategy over the past ten years to address NTS ground water contamination has lead to a methodology that relies heavily all existing data and a combination of regional flow modeling and local CAU-scale modeling. Predictions of contaminant migration from either scale modeling have not been validated or accepted by regulators and stakeholders. Utilization of the sparse, existing data and a strong resistance by the DOE to not characterize groundwater contamination or the groundwater system adjacent to and down gradient of nuclear detonation cavities increase model uncertainty and make credible predictions of the contaminant boundary practically impossible. As demonstrated by the FF-EPRG report, the current strategy to utilize existing data and emphasize modeling over field data acquisition to predict contaminant migration is not credible enough for a such a large, politically sensitive, and contaminated site such as the NTS.

Alternate strategies that emphasize problem identification and a phased, iterative approach of data collection, modeling with appropriate techniques, and decision making based on the latest information is a method likely to be more defensible, successful, and acceptable to regulators and stakeholders. The current methodology as demonstrated in the FF-CAU failed to make a credible case for prediction of the 4 mrem/yr boundary, and a new work scope is underway to acquire more data and rectify the deficiencies in this particular CAU. Moreover, an unsuccessful, first demonstration of the current FFACO UGTA strategy as presented for the FF-CAU leaves the DOE without a credible, transferable strategy to other CAUs at the NTS. The approximate $16 million spent on FF to date has yielded precious, little, new knowledge of the groundwater system in this area and the surrounding region. More accountability for the limited financial resources directed toward environmental restoration work on the groundwater problem at the NTS is needed. Utilization of alternate strategies and consideration of suggestions are offered as possible methods to improve the overall prediction of the CB around contaminated sites, but also to help focus and eventually reduce the technical work of the project. Ineffective modeling without the necessary data is a waste of time and money. The information gained from data acquisition when done correctly in concert with defensible modeling leads to an accumulation of knowledge that will eventually support decision makers to manage the problem appropriately.

Project management can be handled according to a solid technical strategy that is defensible, accountable, and successful because it makes use of new data, appropriate modeling, and incorporates the latest results in decision-making.

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