
**Pacific Northwest
National Laboratory**

Operated by Battelle for the
U.S. Department of Energy

**Rapid Risk Assessment
FY05 Annual Summary Report
Laboratory Directed Research and
Development**

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1.0 Summary

The Pacific Northwest National Laboratory (PNNL) is developing decision support tools that will assist in the transition of incident information into Protective Action Recommendations (PARs) that are understandable and can be executed in a real-world, operational environment. A natural event, man-made accident, or terrorist-initiated incident can have many effects on a local or regional site. A single chemical release can impact a site through multiple direct and indirect transfer mechanisms, including airborne dispersion, surface contact, groundwater, surface water, food ingestion, etc. Multiple events/incidents are even more difficult to characterize, assess, and transition into meaningful PARs.

During emergencies, responders must rapidly assess risks and decide on the best course of action—all within minutes to hours. PNNL is blending existing modeling and decision support technology to develop new methods for transitioning science-based threat assessment to protective-action recommendations. The rapid risk assessment tool will be both understandable and applicable to the emergency management community and would be a valuable tool during any water security-related incident.

In 2005, PNNL demonstrated the integration of the multi-thematic modeling with emergency management decision support tools to create a Rapid Risk Assessment (RRA) tool that will transition risk to PARs that assist in responding to or mitigating the direct and indirect impacts of the incident(s). The RRA tool does this by aligning multi-thematic modeling capabilities with real-world response zones established by emergency and site operations managers. The RRA tool uses the risk assessment tool to drive prognostic models that use the type of incident, time of impact, severity of impact, and duration of impact to select the most appropriate PAR. Because PARs (and the thresholds by which they are selected) are jointly established by the technologists and the emergency management and operations decision makers, the science-based risk assessment can transition into a recommendation that can be understood and executed by people in the field.

The RRA tool will help responders quickly view non-contiguous regions impacted by water processes and pathways, which are often based on economic and community needs and rights rather than natural environmental patterns. PNNL is combining its Framework for Risk Analysis in Multimedia Environmental Systems (FRAMES) multi-thematic modeling capability with its **EMAdvantage** emergency planning and response tools to produce the RRA tool. The new tool will provide a real-time, two-way information-sharing link between the science of threat assessment and emergency responders who need the most accurate, immediate information to take effective action. In terms of water systems, it can address the often non-contiguous environment of water pathways and processes.

FRAMES is a software platform that provides seamless and transparent communication between components. FRAMES was developed for applying multiple characterization and analysis tools that can generate a single integrated risk assessment for contaminant releases. The FRAMES

architecture can support the complete characterization and assessment of a source term by traversing all of the potential fate and transport pathways and examining the direct and indirect impacts associated with each pathway. The FRAMES architecture also allows multiple events (sources) to be examined and collected into a single assessment. Time-sequenced inputs enable a site to identify multiple sources that may have occurred within the time frame being examined. This architecture provides the infrastructure needed to allow a site to examine multiple asymmetric events or incidents within a specified time period. For the emergency responder applications, FRAMES uses a multi-thematic approach to provide a flexible and holistic understanding of how environmental releases potentially affect humans and the environment. It incorporates models that integrate across scientific disciplines, allowing for tailored solutions to specific activities. Combined with **EMAdvantage**, FRAMES provides meaningful, risk-based guidance to emergency response and technical managers.

EMAdvantage is an automated decision-support system that expands the operational awareness of emergency response managers during planning, daily operations, and response. During planning, **EMAdvantage** helps managers pre-establish PARs and prepare emergency response plans. During daily operations, **EMAdvantage** provides information about community conditions and current activities that may affect a site's capability to respond to a potential event. During an incident, **EMAdvantage** combines incident characterization and PARs with information about community conditions so that managers can select and execute the best response plan.

Because FRAMES supports multi-thematic modeling, it provides recommendations that are more holistic, identifying potential zones or facilities that are usually not considered. This feature is useful in a water-related emergency where water processes and pathways are non-contiguous. **EMAdvantage** uses FRAMES' recommendations to help select and execute "best-fit" responses to meet the active guidance recommendations. Through map displays, status boards, checklists, and other user-oriented displays, **EMAdvantage** increases situational awareness for responders.

Because the transition from event source, to incident characterization, to risk assessment, to PARs can be codified, initial recommendations can be documented and tracked, as illustrated by Figure 1.1. As initial recommendations are implemented or ignored, the real-world protective action (PA) decisions can be tracked. This provides a feedback loop that can allow a site to transition modeling information from Preparedness (environmental impact modeling), through Daily Operations (environmental or emergency incident identification), to initial and sustained Response and ultimately, Recovery and Mitigation. The overall objective of the RRA tool is to allow a site to use any site characterization and modeling efforts to support daily operations, environmental protection, and emergency management.

The rapid response analysis tool will provide a new and innovative prediction capability for emergency responders. It links command and control decision, action plan, and consequence characterization to state-of-the-art models for fate, transport, and effects assessment. The rapid nature of this approach and the availability of the feedback provide greater accountability for decisions made in the field—something emergency managers are constantly striving to achieve.

An example application of this RRA methodology is presented. It involves the release of an unknown contaminant, of unknown strength, of unknown location to a large surface water body, which supplies drinking water and irrigation supplies to a nearby community. The approach demonstrates the linkage, application, and implementation of

- contaminant releases to a large surface water body
- automatic and seamless transfer of data from a sensor network
- three-dimensional surface water modeling, backward calculating an estimate of a given source location and strength
- three-dimensional surface water modeling, estimating where the plume will migrate over time

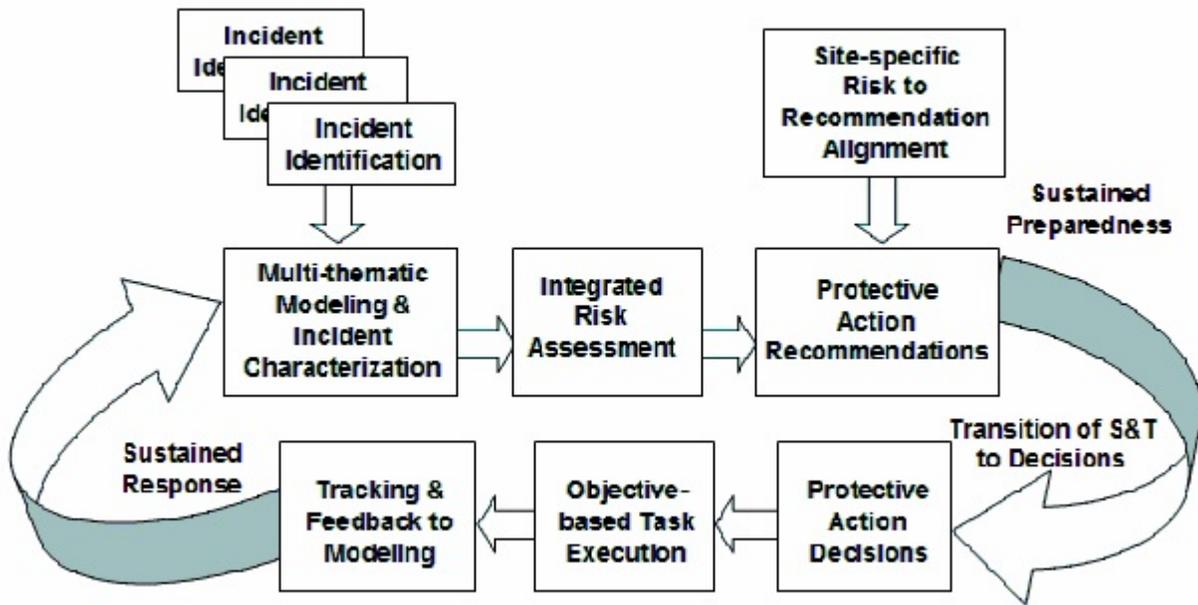


Figure 1.1. Linkages and feedback Loops Between Incident Characterization, Integrated Risk Assessment, and PARs/Actions

- exposure and impact analyses
- an evaluation of threats and determination of PARs
- Emergency Operations Center (EOC) status board capabilities.

It should be emphasized that most data, all locations, and all emergency response zones are real. Essentially, only the release scenario, contaminant, sensor information, and emergency response actions are hypothetical. The intent of this application is to demonstrate that the approach would work at real sites with data that are typically available.

2.0 Introduction

RRA integration and feedback provides a sustainable system that can be applied to emergency preparedness, response, recovery, and mitigation. This flexible and extensible integration of science and technology based risk assessment modeling and actionable emergency management system provides a basis to support human health and the environment from disruptive events. This information sharing approach/tool kit enables the repurposing of required assessments to serve as a baseline for future cleanup and emergency management planning. This system provides integration and feedback opportunities that can be used to enable existing activities to perform double duty by also applying them to science and technology lessons learned and as input to preparedness activities.

The environmental research and emergency response communities are fundamentally different, yet they depend on each other. The ability for the research to respond quickly to events is a challenge and requires researchers to stretch the bounds of existing modeling systems. In addition to the traditional emergency response evaluations, this innovative RRA approach integrates 1) the risk from assaults to critical infrastructure areas that are the basis for supporting larger populations (food, water, power, etc.) with 2) the ability to make probabilistic assessments based on potential impact scenarios, which will enhance security requirements and response planning. Additionally, potential threat scenarios can be updated and revised as additional knowledge is acquired, and new scenarios are determined to be viable. The results of this research will be methods and tools to support new security strategies because of the wide range of impacts from an assault that can be incorporated into the strategies (i.e., strategies that might not otherwise be formulated given the boundaries of current emergency planning tools).

Current assessment tools regularly account for impacts due to planned and unplanned releases to the air. For example, the National Atmospheric Release Advisory Center (NARAC; <http://narac.llnl.gov/>) provides tools and services that map the probable spread of hazardous material accidentally or intentionally released into the atmosphere. NARAC provides atmospheric plume predictions in time for an emergency manager to decide if taking PA is necessary to protect the health and safety of people in affected areas. But, no framework is available to easily link soil, surface water, groundwater, air, exposure pathway/routes, decision support, etc. into one comprehensive, integrated, multi-thematic capability, where that capability is fully integrated with incident characterization and emergency response and recovery, as illustrated in Figure 2.1. This research provides an illustrative example that combines flexible environmental computer modeling and assessment capabilities with emergency planning and response tools to create an automated system. This system offers a real-time, two-way information sharing link between the scientific and the emergency response communities, covering Preparedness, Response, Recovery, and Mitigation. Specifically, several linkages were completed:

- Plausible linkage to scenario-specific sensor data
- Two-way linkage between command and control and detailed water modeling
- Automated linkage between command and control and health impact look-up tables
- Automated linkages between risk-based decision logic and command and control decision delivery system
- Feedback loop to science and technology containing actual decision information for future planning and response use, and recovery/mitigation evaluations
- Reach-back capability to view scientific bases for PARs.

The assessment demonstrates the actual running of software. The proposition, which is addressed by this report, is to investigate and respond to the release of an unknown contaminant, of unknown strength, of unknown location to a water body, where a nearby population is potentially exposed. The question is:

What is the potential impact to the surrounding area, and what response plan do you implement, if the contaminant levels are unacceptable?

The illustrative scenario, which demonstrates this capability, is as follows:

- A delivery mechanism dumps a radioactive contaminant into a body of water.
- Sensors in that body of water signal that the contamination has surpassed some threshold of concern.
- The sensor information is immediately sent to a command and control system to determine if it needs to be analyzed and responded to.
- Surface water models are used to determine likely levels and locations of impacts over time.
- This information is then used to refer to look-up tables of expected effects and recommended actions for these locations over time.
- The decisions that are implemented are then fed back into the system to provide input into longer-term environmental and human-health assessments to confirm action-level durations and to determine cleanup actions that may be needed.

PNNL is combining its FRAMES multi-thematic modeling capability with its **EMAdvantage** emergency planning and response tools to produce the RRA tool, as illustrated in Figures 2.2 through 2.4. Figure 2.2 describes the relationship between environmental modeling, a decision framework, and the necessary feedback loop, required to effectively evaluate science-based input. Figure 2.3 illustrates how FRAMES links scientific assessments with **EMAdvantage** to support the RRA process. Figure 2.4 describes how **EMAdvantage** provides consequence characterization using a command and control system. The new tool will provide a real-time, two-way information-sharing link between the science of threat assessment and emergency responders who need the most accurate, immediate information to take effective action.

FRAMES is a software platform that provides seamless and transparent communication between components. **EMAdvantage** is an automated decision-support system that expands the operational awareness of emergency response managers during planning, daily operations, and response. During planning, **EMAdvantage** helps managers pre-establish PARs and prepare emergency response plans. During daily operations, **EMAdvantage** provides information about community conditions and current activities that may affect a site's ability to respond to a potential event. During an incident, **EMAdvantage** combines incident characterization and PARs with information about community conditions so that managers can select and execute the best response plan. The system links command and control decision, action plan, and consequence characterization to state-of-the-art models for fate, transport, and effects assessment. The rapid nature of this approach and the availability of the feedback provide greater accountability for decisions made in the field—something emergency managers are constantly driving to achieve.

Relationship Between Incident Characterization and Emergency Response & Recovery

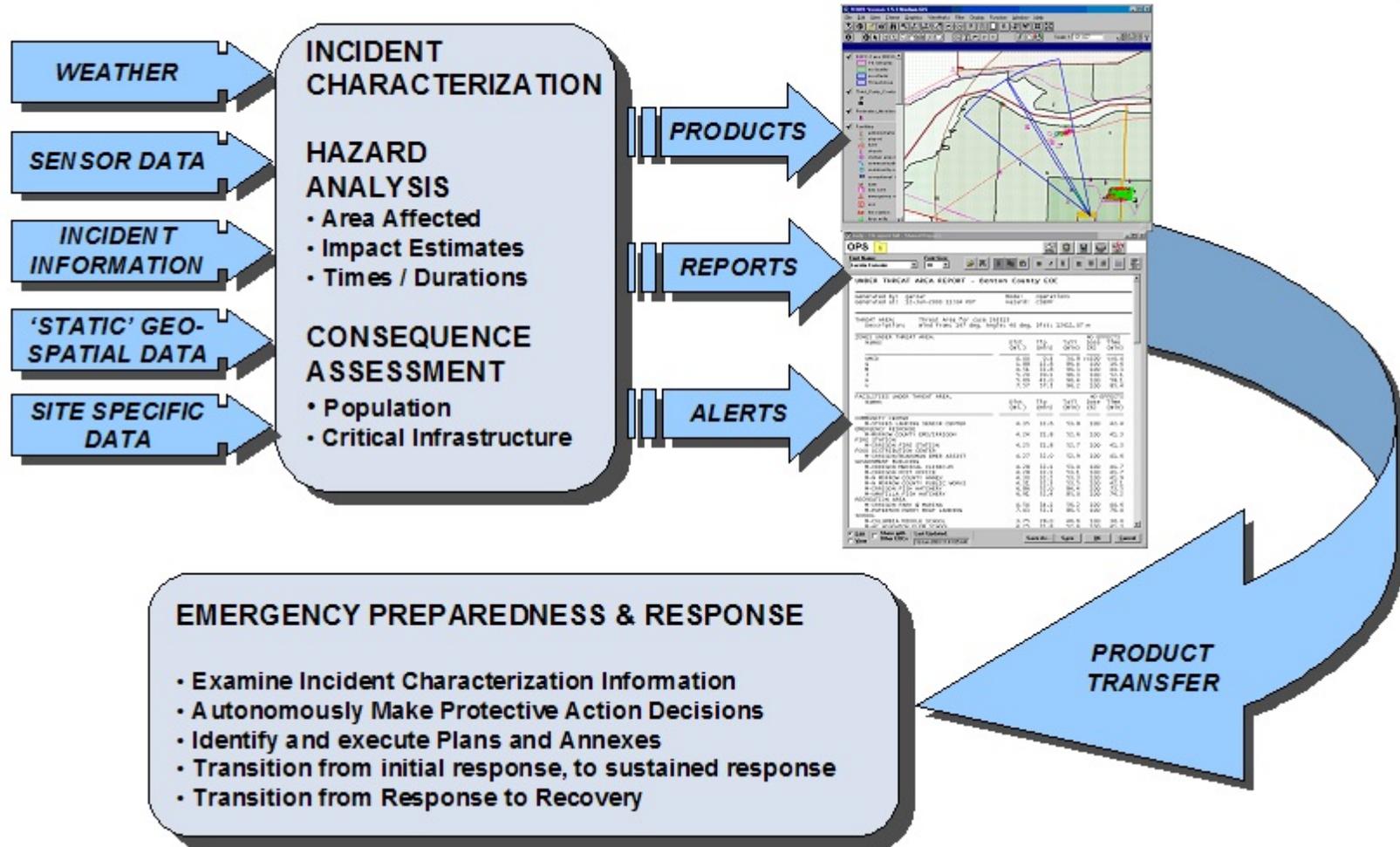


Figure 2.1. Relationship Between Incident Characterization and Emergency Response and Recovery

Rapid Risk Assessment Integration & Feedback

What is the Relationship between...

CASE STUDY

**Great Lakes Modeling
Lake Michigan (pre-run
simulations)**

•What happens inside the lake if we find elevated concentration or suspicious circumstance at

- Point A
- Point B
- Point C

Rapid Risk Assessment Process

USE RapidRisk Decision Framework (30 minutes)

Did a release occur and when (biomarkers)?
If a release, what uses of water are allowed? i.e. irrigation, eat fish, swim, boat, drinking water source
If intake shutoff, what are the potential consequences? (????)
If intake not shutoff, what are the potential consequences?
(Milwaukee Cryptosporidium)

Decision, Action Plan

Command and Control Systems = ?



Feedback Loop to Decision Makers (30 minutes to days)

if uses of water prohibited, when will they be OK?
If intake is shut off, when will it reopen?
If intake is not shutoff, what uses are allowed and when?
If intake will not reopen, what actions are needed to remediate?

Feedback Loop to Decision Makers (30 days+)

What are the consequences to aquatic life? ecosystem? Human life? (WSARE)
Has this happened before (biomarkers)?

Simpson - RRAIF - 1

Figure 2.2. Relationship Between Environmental Modeling, a Decision Framework, and the Necessary Feedback Loop, Required to Effectively Evaluate Science-Based Input

Rapid Risk Assessment Integration & Feedback

'Scientific Assessments'



- Modeling/Analysis Capabilities
- Environmental Assessment

Where we are...

FRAMES – Risk scenarios are pre-defined

Where we need to be ...

FRAMES works with EMAdvantage to:

- Establish the Threat Area
- Identify affected zones and facilities
- Dosage / Impact on zones
- Dosage / Impact on key facilities
- Protective action decisions based on dosage or impact level

= ?

Rapid Risk Assessment Process

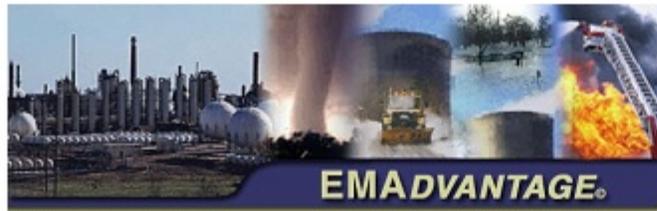


Simpson - RRAIF - 1

Figure 2.3. Illustrates How FRAMES Links Scientific Assessments with EMAdvantage to Support the Rapid Risk Assessment Process

Rapid Risk Assessment Integration & Feedback

'Consequence Characterization'



- Response Process
- Emergency Response

Where we need to be ...

FRAMES / EMAdvantage

- ORWA and Lake Michigan data 'morphed' into a hybrid modeling and analysis data set
- Polygon threat area transitioned from FRAMES models to EMAdvantage
- Zones & key facility location fed back to FRAMES to establish dosage / impact values in FRAMES
- FRAMES returns dose / impact 'decisions' to EMAdvantage protective action decision table
- EMAdvantage collects / displays protection action decisions and uses them to access the 'best' pre-written plans

Where we are ...

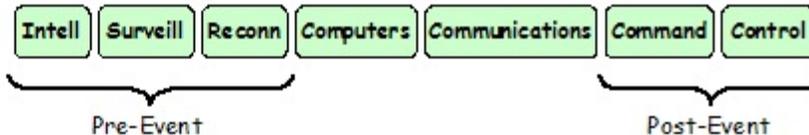
EMAdvantage

- Oregon and Washington (pre-established Geo-referenced situations)
- Protective action decision table
- Zone of facility and impact time (or effluent level, etc.)
- Polygon threat area (either impacted or not. If impacted then this is the response you do).
- Make a protection action decision
- Implement protective action decision -- Pre-written plans



Command and Control Systems

= ?



Simpson - RRAIF - 1

Figure 2.4. EMAdvantage Providing Consequence Characterization Using a Command and Control System

3.0 Problem Definition

An example application of this RRA methodology is presented. It involves the release of an unknown contaminant, of unknown strength, of unknown location to a large surface water body, which supplies drinking water and irrigation supplies to a nearby community. The approach demonstrates the linkage, application, and implementation of

- contaminant releases to a large surface water body
- consumption of data from a sensor network
- three-dimensional surface water modeling, backward calculating an estimate of a given source location and strength.
- three-dimensional surface water modeling, estimating where the plume will migrate over time
- exposure and impact analyses
- an evaluation of threats and determination of PARs
- EOC status board capabilities.

It should be emphasized that most data, all locations, and emergency response zones are real. Essentially, only the release scenario, contaminant, sensor information, and emergency response actions are hypothetical. It was assumed that there exists a sensor network, employing beta sensors, that currently does not commercially exist. The intent of this application was to demonstrate how the approach would work, that it could consume sensor or monitoring data, and it could be based on real sites with data that are typically available.

Although the contaminant of concern, its release rate, its concentration level, and its release location are described in this section, it was unnecessary to know this information *a priori* to implement the assessment. This information is only presented to demonstrate that the response was based on plausible situations, using plausible values, constituents of concern, and release mechanisms.

Before this assessment, certain assumptions are assumed to be valid:

1. The emergency operation center is responsible a given area or PA zones. The concept of a PA or response zone is a definable geographic area established by the policy and decision makers that choose an area that can be easily understood by the general public and can be used to establish/execute PA decisions that are meaningful to the decision makers and the general public. These zones may represent county, state, or national boundaries; geo-spatial boundaries (such as a river); man-made boundaries (such as a highway or prominent structure); etc. In this particular case, these boundaries are pre-determined and classified further as water, shoreline, or land-based zones.
2. For the system to demonstrate that it can directly consume surface water sensor data, it is assumed that surface water sensors exist.
3. Sensors monitor particular types of contamination, and this sensor array is assumed to monitor radionuclide beta emitters, using ^{90}Sr as the illustrative beta emitter and Contaminant of Concern.
4. Each PA zone is assumed to be classified as a water, shoreline, or land-based zone. This is done to solidify human health exposure routes and pathways, which are a function of human activities, based on the land use scenario for each zone.
5. Surface water fate and transport models have been calibrated and validated for this surface water body.
6. The EOC has developed Protective/Response Action Plans that are available. These plans provide guidance to the operation center personal if an event occurs.

7. PA Thresholds and Recommendations have been pre-defined and established. In other words, the EOC is not fully engaged until some acceptable threshold limit is passed.

To allow for the effective communication of everything between these components, a software infrastructure is required that allows for the linkage of databases, decision-support tables and models, and Command and Control Status Board software. FRAMES is used to link these components together so as to allow for seamless communication, as illustrated but the Figure 3.1 pictorial.

3.1 Contaminant of Concern

Strontium-90 is considered to be a potential material for use by terrorists in dirty bombs. The chemical and radiological properties of ^{90}Sr and its compounds also make it a potential hazard for release to water bodies that have the potential for use as a source of drinking water by the public. Strontium-90 is a byproduct of nuclear reactors and could conceivably be obtained by terrorists. The solubility limit of ^{90}Sr is assumed as the limit of solubility of $\text{Sr}(\text{NO}_3)_2$ in cold water, which is 709 g/L cold water (CRC Handbook 67th Edition). This is equivalent to about 298 g/L of ^{90}Sr (or $1.54\text{E}+15$ Bq/L).

3.2 Strontium-90 Source-Term Release Scenario

A 37-yd³ (i.e., ~7500 gal) refrigerated tanker truck contains a solution of $\text{Sr}(\text{NO}_3)_2$ at a concentration level of approximately 300 g/L, which equates to a concentration level of ^{90}Sr of approximately 127 g/L. A refrigerated tanker truck may be required because of the heat generated from the activity associated with the ^{90}Sr . Immediately following a rain event, the tanker truck discharges its contents in one hour at a rate of $7.8\text{E}-3$ m³/s (~2 gal/s) into a nearby stormwater outfall. The stormwater outfall has a discharge of 10 m³/s, resulting in a ^{90}Sr concentration of 100 mg/L.

3.3 Location of Concern

Real data were used because the development of the RRA approach is based on limited resources, especially if the deliverable was an application of the approach at real sites. Therefore, data for the chosen “site” must have already been collected, as there were no funds to collect basic data to drive the models. A site was required that must have

1. been modeled with a multi-dimensional numerical surface water model, accepted by the regulatory community (e.g., U.S. Environmental Protection Agency [EPA])—PNNL was involved in the application of a three-dimensional circulation and transport model to predict the beach bacteria concentrations at the Indiana Dunes Lakeshore site in southern Lake Michigan for EPA. The numerical model has been set up to create dynamic realistic simulations of the Burns Ditch bacteria/effluent plume and its movement caused by wind-induced currents. The model was developed as a predictive tool that would enable beach closure decisions to be made such that maximum protection is provided to the public during the entire event of bacteria plume discharge. The Southern Lake Michigan hydrodynamic and effluent transport model was used to demonstrate the surface modeling component concept in the RRA project. The model was applied to simulate localized effluent plume transport for instantaneous point source release (i.e., 1-hour duration) scenario, and provide

“sensor observations” in the model domain. A plume backtrack scheme was developed to identify the release location of the point source based on sensor readings and ambient flow conditions. The results of this plume transport and dispersion modeling forms the basis for the surface water release scenario to simulate zones of potential impacts along the Lake Michigan shoreline.

2. a pre-defined and developed emergency response management plan—PNNL was involved with the Chemical Stockpile Emergency Preparedness Program (CSEPP) to support emergency management needs at 25 jurisdictions. One of these locations was the Umatilla Chemical Depot (UMCD) in Hermiston, Oregon, along the Columbia River. This application provided data associated with

- Activity Descriptions
- Hazard Modeling and Threatened Area
- Risk Identification and PA Decisions
- Electronic Plan Generation/Execution
- EOC Activation/Emergency Declaration
- Facility/Resource Management
- Activity Tracking and Status Boards
- User Defined Status Boards
- WebOSB™—Operational Status Boards

These capabilities allow an EOC to 1) plan for potential emergencies, 2) perform daily operations, and 3) respond to emergencies.

To take advantage of the data from both applications and sites, the actual town and response zones and plans associated with Umatilla, Oregon, and the UMCD were morphed from the south side of the Columbia River on to the southern banks of Lake Michigan, supplying this region with an actual city, roads, hospitals, fire and police stations, emergency facilities, counties, response zones, protection action plans, etc. Information directly associated with the operation of Umatilla Chemical Depot, as well as any information not readily available through public sources, have been removed from the demonstration system. Figure 3.2 illustrates the overlay of the Umatilla region on the southern boundary of Lake Michigan.

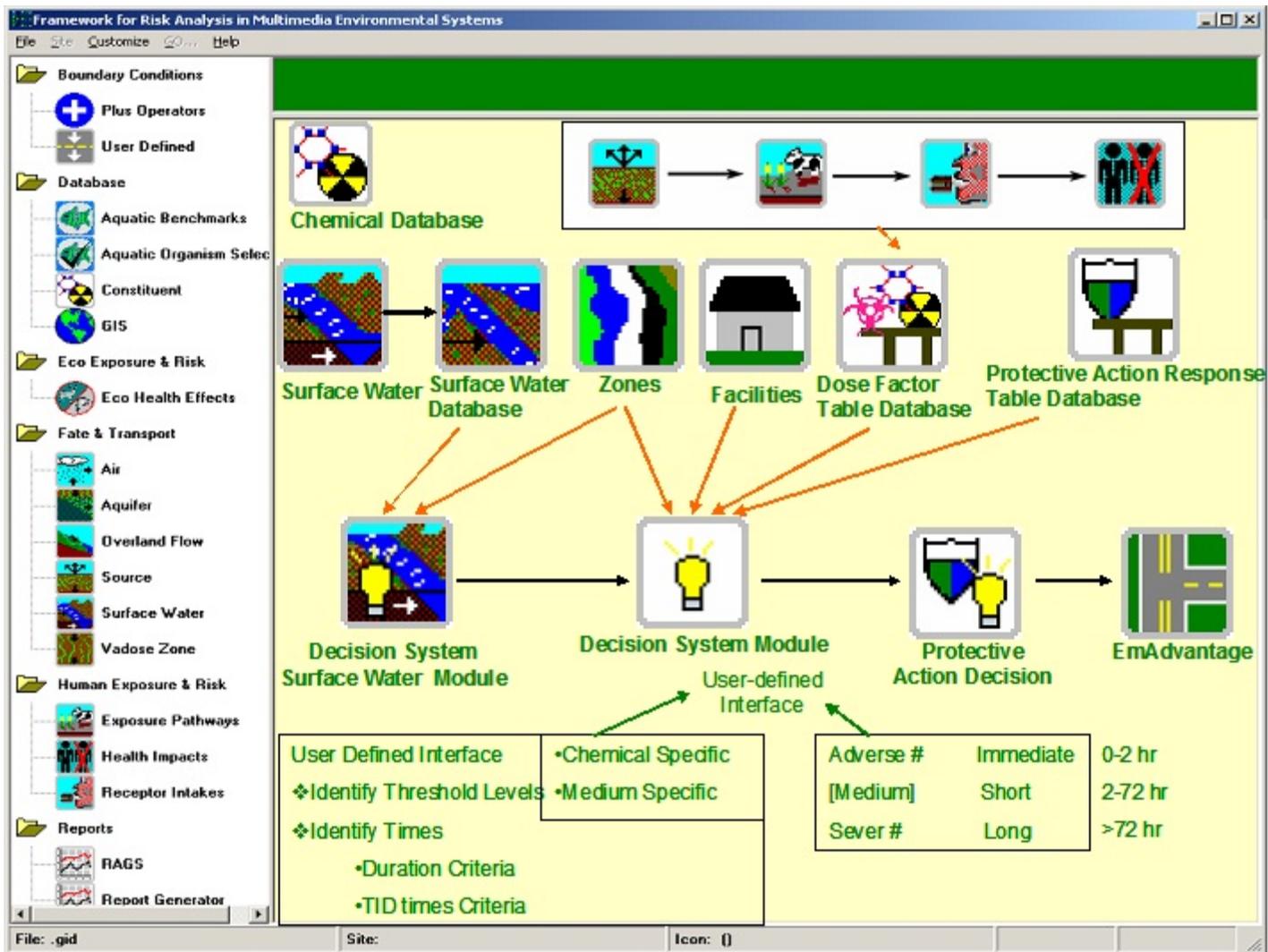


Figure 3.1. Pictorial Component Linkages to Using FRAMES

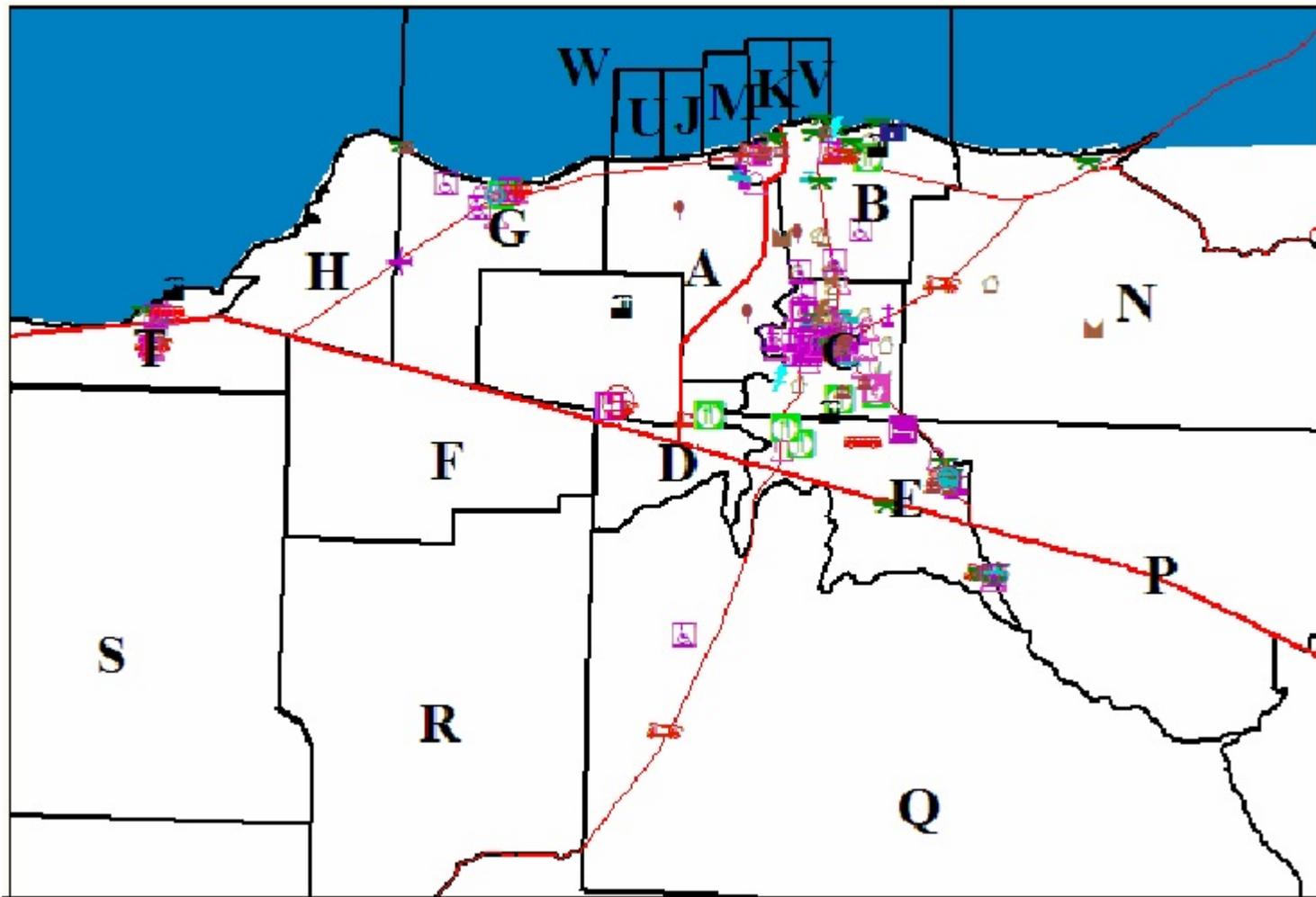


Figure 3.2. Spatial Description of Site: Water (W, U, J, M, K, and V zones), Shoreline (T, H, G, A, G, and N zones), and Land (all other zones)

4.0 Emergency Response Definitions

1. **Threat Areas** = One or more “polygons” that represent the area directly affected by the event or incident. Models are used to generate the stand-off area or buffer zone that represents the **actual area of contamination** deemed to be a threat. Many times, these are described by plumes and not rectangular-based polygons. These polygonal areas may change, depending on the source term, weather, and other factors.
2. **Protective Action Zones** = These are geo-political polygons established by the emergency management community (county, fire district, evacuation zones, etc) that may or may not be directly impacted by the geo-spatial location of the contamination plume. We use the term “zone” here because this is a fixed polygonal boundary established by decision makers. The boundaries do not change over time and become part of the decision making culture. All of these polygons may or may not be directly impacted by the geo-spatial location of the contamination plume.
3. **Risk Areas** = Those PA Areas that are impacted by the Threat Areas. In other words, the Risk Areas represent the intersection of PA Zones and Threat Areas. The Risk Area is a collection of specific PA Zones that are “affected” by selected Threat Areas. For most simple incident characterization systems, Risk Areas represent the geographical intersection of PA Zones and selected Threat Areas.
4. **Protective Action Areas** = This is a collection of specific PA Zones for which specific PARs are made. The concept is that the direct impact Risk Area needs to be extended to show the additional zones that have been impacted. The related impact is not by direct geographical proximity. Instead, it is by some other pathway identified by multi-thematic modeling.

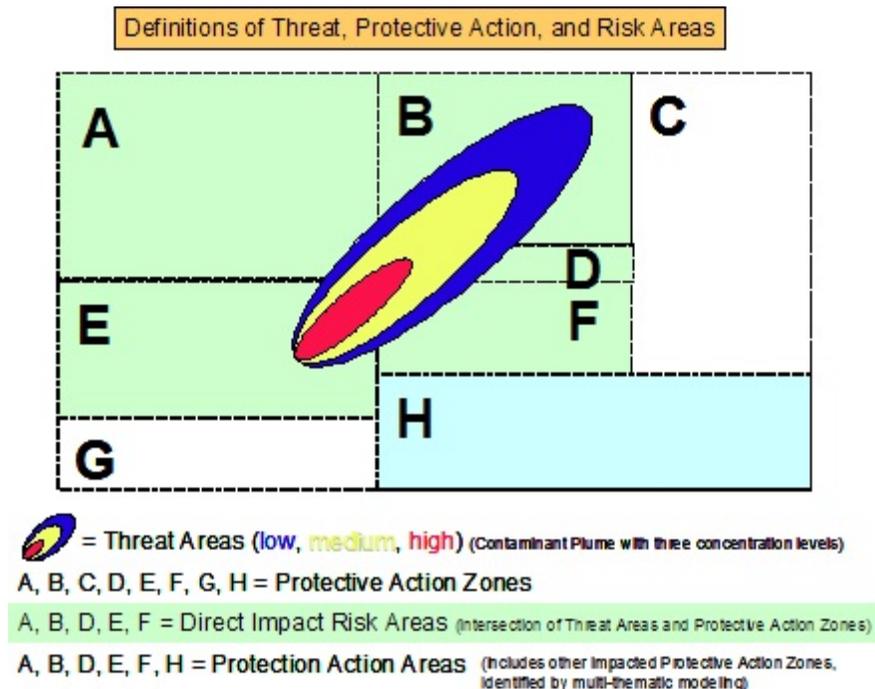


Figure 4.1. Emergency Response Definitions

5.0 Emergency Response Zones

5.1 Umatilla Chemical Depot

The UMCD lies approximately 3 miles south of the Columbia River, in Umatilla and Morrow Counties, Oregon (population 59,250, and 7,650, respectively). The facility is located about 12 miles northwest of Hermiston (population about 10,050). There is currently no on-post housing. The Depot occupies a roughly rectangular area of 19,728 acres. The U.S. Army owns about 17,054 acres. The remaining acreage is covered by restrictive easements.

According to <http://www.globalsecurity.org/wmd/facility/umatilla.htm>, the UMCD is a 19,728-acre military facility located in northeastern Oregon, on the border of Morrow and Umatilla counties. Formerly known as the Umatilla Depot Activity (UMDA), the facility was established in 1941 as an ordnance facility for storing conventional munitions in support of the United State's entry into World War II. The construction of 1,001 ammunition storage igloos began in February 1941. Subsequently, the functions of the Depot were extended to include ammunition demolition (1945), renovation (1947), and maintenance (1955). The U.S. Army began storing chemical munitions at the facility in 1962. Conventional (explosive) ordnance is no longer stored at UMCD. Activities at the facility have included the disassembly, analysis, modification, reassembly, repacking, and storage of conventional munitions, and the storage of chemical-filled munitions and containerized chemical agents. From 1945 to the present, ordnance and other solid wastes generated at UMCD were burned, detonated, or otherwise disposed of at the Ammunition Demolition Area (ADA). Twenty sites were identified at which these activities were conducted. The risk associated with future exposure to the contaminated soil in the ADA exceeded the National Contingency Plan (NCP) guidelines and indicated remediation was required. In addition, the sites contain unexploded ordnance as a result of ordnance disposal operations.

The facility was placed on the EPA National Priorities List (NPL) in 1987. The Base Realignment and Closure (BRAC) Commission in 1988 listed UMCD for closure, which was scheduled for 2004, making the land available for private sale and use after that time. Current plans call for the facility to be made available for wildlife management, commercial and industrial development, and possibly for agricultural use. Retention of the ADA under Government control for use in military training is also being considered.

Umatilla's stockpile consists of projectiles, rockets, land mines, spray tanks, and bombs containing the nerve agents GB and VX. Ton containers stored at the depot are filled with the blister agent HD, more commonly referred to as mustard agent. Chemical weapons storage facilities are operated under the U.S. Army Chemical and Biological Defense Command. Currently, 12% of the nation's stockpiled chemical munitions are stored within UMCD. In 1986, in response to public concern about the potential health threat posed by the disposal of chemical weapons, Congress passed Public Law 99-145, which requires the Department of Defense (DOD) to dispose of chemical weapon stockpiles. In accordance with 50 U.S.C. (War and National Defense), (Chapter 32) Section 1521, that mandates the destruction of chemical weapons by December 31, 2004, the U.S. Army plans to build and operate an incineration facility to treat the chemical weapons stockpiled at UMCD.

From 1990 to 1994 (<http://www.cma.army.mil/umatilla.aspx>), the facility reorganized in preparation for eventual closure, shipping all conventional ammunition and supplies to other installations. Today, the chemical weapons are the only items still stored at the depot. The UMCD is now designed for the sole

purpose of destroying the stored chemical weapons. The facility was completed in 2001, and the Army plans to begin weapons disposal in 2004. The facility uses high-temperature incineration technology to destroy weapons, a technology employed by the Army for more than a decade, safely and successfully disposing of more than a quarter of the nation's original chemical weapons.

5.2 Emergency Response Zones

In support of the CSEPP program, the Department of Defense, and the Federal Emergency Management Agency, as well as emergency management personnel from the states of Washington and Oregon and Umatilla, Morrow and Benton Counties worked to identify emergency response zones. Emergency response zones are geo-political areas that can be used to make and/or execute PA decisions. Zones were established and reviewed to confirm that they

- represented the resolution needed to plan and respond to a chemical incident
- respected the jurisdictional interests and boundaries of the involved agencies and jurisdictions
- covered the geographic area that could be impacted by a natural or man-made incident at the Depot
- could be easily conveyed to and understood by the general public during real-world preparedness and response activities
- could be used outside of the CSEPP to support other potential hazards and events that may occur (e.g., adverse weather, fire, floods).

Emergency Response Zones used to demonstrate the RRA are a combination of the real-world zones established for Oregon's Umatilla and Morrow Counties and contrived zones used to partition and identify areas within the water body being appended to create the demonstration site. In the demonstration system, three types of "zones" were established: Water, Land, and Shoreline. "Water" zones represent geographic areas in the water body. "Land" zones represent geographic areas that are totally surrounded by other land. "Shoreline" zones represent geographic areas that reside in Umatilla or Morrow County that are adjacent to a "Water" zone. Figure 3.2 illustrates the Water, Land, and Shoreline zones used in this study.

Zone types are used by the multi-thematic modeling system to help characterize the relationship between zones. Water zones that are adjacent to Shore zones may directly transfer contaminants (and risk) by their proximity to each other. Additional characterization is needed to identify the indirect relationships between Water zones and Land zones. For example, a common practice in the southeastern area of Washington and Oregon is to use river water to support non-potable water for private and agricultural use. Water may be taken from one location and transported via a canal to be used to irrigate vineyards, orchards, and other crops miles away from the intake source. Providing zone types that can represent potential source and recipient locations for contaminants and impacts was needed for this demonstration. The FRAMES modeling system was used to depict the relationships between zones. These relationships were used to determine the multi-thematic modeling components to be employed to provide the cumulative risk assessment from indirect fate and transport pathways.

6.0 Surface Water Modeling

6.1 Introduction

A three-dimensional circulation and transport model was previously developed by PNNL for EPA to predict the beach bacteria concentrations at the Indiana Dunes Lakeshore site in Southern Lake Michigan. The numerical model has been set up to create dynamic realistic simulations of the Burns Ditch bacteria/effluent plume and its movement caused by wind-induced currents. The model was developed as a predictive tool that would enable beach closure decisions to be made such that maximum protection is provided to the public during the entire event of bacteria plume discharge.

The Southern Lake Michigan hydrodynamic and effluent transport model was used to demonstrate the surface modeling component concept in the RRA project. The model was applied to simulate localized effluent plume transport for instantaneous point source release (i.e., 1-hour duration) scenario, and provide “sensor observations” in the model domain. A plume backtrack scheme was developed to identify the release location of the point source based on sensor readings and ambient flow conditions. The results of this plume transport and dispersion modeling forms the basis for the surface water release scenario to simulate zones of potential impacts along the Lake Michigan shoreline for an RRA.

6.2 Southern Lake Michigan Circulation and Transport Model

6.2.1 Study Area and Physical Processes

The study area, Indiana Dunes National Seashore, is located in southern Lake Michigan. The stream flow from the Little Calumet River discharges directly into Lake Michigan at the Portage-Burns Waterway (Burns Ditch) from Indiana. The Burns Ditch is located right by the northeastern end of the National Seashore (Figure 6.1). Field observations show that the far-field transport of the effluent plume discharged from Burns Ditch is strongly subject to the directions of surface currents. Water depths in southern Lake Michigan are generally shallow. Water depths are less than 10 meters within 1000 meters from the shoreline and less than 20 meters in the entire model domain. The bathymetry data in the model domain were obtained from the National Oceanographic and Atmospheric Administration (NOAA). Figure 6.2 shows the bathymetry represented in the model. The ambient currents in the study area are dominated by wind and affected by density-induced lake circulation. Because of lack of temperature data for the specifications of the boundary and initial conditions, the ambient currents are assumed to be solely induced by the local wind effect in the model.

The process of dilution and mixing of effluent released from point sources such as outfalls includes a near-field zone of initial dilution followed by far-field mixing. Simulating these processes continuously over several days would require a near-field dilution model to provide concentrations after initial dilution that occurs over several minutes and a far-field transport model to carry the waste-field away over several days. The Burns Ditch inflow appeared to mix with ambient fluid with little momentum, and there did not appear to be a major zone of jet-induced mixing. The approach selected in this study was to incorporate initial mixing by extending the far-field hydrodynamic model into the Burns Ditch such that effluent inflow, it's mixing with the ambient, buoyancy induced spreading, and far-field transport would be included in the

far-field hydrodynamic model directly. This would be accomplished by extending the receiving water model upstream into the Burns Ditch conduit.

6.2.2 Model Setup

The hydrodynamic and transport model used in this study is the Environmental Fluid Dynamics Code (EFDC). EFDC is designed to simulate hydrodynamics and transport processes in rivers, reservoirs, lakes, estuaries, and coastal waters. EFDC simultaneously solves the 3-D equations of motion for velocities and transport equations for temperature, salinity, dye tracer, and suspended sediment concentrations in a finite difference framework. It is well suited for the Burns Ditch site for use in bacteria simulation. The model setup generally consists of three steps: 1) Development of model grid, 2) specifications of boundary conditions, and 3) specification of model forcing.

To simulate the circulation and bacteria plume transport at the Burns Ditch site using EFDC, a curvilinear-orthogonal boundary-fitted model grid was developed with sufficiently high resolution to include the burns ditch channel and the receiving waters of the lake as part of the grid. The dimensions of the model grid were about 10-km offshore and 20-km alongshore. The model grid would be boundary-fitted to the shoreline to represent the geometry accurately. The model grid resolution would be varied with high resolution (grid size less than 100 m) near the source of the effluent discharge at Burns Ditch and increase gradually away from the source to the open boundaries. The model grid consists of 15,502 horizontal cells. A total of 10 vertical sigma-stretched layers were used in the model. Figure 6.3 shows the model grid.

There are three open boundaries and one land boundary in the model domain. The major forcing mechanisms in the model are surface wind stress and density stratification. Circulation induced by surface wind would be simulated in the hydrodynamic model. The discharged flow and effluent/bacteria concentration from Burns Ditch was specified. The effluent/bacteria concentrations in the ambient water would be assumed to be zero.

The meteorological data (wind, air and dew point temperatures, atmospheric pressure, and cloud cover) were obtained from the NOAA Center for Operational Oceanographic and Products Services (CO-OPS), located at the Calumet Harbor station. Figure 6.4 presents the wind stick distribution for the simulation period. Most of the time, the wind speeds are in the range of 5 to 10 m/s, and the wind directions are in northeastern and southwestern directions.

6.2.3 Model Simulation of Circulation in Southern Lake Michigan

Once the model was set up, it was applied to simulate the circulation in the study domain for a 15-day period (Julian Day 255-270) using September 1999 wind data. Figure 6.5 shows the simulated surface velocity vectors over time at a location near the Burns Ditch outfall, along with concurrent wind data. Figure 6.5 shows that the simulated surface velocities are in good correlation with the wind distributions. Horizontal 2-D plots of the simulated surface velocity vectors were also generated. The 2-D surface velocity vector distributions at Julian Day (JD) 257 (corresponding to eastward winds) and JD 261 (corresponding to westward winds) are presented in Figures 6.6a and 6.6b.

6.3 Demonstration of Surface Water Modeling Concept for Rapid Risk Assessment

6.3.1 Description of Modeling Scenarios

For the surface water modeling component demonstration in the RRA application, two modeling scenarios corresponding to two different hydrodynamic conditions were conducted using the existing Southern Lake Michigan model described in Section 2. The first scenario is to demonstrate the surface water modeling component under westward wind condition, and the second scenario corresponds to the eastward wind condition. The effluent transport model was applied to simulate the effluent (^{90}Sr) plume discharging and mixing into the ambient water.

The surface water modeling component for the RRA demonstration primarily consists of following three steps:

- Use the EFDC model to generate a series of “sensor observations” after the release of the effluent from the Burn Ditch at different sensor locations
- Develop and apply a plume backward tracking scheme to identify the most possible source location of the ^{90}Sr based on sensor readings and average velocity characteristics
- Conduct several model forward simulations with highly possible locations
- Conduct the forward model runs with effluent released at those highly possible locations identified in the last section
- Compare the model predictions to the observed “sensor readings” and identify the final effluent plume location.

6.3.2 Sensor Observations for Instantaneous Point Source Releases

To simulate the “sensor observations” for effluent concentrations in an RRA system, a series of sensor stations must be first specified. In this demonstration, 11 sensors were deployed around the Burn Ditch area where the point source was discharged. Six sensors were deployed along the shoreline with about 1000 meters apart, and another set of 5 sensors was specified at locations about 1000 meters offshore (Figure 6.7).

Sensor observations for the ^{90}Sr concentrations were generated with point sources discharged at JD 257 under a westward wind condition and at JD 261 under an eastward wind condition, respectively. The discharge flow rate of the effluent (^{90}Sr) was specified as 10 cms (Figure 6.8). The discharge effluent concentration was 100 mg/L with duration of 1 hour (Figure 6.9). The model simulated time histories of sensor-observed ^{90}Sr concentrations at all sensor locations for the westward wind and eastward wind conditions were presented in Figures 6.10 and 6.11, respectively.

6.3.3 Backward Tracking Scheme for the Point Source Release Location

To identify the point source release location, a backward plume tracking scheme was developed to determine possible point source release locations and times based on the model-predicted ambient velocity information and sensor observations. Specifically, the backward tracking scheme consists of following steps:

- Calculate the averaged velocity (U) in the region where sensor readings are above warning criteria
- Estimate the potential release locations with distance (LR) from the sensor location based on velocity information (see Figure 6.12)
- Estimate the point source release time based on the following equation:

$$TR = TC - LR / U \tag{1}$$

where

- TC = sensor detection time
- TR = estimated release time at distance LR
- LR = distance
- U = average flow velocity.

- Given a series of potential release locations with distance LR from the sensors, a series of releasing time can be calculated based on above equation.
- Conduct a series of forward model runs with point source released at the initial guess locations and estimated released times.
- Compare concentrations time histories at the sensor locations in the forward model runs to the “sensor observed concentrations” time histories and identify the best match based on the shapes and phases of the time history distributions (Figures 6.13 and 6.14).
- Scale the magnitude of the source strength to match the observed concentration magnitude for final forward model simulation.

6.3.4 Forward Model Prediction of Plume Movement

Once the plume release location and time are estimated, and source strength is scaled, the forward model prediction of plume movement can be conducted. Figure 6.15 shows the surface ⁹⁰Sr plume concentration contours after 18 hours of point source release under the westward wind condition. Three critical drinking water ingestion levels were used in the contour plot (1.26 105, 1.26 104 and 1.26 103 mg/L). A similar contour plot of surface ⁹⁰Sr plume concentration is shown in Figure 6.16 for the eastward wind condition after 18 hours of release.

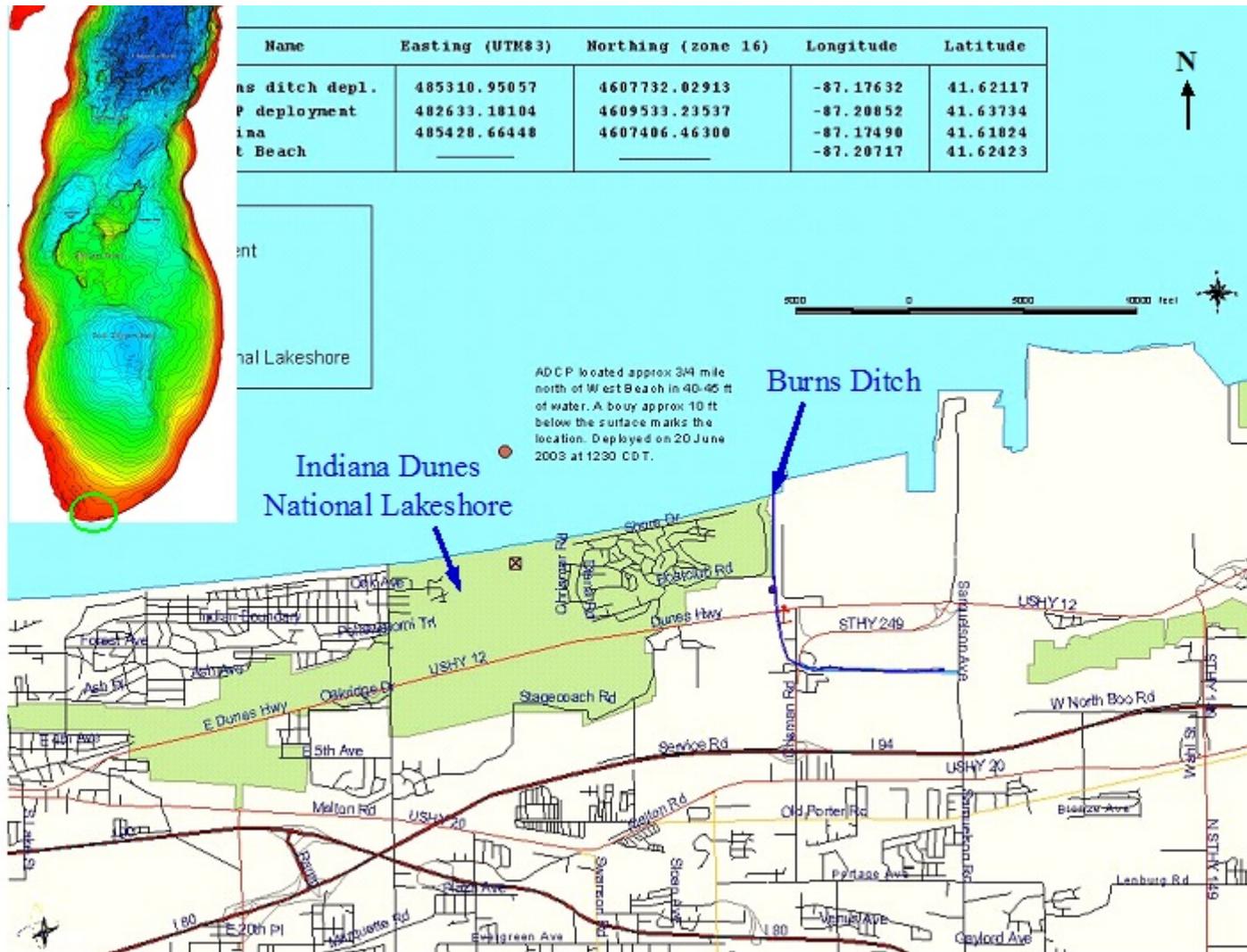


Figure 6.1. Study Area—Coast of Indiana Dunes National Lakeshore in Southern Lake Michigan

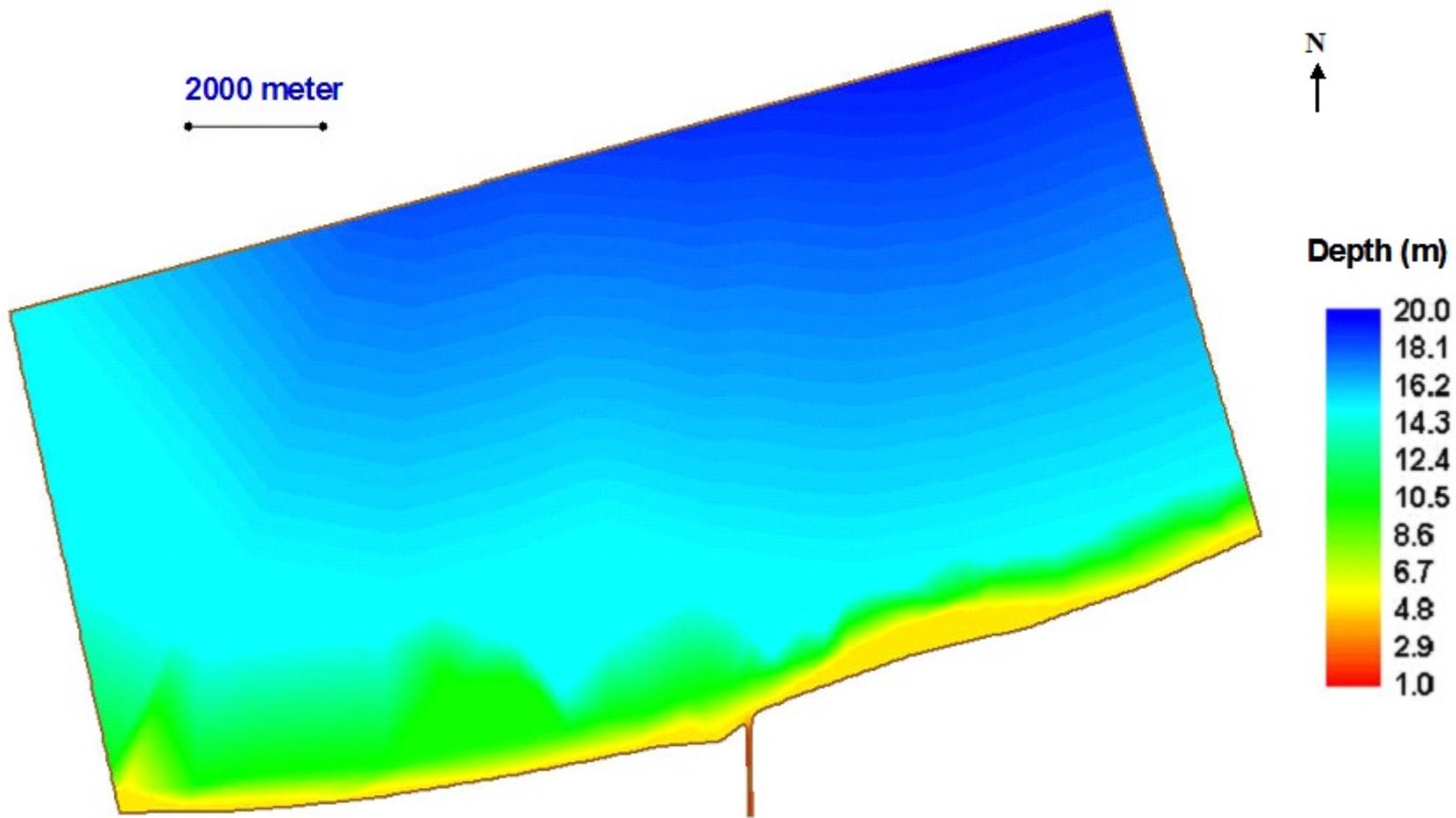


Figure 6.2. Bathymetry in the Study Area

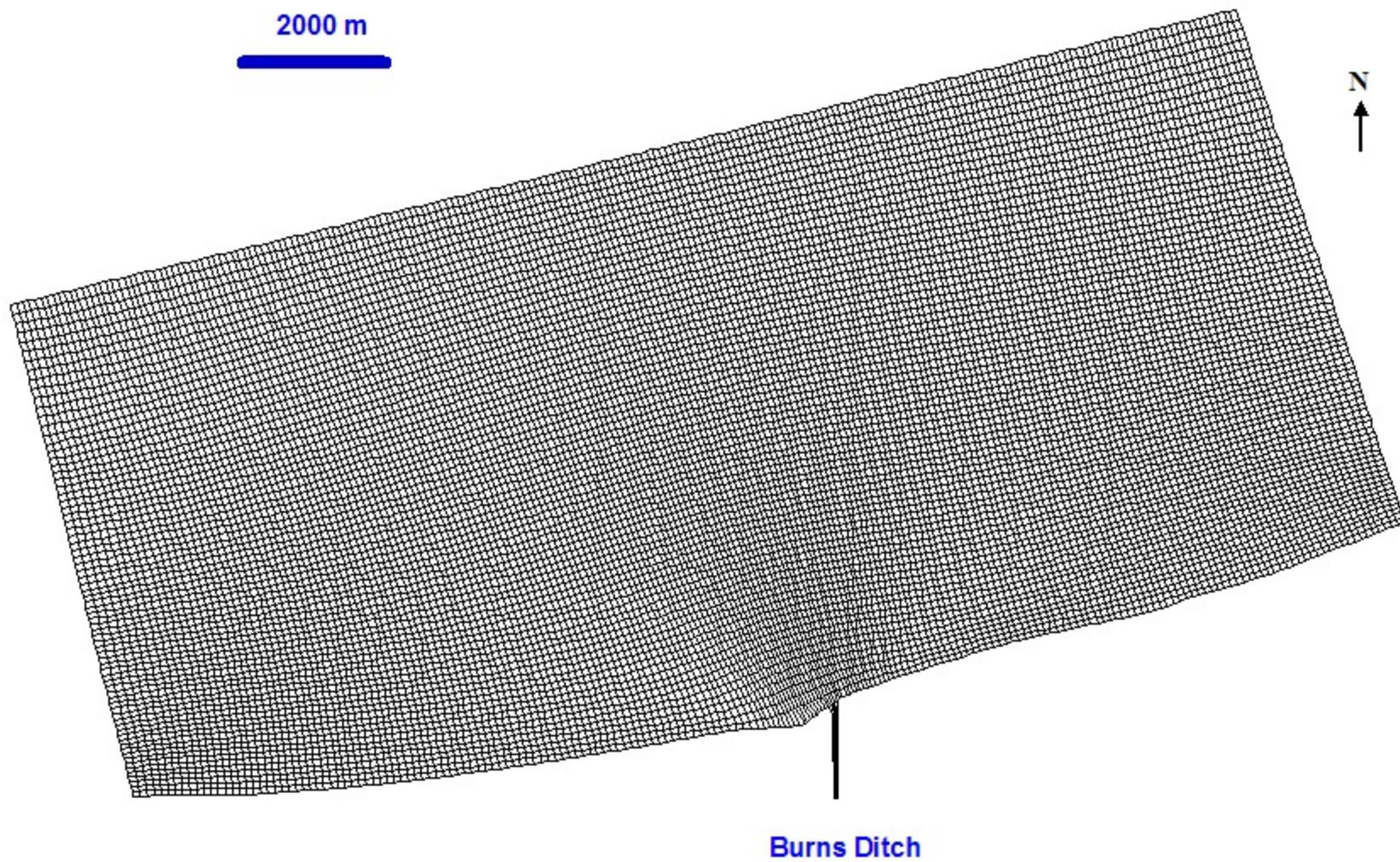


Figure 6.3. Model Grid

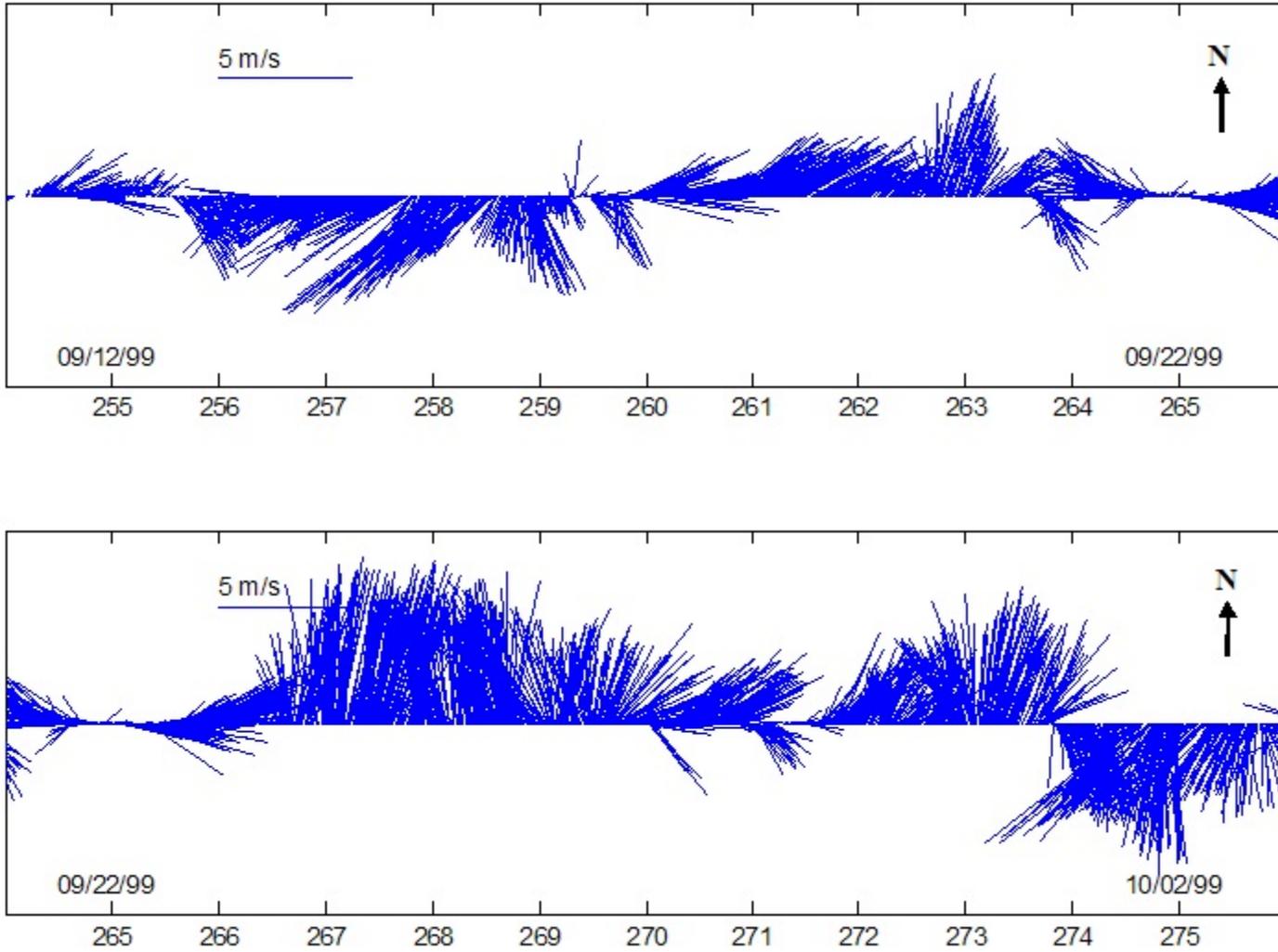


Figure 6.4. Wind Data from Calumet Harbor, IL (Wind Stick Is Pointing to the Direction Wind Is Going to)

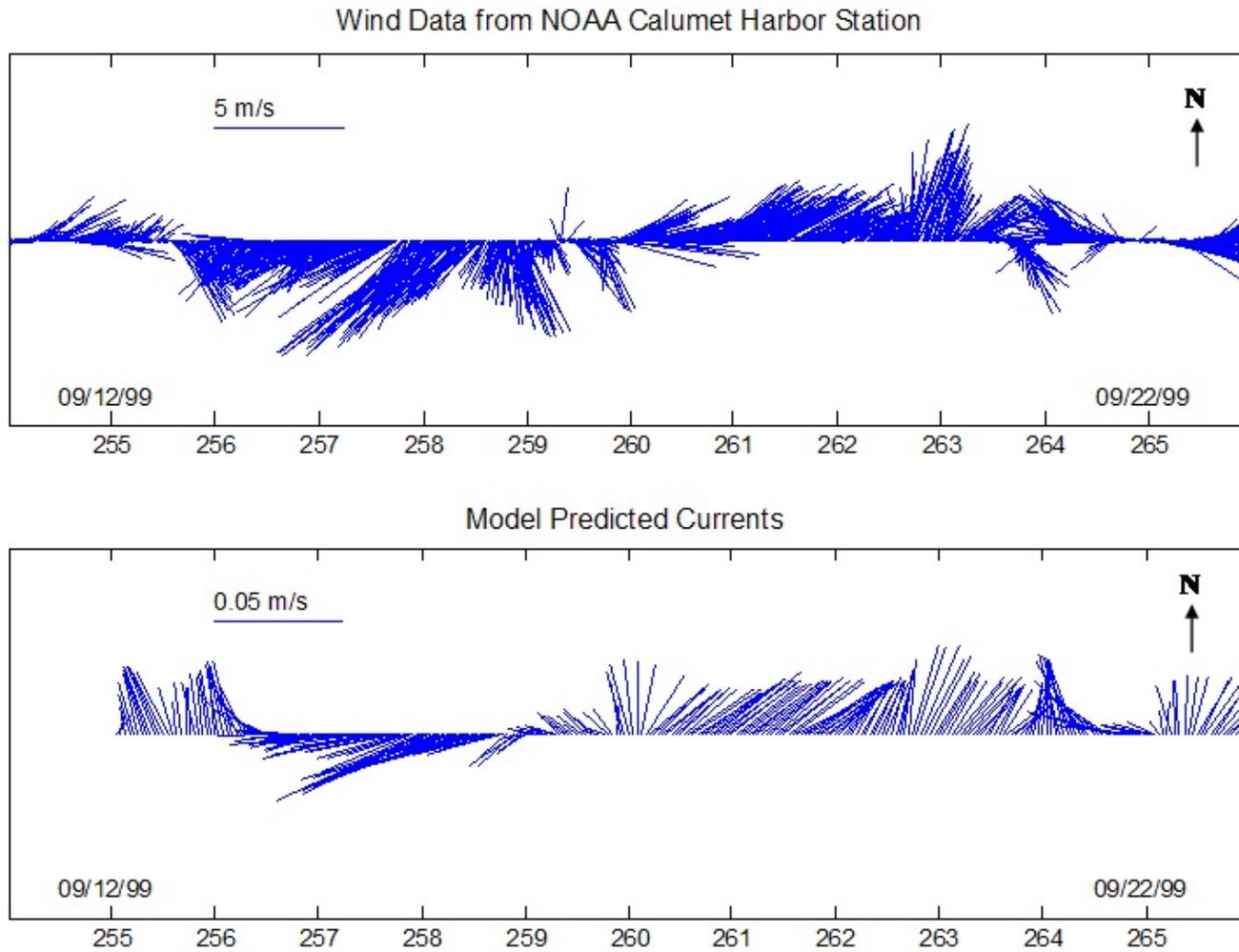


Figure 6.5. Model Simulated Surface Velocity near Burns Ditch with Comparison to Wind Data (Stick Is Pointing to the Direction Wind or Flow Is Going to)

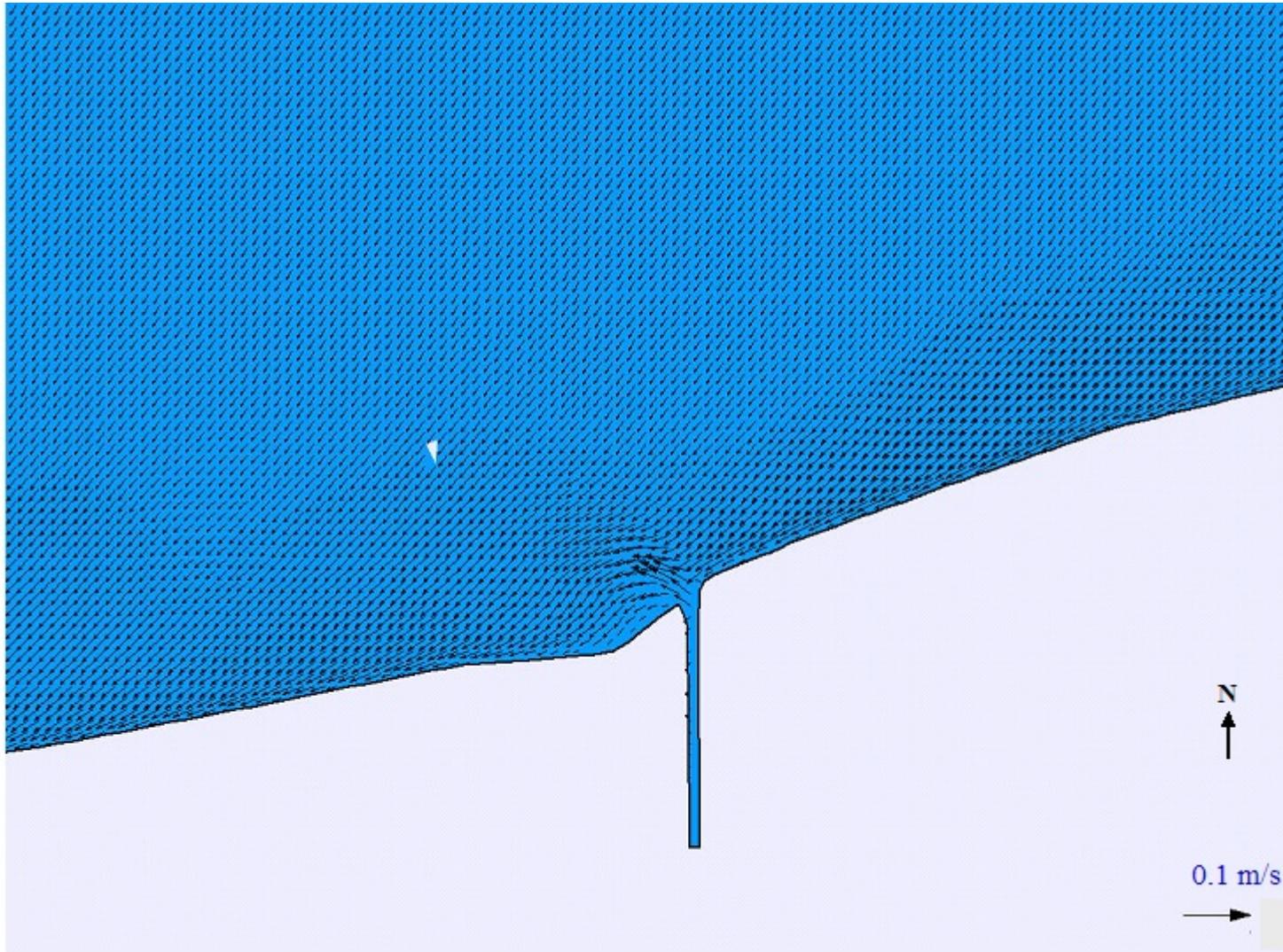


Figure 6.6a. Predicted Surface Velocity Vectors in Julian Day 257 (1999) When Wind Was Blowing to the West

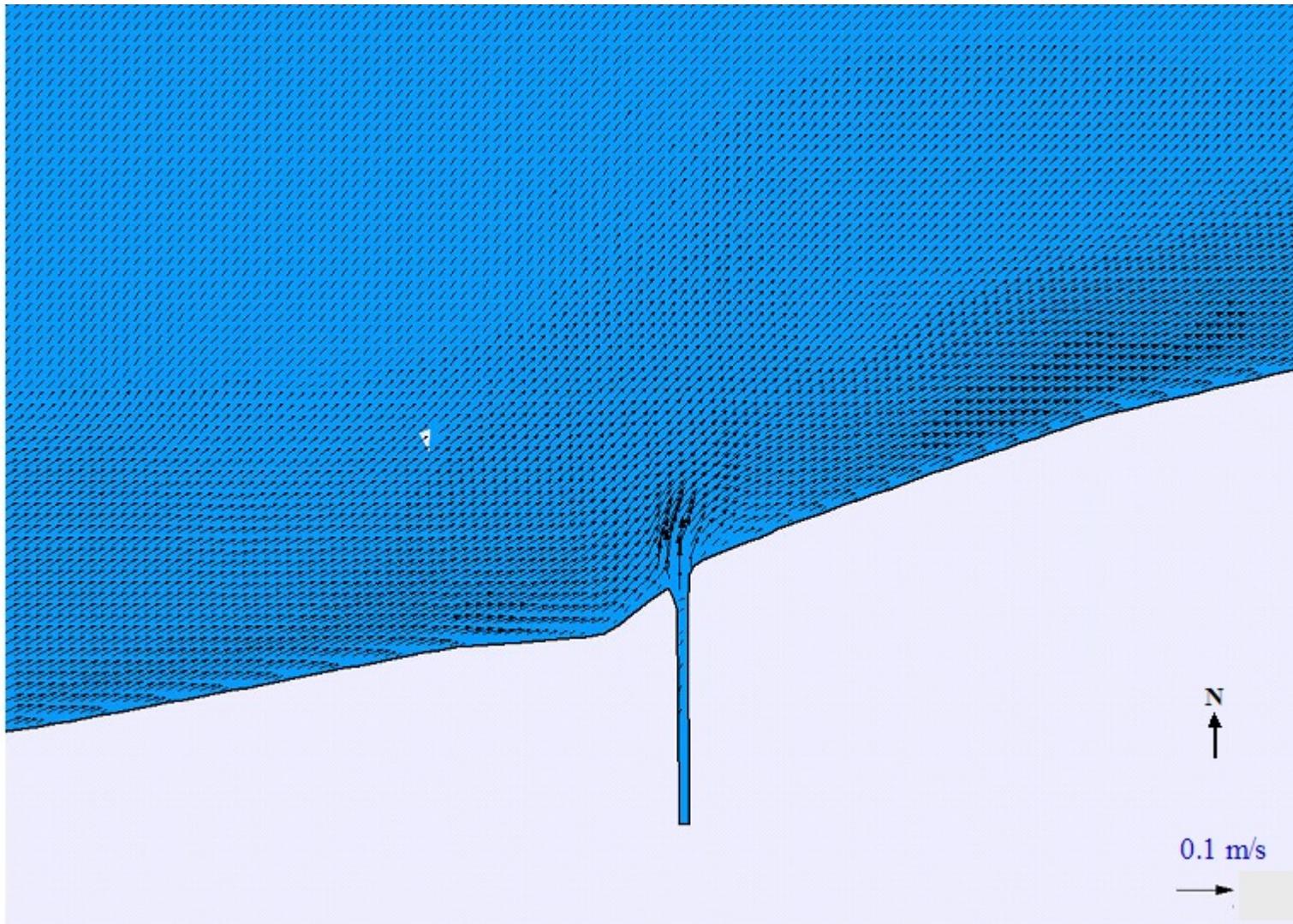


Figure 6.6b. Predicted Surface Velocity Vectors in Julian Day 261 (1999) When Wind Was Blowing to the East (North goes from the bottom to the top of the page.)

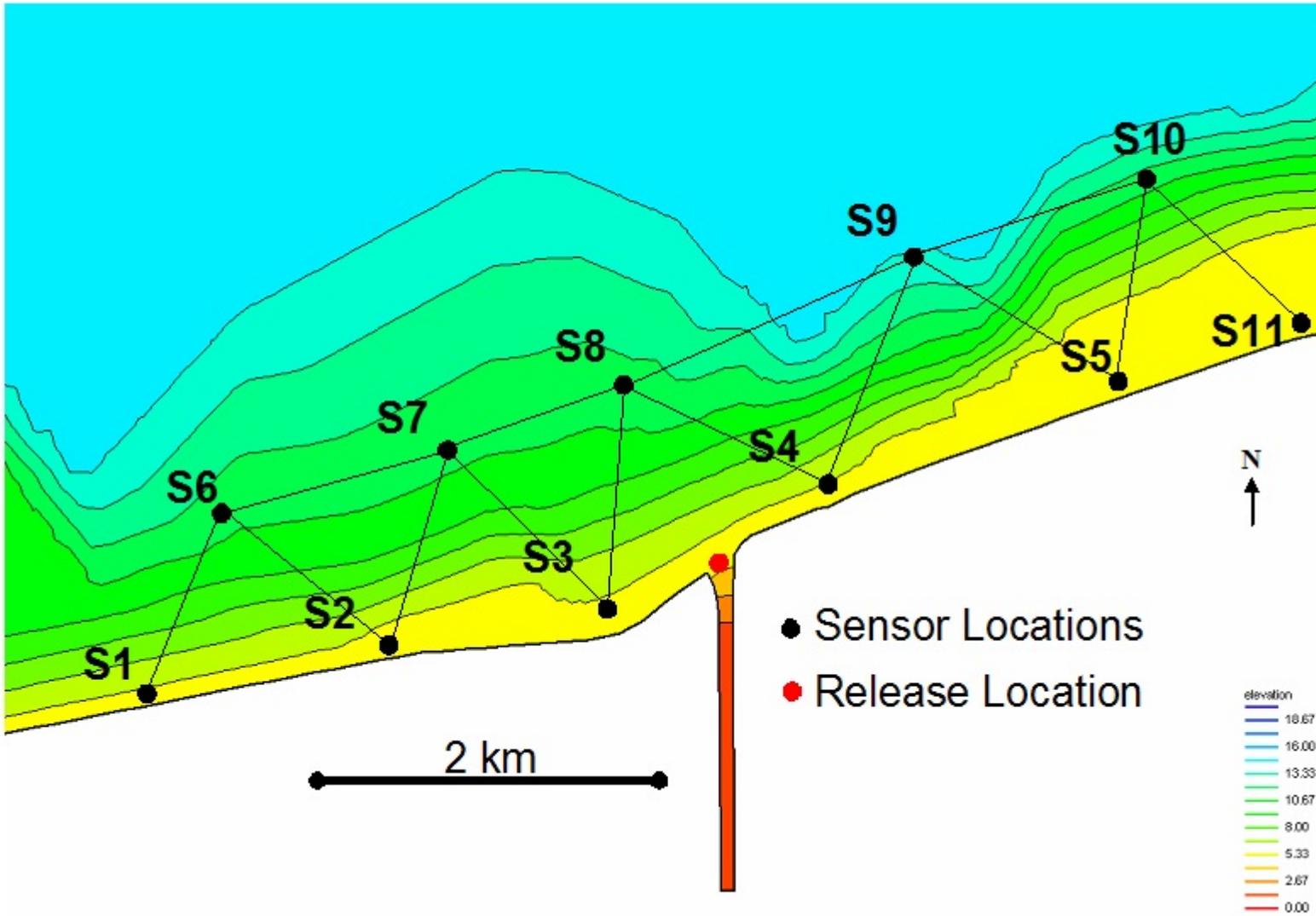


Figure 6.7. Sensor Locations

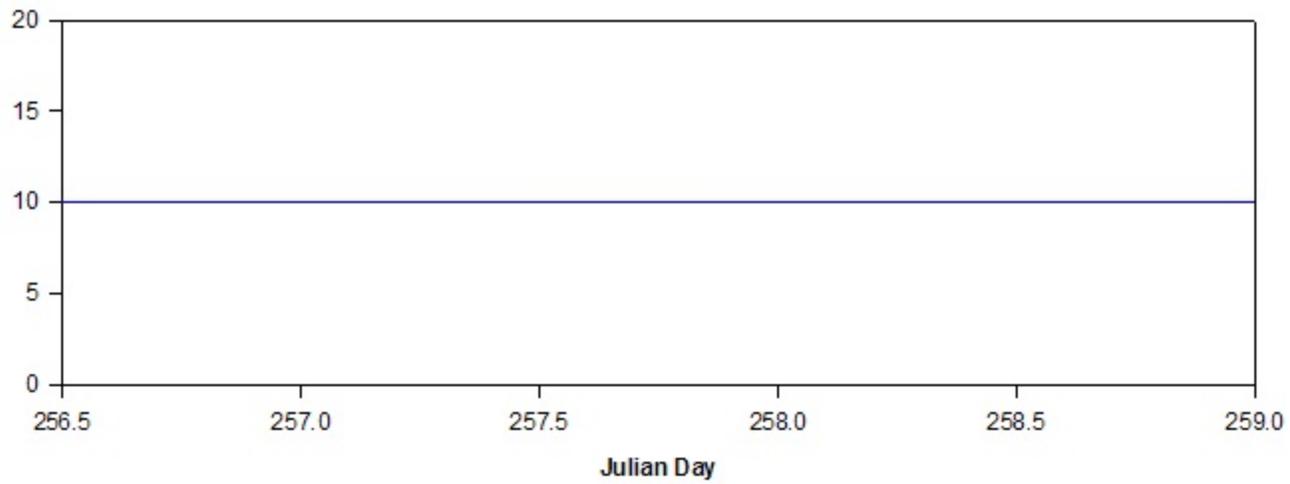


Figure 6.8. Discharge Flow Rate at Outfall (Burns Ditch)

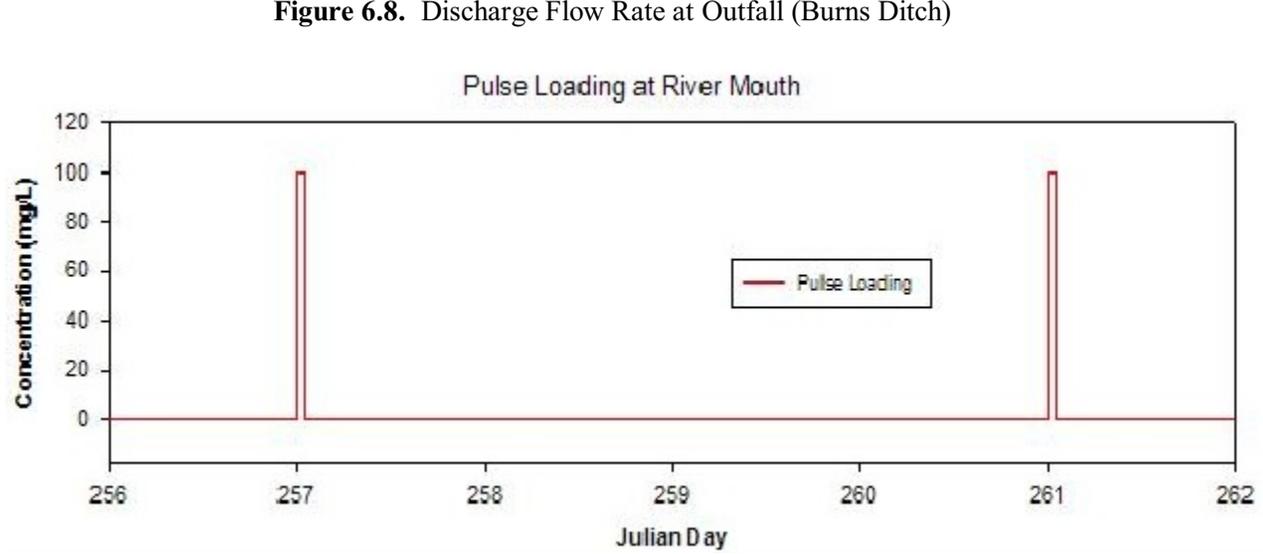


Figure 6.9. Instantaneous Discharge ⁹⁰Sr Concentrations at Outfall (Burns Ditch)

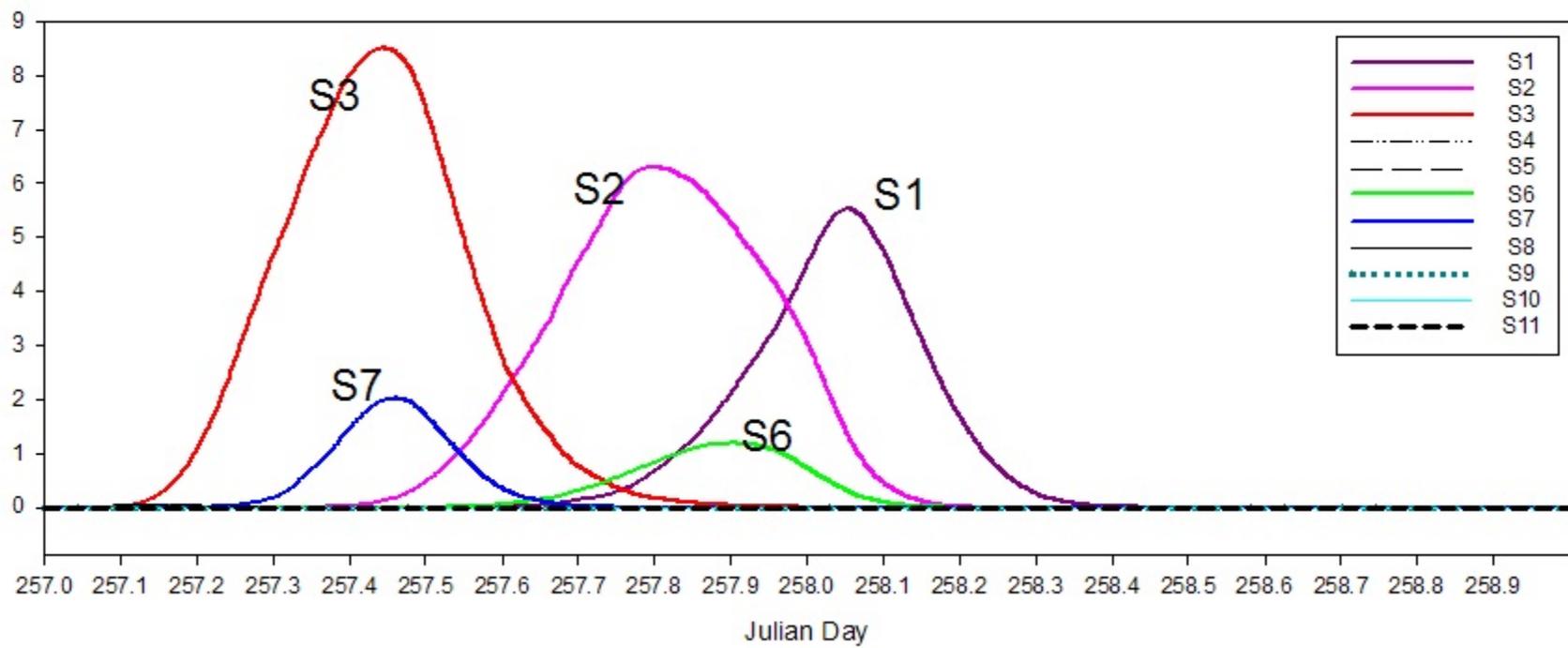


Figure 6.10. Time Histories of ^{90}Sr Concentrations at Sensor Locations under Westward Wind Condition

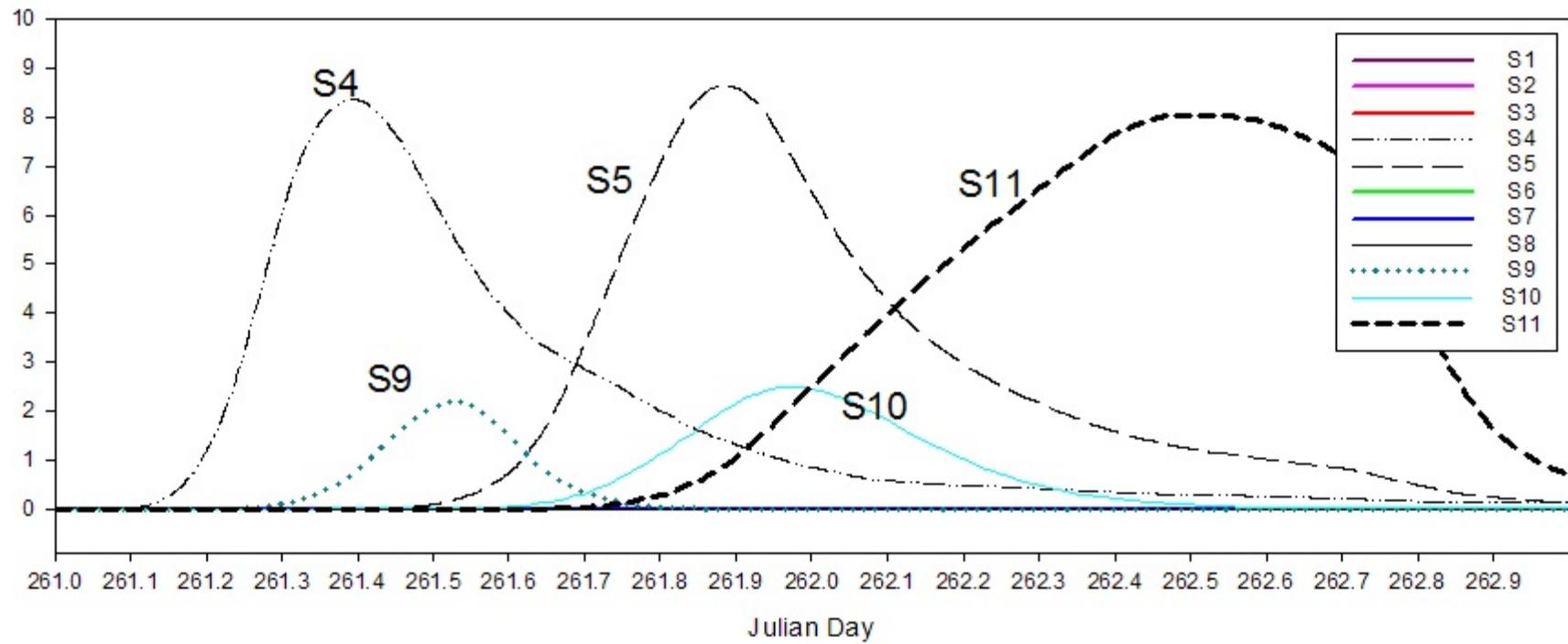
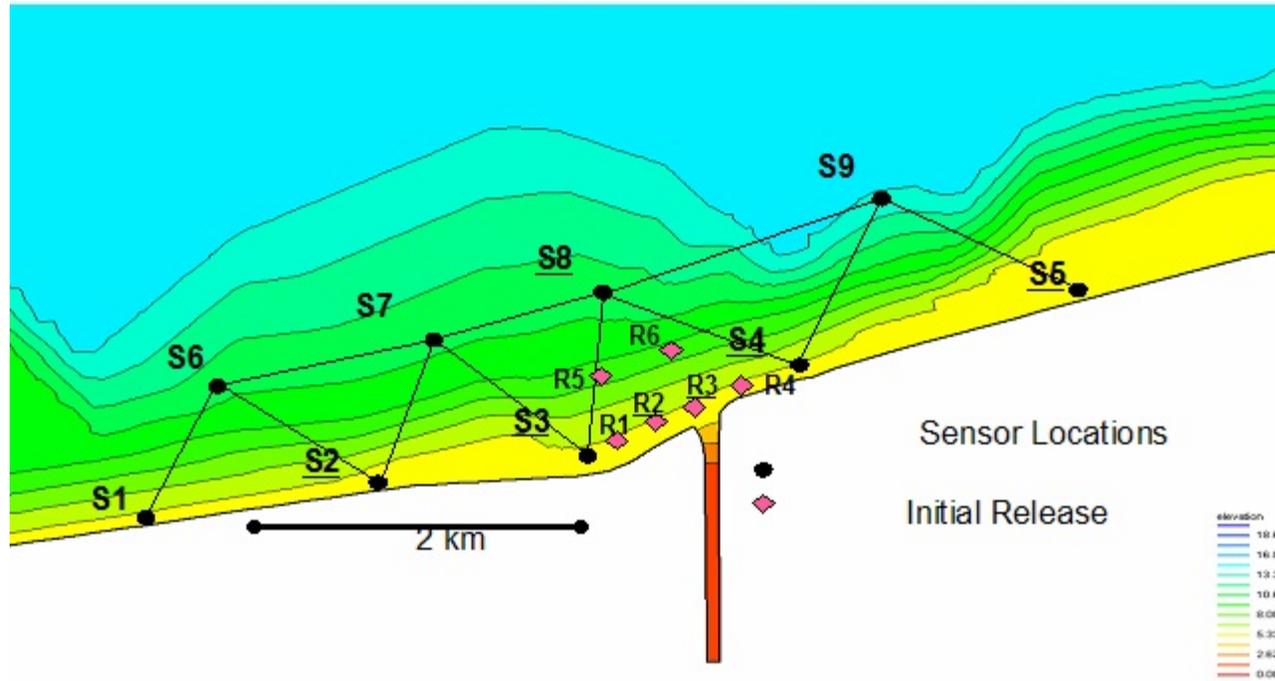


Figure 6.11. Time Histories of ^{90}Sr Concentrations at Sensor Locations under Eastward Wind Condition

Surface Water Back Calculations



Estimate Potential Release Points and Source Strengths

Figure 6.12. Surface Water Back Calculation and Source Term Identification

Surface Water Transport Forward Calculation

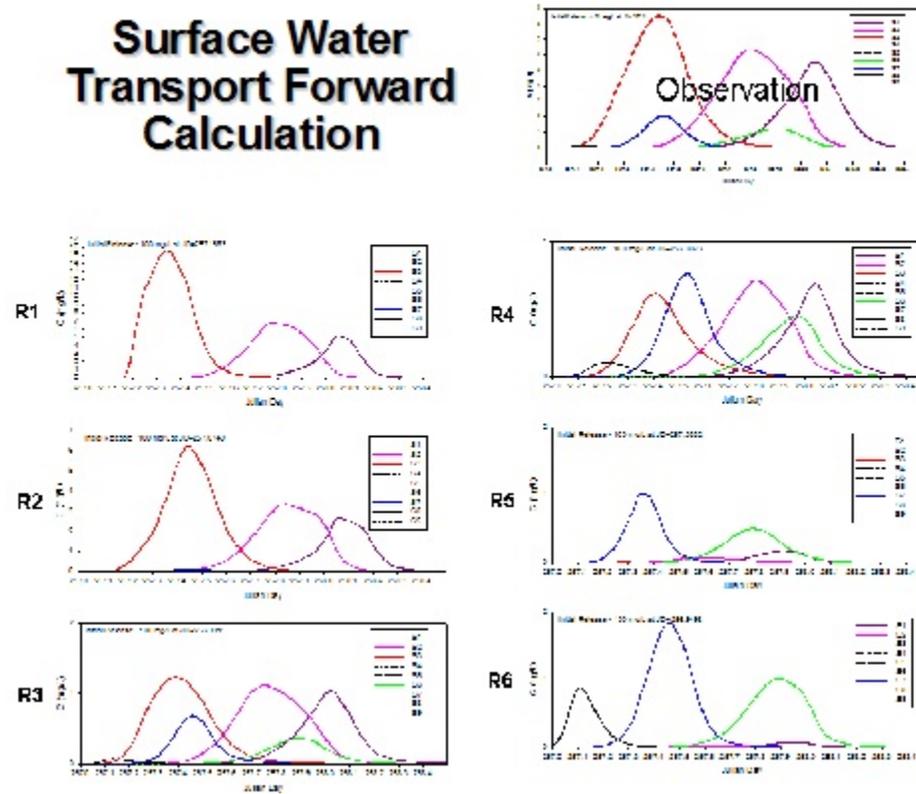


Figure 6.13. Comparisons of Concentrations Time Histories between Potential Release Locations and True Source Location under Westward Wind Condition

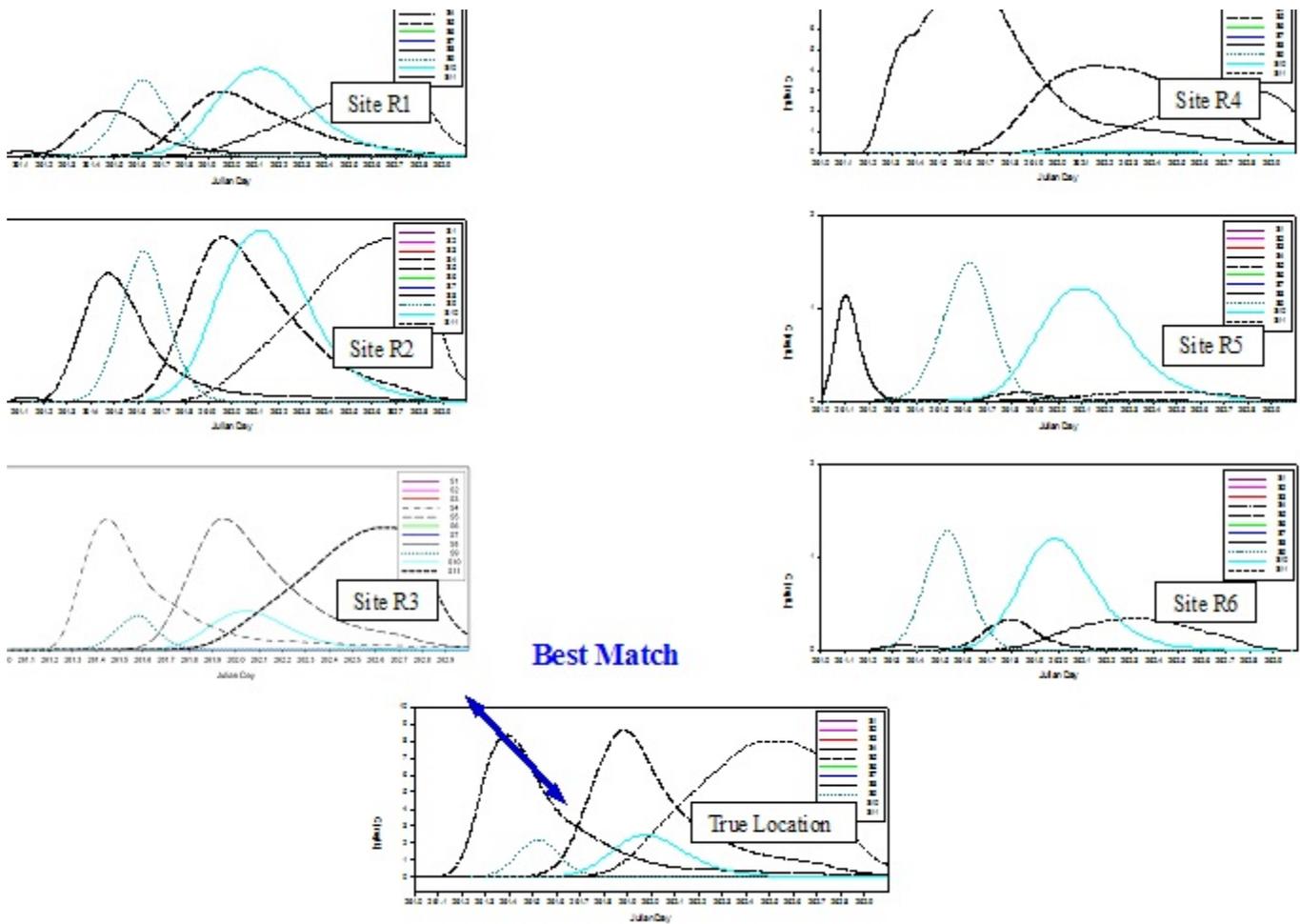


Figure 6.14. Comparisons of Concentrations Time Histories between Potential Release Locations and True Source Location under Eastward Wind Condition

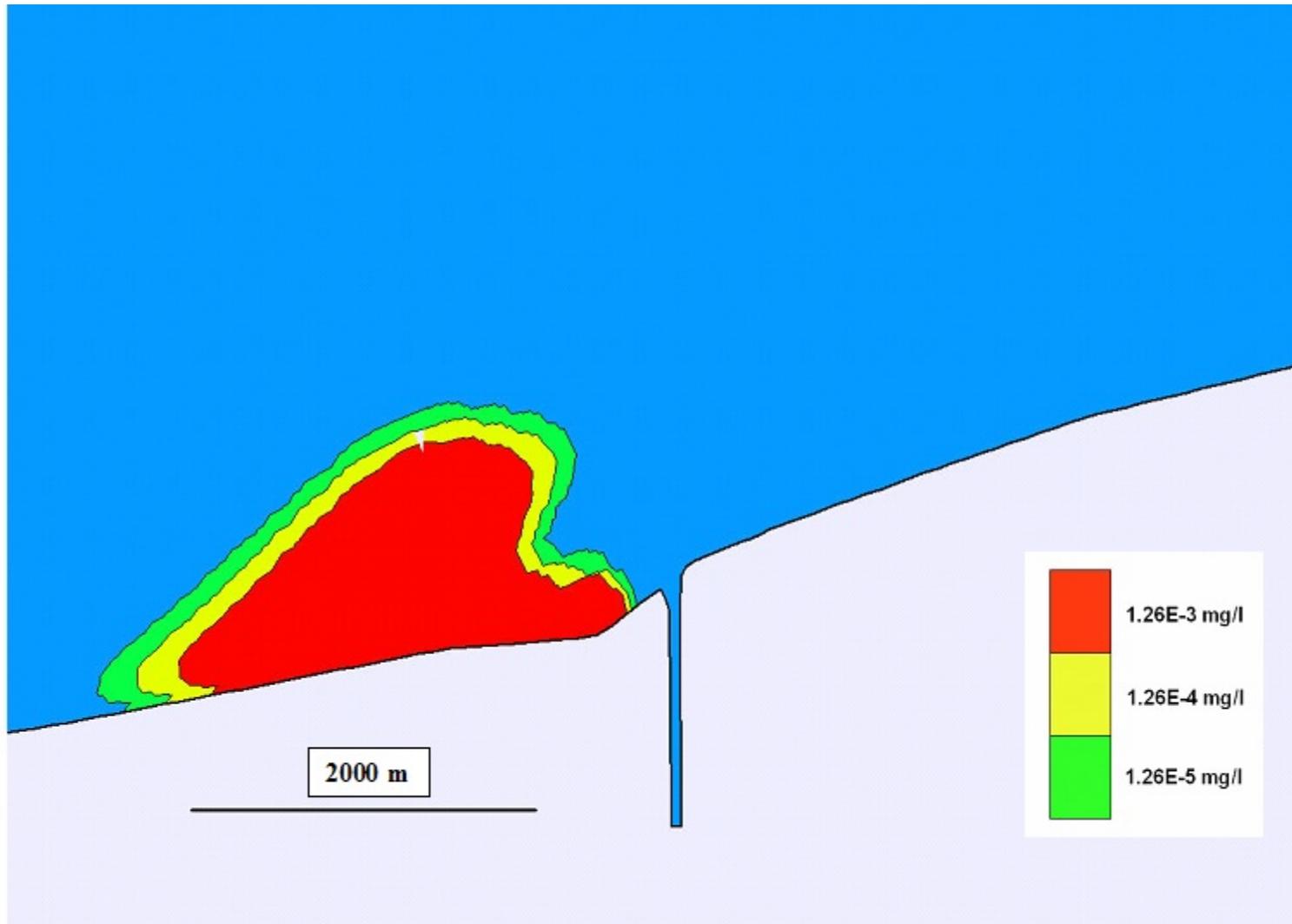


Figure 6.15. Surface Strontium-90 Concentration Contours Under Westward Wind Conditions

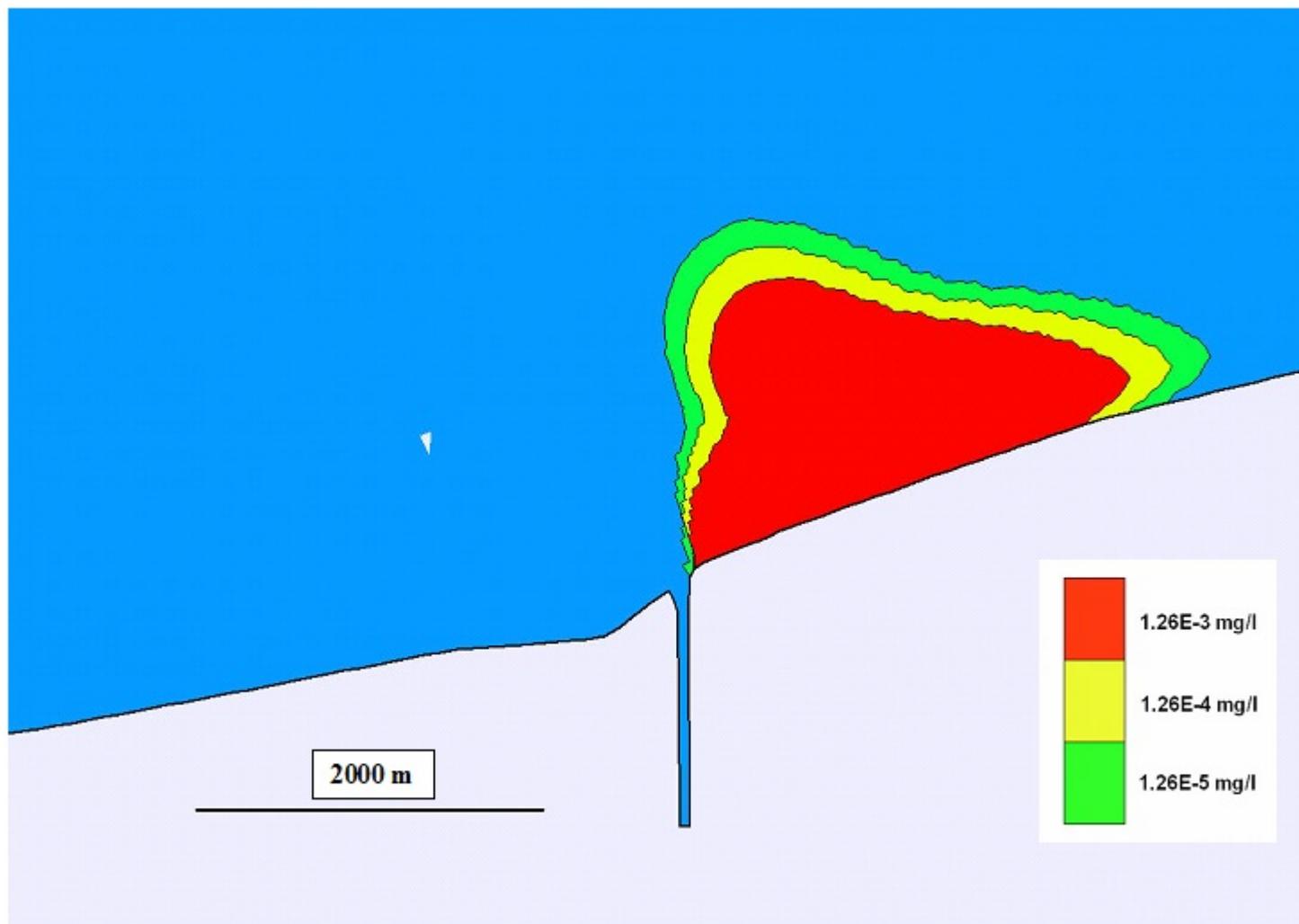


Figure 6.16. Surface Strontium-90 Concentration Contours Under Eastward Wind Conditions

7.0 Exposure Scenarios

Radioactive (and other toxic) materials have the potential to impact human health when released to surface water bodies. The evaluation of the potential impact of a suspected release is based on sensor readings at various locations in a water body as a function of time. The modeling associated with the software provides an estimate of the radionuclide concentration in the water as a function of time and location. The impacts can occur within three zone types, as defined by their exposure characteristics: open water, shoreline, and land (away from the water body).

7.1 Exposure Scenario Risk Factors for Water Zone

The Open Water Zone has limited potential for direct impact on humans and exposure while boating and swimming. Individuals are assumed to swim from the boat but not for long periods of time.

1. Dose from being on the boat

The dose to individuals on a boat occurs from penetrating radiation emitted in the water by the radionuclide. The dose is calculated as follows.

$$\text{Boating Dose} = C_w \cdot \text{EDFB} \cdot T_{\text{exposure}} \cdot \text{UCF} \quad (2)$$

where

Boating Dose	=	Dose from being on the boat in mSv
C_w	=	Water Concentration in Ci/L
EDFB	=	External Dose Factor from Boating in rem/hr per Ci/L
T_{exposure}	=	Exposure Duration Time in hours
UCF	=	Units Conversion Factor between mSv and rem (10 mSv = 1 rem).

A Boating Dose Factor can be defined by removing the water concentration and exposure duration from Equation (2):

$$\text{Boating Dose Factor} = \text{Boating Dose} / (C_w \cdot T_{\text{exposure}}) \quad (3)$$

where Boating Dose Factor has units of mSv per Ci/L in water per hour of exposure. Equation (3) can be solved for the water concentration that will result in a given level of dose, as follows.

$$C_w = \text{Dose Level} / (\text{Boating Dose Factor} \cdot T_{\text{exposure}}) \quad (4)$$

where Dose Level is the target dose for the exposure criterion in mSv. As an example of the application of the Boating Dose factor, assume that the PA guide for interdiction is 5 mSv (Food and Drug Administration [FDA] Derived Intervention Level guidance for interdiction of contaminated foods) and that the exposure duration is 2 hours. The water concentration that will provide this level of dose is evaluated as follows:

$$\text{Water Concentration (5 mSv, 2 hr)} = 5 \text{ mSv} / (\text{Boating Dose factor} \cdot 2 \text{ hours}) \quad (5)$$

The water concentration is the concentration that will result in a boating dose of 5 mSv if the humans are present in the boat for two hours at the given radionuclide water concentration. Table 7.1 provides some boating dose factors and the water concentration that will provide a dose of 5 mSv for a 2-hour exposure for common radionuclides. Note that the contribution to boating dose is primarily from penetrating radiation.

Table 7.1. Boating Dose Factors for Open Water Zone

Radionuclide	Radiation Type	Boating Dose Factor (mSv per Ci/L per hr)	5 mSv Concentration (Ci/L to give 5 mSv/hr)
⁹⁰ Sr	Beta	9.70E-01	5.15E+00
¹³⁷ Cs	Beta/gamma	3.45E+03	1.45E-03
⁶⁰ Co	Gamma	1.82E+04	2.75E-04
²²⁶ Ra	Alpha/gamma	4.63E+01	1.08E-01

2. Dose from swimming from a boat

Individuals on a boat in open water may be exposed while swimming from the boat. The exposure will include an external dose component and an internal dose component from inadvertent ingestion of water while swimming. The external dose while swimming is evaluated as follows:

$$\text{Swimming External Dose} = C_w \cdot \text{EDFS} \cdot T_{\text{exposure}} \cdot \text{UCF} \quad (6)$$

where

- Swimming External Dose = dose while swimming in contaminated water mSv
- C_w = Water Concentration in Ci/L
- EDFS = External Dose Factor for Swimming in rem/hr per Ci/L
- T_{exposure} = Exposure Duration Time in hours
- UCF = Units Conversion Factor between mSv and rem (10 mSv = 1 rem).

While swimming, an individual can also be exposed by inadvertent ingestion of water. The dose from this pathway is evaluated as follows:

$$\text{Swimming Ingestion Dose} = C_w \cdot \text{IDF} \cdot \text{IRS} \cdot T_{\text{exposure}} \cdot \text{UCF} \quad (7)$$

where

Swimming Ingestion Dose	=	Swimming Ingestion Dose in mSv
C_w	=	Water Concentration in Ci/L
IDF	=	Ingestion Dose Factor in rem/Ci
IRS	=	Ingestion Rate while Swimming in L/hr
T_{exposure}	=	Exposure Duration Time in hours
UCF	=	Units Conversion Factor between mSv and rem (10 mSv = 1 rem).

The total dose for swimming is the sum of the doses from external exposure and ingestion exposure. A Swimming Dose Factor can be defined by removing the water concentration and exposure duration from Equations (6) and (7).

$$\text{Swimming Dose Factor} = (\text{Swimming External Dose} + \text{Swimming Ingestion Dose}) / (C_w \cdot T_{\text{exposure}}) \quad (8)$$

where Swimming Dose Factor has units of mSv per Ci/L in water per hour of exposure.

Table 7.2 provides swimming dose factors and the water concentrations that will provide a dose of 5 mSv for a 1-hour exposure. Note that the contribution to external swimming dose is primarily from penetrating radiation, and the contribution to internal swimming dose is primarily from alpha and beta radiation. The total dose to an individual in the open water zone is the sum of the doses while boating and while swimming.

7.2 Exposure Scenario Risk Factors for Shoreline Zone

Individuals at a shoreline zone can be exposed while swimming near the shore and from contamination transferred onto the beach from the water along the shoreline.

1. Swimming External and Ingestion Dose

The external dose while swimming is evaluated using the same equations as for the open water zone [i.e., using Equations (6), (7), and (8)]. The water concentration and exposure duration for the shoreline zone replace the values for the open water zone.

Table 7.2. Swimming Dose Factors for Shoreline Zone

Radionuclide	Radiation Type	Swimming Dose Factor mSv per Ci/L per hr	5 mSv Water Concentration Ci/L to give 5 mSv/hr in 1 hr
<i>Contribution from External Dose While Swimming</i>			
⁹⁰ Sr	Beta	1.94E+00	2.58E+00
¹³⁷ Cs	Beta/gamma	3.45E+03	7.25E-04
⁶⁰ Co	Gamma	1.82E+04	1.37E-04
²²⁶ Ra	Alpha/gamma	4.63E+01	5.41E-02
<i>Contribution from Ingestion Dose While Swimming</i>			
⁹⁰ Sr	Beta	7.10E+04	7.04E-05
¹³⁷ Cs	Beta/gamma	2.50E+04	2.00E-04
⁶⁰ Co	Gamma	1.35E+04	3.72E-04
²²⁶ Ra	Alpha/gamma	6.60E+05	7.58E-06
<i>Total Dose While Swimming</i>			
⁹⁰ Sr	Beta	7.10E+04	7.04E-05
¹³⁷ Cs	Beta/gamma	3.19E+04	1.57E-04
⁶⁰ Co	Gamma	4.99E+04	1.00E-04
²²⁶ Ra	Alpha/gamma	6.60E+05	7.57E-06

2. External Radiation and Inadvertent Ingestion of Sediments from Contact

Material in the water along the shoreline can be transferred and deposited onto the beach, where individuals may be exposed from external radiation and inadvertent ingestion of sediments from contact. The concentration in the shoreline sediment is evaluated as a function of time assuming a constant deposition rate from the water and is evaluated as follows.

$$\text{Shoreline Sediment Concentration} = C_w \cdot \text{TRC} \cdot T_{\text{transfer}} / 2 \tag{9}$$

where

- Shoreline Sediment Concentration (C_s) = Shoreline Sediment Concentration in Ci/m²
- C_w = Water Concentration in Ci/L
- TRC = Transfer Rate Constant in L/m²/hr
- T_{transfer} = Transfer Time in hours.

The deposition is assumed to be at a constant rate, so the average concentration over the transfer time is half the amount at the end of the transfer time period (i.e., first-order reduction). Note that the transfer time is less than or equal to the exposure time because transfer times greater than the exposure time is of little interest because there is no exposure when the individuals are not present. The Transfer Rate Constant is estimated from the Multimedia Environmental Pollution Assessment System (MEPAS) and GENERation II (GENII) rate constant of 100 L/m²/day, which is equivalent to 4.167 L/m²/hr.

The external dose to an individual on the beach is evaluated as follows:

$$\text{Shoreline External Dose} = C_s \cdot \text{EDGF} \cdot \text{SWF} \cdot T_{\text{exposure}} \cdot \text{UCF} \quad (10)$$

where

Shoreline External Dose	=	Shoreline External Dose in mSv
C_s	=	Shoreline Sediment Concentration in Ci/m ²
EDGF	=	External Ground Dose Factor in rem/hr per Ci/m ²
SWF	=	Shore Width Factor in dimensionless (assumed to be 1.0)
T_{exposure}	=	Exposure Duration Time in hours
UCF	=	Units Conversion Factor between mSv and rem (10 mSv = 1 rem).

The dose from inadvertent ingestion of shoreline sediment is evaluated as follows:

$$\text{Shoreline Sediment Ingestion Dose} = C_s \cdot \rho_s \cdot Th \cdot \text{IDF} \cdot \text{SIR} \cdot T_{\text{exposure}} \cdot \text{UCF} \quad (11)$$

where

Shoreline Sediment Ingestion Dose	=	Shoreline Sediment Ingestion Dose in mSv
C_s	=	Shoreline Sediment Concentration in Ci/m ²
ρ_s	=	Sediment density in kg/m ³
Th	=	Sediment thickness in m
IDF	=	Ingestion Dose Factor in rem per Ci
T_{exposure}	=	Exposure Duration Time in hours
UCF	=	Units Conversion Factor between mSv and rem (10 mSv = 1 rem).

A Sediment Dose Factor can be defined by removing the water concentration and exposure duration from Equations (10) and (11).

$$\text{Sediment Dose Factor} = (\text{Shoreline Sediment External Dose} + \text{Shoreline Sediment Ingestion Dose}) / (C_w \cdot T_{\text{transfer}}) \quad (12)$$

where Sediment Dose Factor has units of mSv per Ci/L in water per hour of exposure. The sediment is assumed to have a density of 1500 kg/m³, and the contamination is assumed to be in the top 1 cm of sediment. The total dose for shoreline sediment exposure is the sum of the dose from external exposure and ingestion exposure. Table 7.3 provides shoreline sediment dose factors and the water concentration that will provide a dose of 5 mSv for a 1-hour exposure. Note that the contribution to external shoreline dose is primarily from penetrating radiation, and the contribution to internal sediment dose is primarily from alpha and beta radiation.

Table 7.3. Shoreline Sediment Dose Factors for Shoreline Zone

Radionuclide	Radiation Type	Shoreline Dose Factor mSv per Ci/L per hr	5 mSv Concentration Ci/L to give 5 mSv/hr
<i>Contribution from External Dose from Shoreline Sediment</i>			
⁹⁰ Sr	Beta	9.48E-01	5.28E+00
¹³⁷ Cs	Beta/gamma	1.70E+03	2.94E-03
⁶⁰ Co	Gamma	7.83E+03	6.39E-04
²²⁶ Ra	Alpha/gamma	2.14E+01	2.33E-01
<i>Contribution from Ingestion Dose from Shoreline Sediment</i>			
⁹⁰ Sr	Beta	4.72E+02	1.06E-02
¹³⁷ Cs	Beta/gamma	1.67E+02	3.00E-02
⁶⁰ Co	Gamma	8.97E+01	5.58E-02
²²⁶ Ra	Alpha/gamma	4.40E+03	1.14E-03
<i>Total Dose from Shoreline Sediment</i>			
⁹⁰ Sr	Beta	4.74E+02	1.05E-02
¹³⁷ Cs	Beta/gamma	1.87E+03	2.68E-03
⁶⁰ Co	Gamma	7.91E+03	6.32E-04
²²⁶ Ra	Alpha/gamma	4.42E+03	1.13E-03

7.3 Exposure Scenario Risk Factors for Land Zone

Contaminated water can contribute to the exposure of individuals who are located away from the water at locations that use the water for domestic purposes. The primary exposure pathways of concern are drinking of water, ingestion of fish, and ingestion of crops produced using contaminated water as a source of irrigation water. The source of the water and contaminated fish can be either the open water zone or the shoreline zone.

1. Drinking Water Ingestion Dose

Water removed from the water body and supplied to local populations may result in dose to people using the water supply for domestic purposes. The primary exposure route of interest is use of the water as a source of drinking water. The dose from this pathway is evaluated as follows:

$$\text{Drinking Water Ingestion Dose} = C_w \cdot \text{IDF} \cdot \text{IRW} \cdot T_{\text{exposure}} \cdot \text{UCF} \quad (13)$$

where

Drinking Water Ingestion Dose = Dose from drinking contaminated water in mSv
 C_w = Water Concentration in Ci/L
 IDF = Ingestion Dose Factor in rem/Ci
 IRW = Ingestion Rate of Water in L/hr
 T_{exposure} = Exposure Duration Time in hours
 UCF = Units Conversion Factor between mSv and rem (10 mSv = 1 rem).

A Drinking Water Dose Factor can be defined by removing the water concentration and exposure duration from Equation (13).

$$\text{Drinking Water Dose Factor} = \text{Drinking Water Dose} / (C_w \cdot T_{\text{exposure}}) \quad (14)$$

where Drinking Water Dose Factor has units of mSv per Ci/L in water per hour of exposure.

The average water intake rate is about 2 L/day. However, for the present analysis, the exposed individual is assumed to ingest 2 L in 1 hour at the time the water contamination reaches the water supply. Table 7.4 provides Drinking Water Dose Factors and the water concentration that will provide a dose of 5 mSv for an intake of 2 L of water in 1 hour.

Table 7.4. Drinking Water Dose Factors for Open Water Zone or Shoreline Zones

Radionuclide	Radiation Type	Drinking Water Dose Factor (mSv per Ci/L per hr)	Concentration for 5 mSv Dose (Ci/L to give 5 mSv/hr in 1 hr)
⁹⁰ Sr	Beta	2.84E+06	1.76E-06
¹³⁷ Cs	Beta/gamma	1.00E+06	5.00E-06
⁶⁰ Co	Gamma	5.38E+05	9.29E-06
²²⁶ Ra	Alpha/gamma	2.64E+07	1.89E-07

2. Fish Ingestion Dose

Fish caught in contaminated waters may result in dose to individuals who consume the fish. The fish ingestion dose is evaluated assuming the edible portions of the fish come into immediate equilibrium with the contaminants in the water. The dose from this pathway is evaluated as follows:

$$\text{Fish Ingestion Dose} = C_w \cdot \text{BCF} \cdot \text{IDF} \cdot \text{IRF} \cdot T_{\text{exposure}} \cdot \text{UCF} \quad (15)$$

where

Fish Ingestion Dose = Fish Ingestion Dose in mSv
 C_w = Water Concentration in Ci/L
 BCF = Bioconcentration factor for the contaminant in fish in L water / kg fish
 IDF = Ingestion Dose Factor in rem/Ci
 IRF = Ingestion Rate of Fish in kg/hr
 T_{exposure} = Exposure Duration Time in hours
 UCF = Units Conversion Factor between mSv and rem (10 mSv = 1 rem).

A Fish Ingestion Dose Factor can be defined by removing the water concentration and exposure duration from Equation (15).

$$\text{Fish Ingestion Dose Factor} = \text{Fish Ingestion Dose} / (C_w \cdot T_{\text{transfer}}) \quad (16)$$

where Fish Ingestion Dose Factor has units of mSv per Ci/L in water per hour of exposure. The pathway is evaluated assuming a total intake of 200 grams of contaminated fish. This is equivalent to an exposure duration of 1 hour with an intake rate of 0.2 kg per hour. Table 7.5 provides Fish Ingestion Dose Factors and the water concentration that will provide a dose of 5 mSv for an intake of 200 grams of fish in 1 hour (about one day's intake).

Table 7.5. Fish Ingestion Dose Factors for Open Water Zone or Shoreline Zones

Radionuclide	Radiation Type	Fish Ingestion Dose Factor (mSv per Ci/L per hr)	Concentration for 5 mSv Dose (Ci/L to give 5 mSv/hr from 0.2 kg fish)
⁹⁰ Sr	Beta	1.42E+04	3.52E-07
¹³⁷ Cs	Beta/gamma	2.00E+05	2.50E-08
⁶⁰ Co	Gamma	1.78E+04	2.82E-07
²²⁶ Ra	Alpha/gamma	1.85E+05	2.71E-08

3. Food Ingestion Dose from Irrigated Crops

Using the contaminated water as a source of irrigation water for local gardens may result in exposure when the contaminated crops are consumed by the individuals. The dose from this exposure pathway is evaluated assuming the water is used for a 1-hour period supplying 1 day's worth of irrigation to the garden. The contaminant is deposited directly onto the plant surfaces and to soil. The soil contamination is assumed to be immediately in equilibrium with the concentration in the plant from root uptake from soil. The individual is assumed to eat one day's worth of contaminated vegetables. The dose from this pathway is evaluated for two routes of contamination of the plant: direct deposition onto the plant and deposition onto soil with root transfer to the edible portion of the plant. The plant concentration from direct deposition is evaluated as follows.

$$\text{Plant Concentration Direct} = C_w \cdot \text{IRR} \cdot \text{TF} \cdot T_{\text{irrigation}} / (\text{YP}) \quad (17)$$

where

Plant Concentration Direct	=	Plant concentration from direct deposition of water in Ci/kg wet plant
C_w	=	Water Concentration in Ci/L
IRR	=	Irrigation Rate L/m ² /hr
TF	=	Interception fraction (i.e., fraction of irrigation water retained on plants [dimensionless])
$T_{\text{irrigation}}$	=	Duration of irrigation period in hours
YP	=	Yield of edible plant in kg wet plant per m ² .

The plant concentration from deposition to soil and root uptake is evaluated as follows:

$$\text{Plant Concentration Soil} = C_w \cdot \text{IRR} \cdot \text{CR} \cdot T_{\text{irrigation}} / (\text{ST} \cdot \text{SD}) \quad (18)$$

where

Plant Concentration Soil	=	Plant concentration from deposition to soil and uptake by roots in Ci/kg wet plant
IRR	=	Irrigation Rate L/m ² /hr
CR	=	Concentration ratio between soil and plant in kg soil per kg wet plant
$T_{\text{irrigation}}$	=	Duration of irrigation period in hours
ST	=	Soil thickness in agricultural soils, m
SD	=	Soil density in agricultural soils, kg/m ³ .

The dose from ingestion of plants is evaluated using the total plant concentration as the sum of the contributions from the two sources.

$$\text{TPC} = \text{Plant Concentration Direct} + \text{Plant Concentration Soil} \quad (19)$$

where TPC is the total plant concentration Ci/kg wet plant. The dose is evaluated as follows.

$$\text{Food Ingestion Dose} = \text{TPC} \cdot \text{IRC} \cdot \text{IDF} \cdot T_{\text{ingestion}} \cdot \text{UCF} \quad (20)$$

where

Food Ingestion Dose	=	Dose from ingestion of food mSv
TPC	=	Total plant concentration Ci/kg wet plant
IRC	=	Ingestion Rate of Crops kg/hr
$T_{\text{ingestion}}$	=	Duration of ingestion period in hours
UCF	=	Units Conversion Factor between mSv and rem (10 mSv = 1 rem).

The dose from food ingestion is evaluated assuming a total intake of 0.2 kg of contaminated crops following the contamination of crops. This is equivalent to consumption of 0.2 kg in 1 hour. A Food Ingestion Dose Factor can be defined by removing the water concentration and exposure duration from Equation (20).

$$\text{Food Ingestion Dose Factor} = \text{Food Ingestion Dose} / (C_w \cdot T_{\text{ingestion}}) \quad (21)$$

where Food Ingestion Dose Factor has units of mSv per Ci/L in water per hour of exposure. The pathway is evaluated assuming a total intake of 200 grams of contaminated crops following use of the contaminated water for crop irrigation. Table 7.6 provides Fish Ingestion Dose Factors and the water concentration that will provide a dose of 5 mSv for an intake of 200 grams of food crops in 1 hour (about 1 day's intake).

Table 7.6. Food Ingestion Dose Factors for Open Water Zone or Shoreline Zones

Radionuclide	Radiation Type	Food Ingestion Dose Factor (mSv per Ci/L per hr)	Concentration for 5-mSv Dose (Ci/L to give 5 mSv/hr from 0.2 kg crop)
⁹⁰ Sr	Beta	1.21E+04	4.15E-05
¹³⁷ Cs	Beta/gamma	4.18E+03	1.20E-04
⁶⁰ Co	Gamma	2.24E+03	2.23E-04
²²⁶ Ra	Alpha/gamma	1.10E+05	4.55E-06

8.0 Protective Action Recommendations

8.1 Determination of Threshold Action Levels

8.1.1 Upper Bound Health Impact Estimation, if the ^{90}Sr in the Wastewater Outfall is Equivalent to the Water Solubility Limit

An analysis has been performed to evaluate the potential for health impacts from the release of soluble ^{90}Sr to water bodies. The analysis has assumed that the initial concentration of the ^{90}Sr is the limit of solubility of $\text{Sr}(\text{NO}_3)_2$ in water, which is 709 g/L cold water (CRC Handbook 67th Edition). This is equivalent to about 298 g/L of ^{90}Sr (or $1.54\text{E}+15$ Bq/L). Assuming a dilution factor of 1000 at the receptor, this would result in a water concentration at the exposure location of 0.298 g/L or 298 mg/L ($1.54\text{E}+12$ Bq/L). If an individual were to drink 1 liter of water over a short period of time (i.e., while the water concentration persisted at the estimated level), the internal dose to the GI Tract would be about 850 Sv over the 7 days following the intake. This is enough radiation dose to result in GI Tract Syndrome and death in a matter of “weeks.” The dose to the bone marrow would also be significant (because ^{90}Sr is metabolized and deposited in the bone) and would result in bone marrow syndrome and death in a matter of “months.” Other observable acute impacts are also possible. The GI Tract syndrome has an LD50 (i.e., Lethal Dose at 50% mortality) value of approximately 2.50 Sv acute external dose to the GI Tract. Ingestion of ^{90}Sr would result in direct internal exposure of the GI Tract and would be expected to have a similar value for LD50. Using this value for LD50, the amount of water that would need to be ingested is just 3 mL, where 3 mL could be easily inadvertently ingested while swimming in a contaminated water body.

8.1.2 Summary of Threshold Action Levels

Three levels are defined for actions to intervene in the event of an accidental or deliberate release of contaminants to a water body. The levels discussed here are specific to release of the radionuclide ^{90}Sr . The methods outlined here could also be applied to other radionuclides. Similar methods could be defined and applied to other types of hazardous materials. The three levels are presented as follows:

1. **Lower Action Level (5 mSv)** – The lower action level represents a dose to an individual of **5 mSv** corresponding to the FDA’s Derived Intervention Level (DIL) guidance for interdiction of contaminated foods. The lower action level corresponds to a risk level of $1.0\text{E}-5$ risk of cancer mortality for an adult who drinks 1 L of the contaminated water.
2. **Mid Action Level (50 mSv)** – The International Atomic Energy Agency (IAEA) recommends a dose level of **50 mSv** for making the decision to evacuate an area within 1 week following a nuclear accident. The National Radiological Protection Board (NRPB) of the United Kingdom recommends a dose range of 30 to 300 Committed Effective Dose Equivalent (CEDE) as evacuation decision levels. In the United States, the FDA has published PA guides for the early phase of a nuclear accident, recommending a range of 10 to 50 mSv for evacuation, and 50 mSv (lifetime) for relocation.
3. **Upper Action Level (500 mSv)** – The upper action level represents a dose to an individual of **500 mSv**, which is approaching a level where health effects may be observable in an exposed population and where immediate action is required, and it represents the International Commission on Radiological Protection (ICRP) recommended level of dose averted for evacuation following a nuclear accident.

8.1.3 Lower Action Level of 5 mSv

Lower-Action Level information is derived primarily from an article by the Center for Food Safety and Applied Nutrition (see <http://www.cfsan.fda.gov/~dms/nucleve2.html>). The Food and Drug Administration (FDA) has published Derived Intervention Levels (DILs) (FDA 1998) that can be used to provide a basis for intervention of contaminated water following release of radionuclides to a water body. The basis for evaluations of DILs is a lifetime dose of 5 mSv committed effective dose equivalent. The associated lifetime risk of total cancer mortality would be 2.25E-4 for this dose level. The equation for calculation of a DIL is as follows:

$$DIL = PAG / (f \cdot FI \cdot DC) \quad (22)$$

where

DIL	=	Derived Intervention Levels (Bq/kg or Bq/L)
PAG	=	PA Guide (mSv)
f	=	fraction for intake that is contaminated (dimensionless)
FI	=	total intake of food or water (kg or L)
DC	=	dose conversion factor for ingestion of a radionuclide (mSv/Bq)

For ingestion of water during a short period of time, an effective DIL can be calculated for Sr-90, where the intake is 1 L of water (FI = 1.0), all of which is contaminated (f = 1.0). The PA Guide is 5 mSv (PAG = 5), and the dose conversion factor for Sr-90, 50-year CEDE is 3.8E-5 mSv/Bq (DC = 3.8E-5).

Based on these values, the Derived Intervention Level (DIL) is calculated to be 1.30E+5 Bq/L for Sr-90 in water. As an alternative, if the DIL were to be based on a cancer mortality risk of 1.0E-5, the corresponding PAG level would be 0.222 mSv. A DIL derived from this value would be 5.77E+3 Bq/L for Sr-90 in water.

8.1.4 Mid and Upper Action Levels of 50 and 500 mSv, Respectively

Upper Action Level information is derived primarily from an internet report, prepared by Radiation Protection in Health Canada at http://www.hc-sc.gc.ca/hecs-sesc/rpb/publications/nuclear_emergency_guideline_intervention/toc.htm

Several agencies have recommended dose action levels for response to accidents at nuclear power generating stations. The International Atomic Energy Agency (IAEA) recommends a dose level of 50 mSv for making the decision to evacuate an area within 1 week following a nuclear accident (IAEA 1994). The ICRP (ICRP 1993) recommends a dose level of 500 mSv as a level of dose averted for evacuation following a nuclear accident. The National Radiological Protection Board (NRPB) of the United Kingdom recommends a dose range of 30 to 300 CEDE as evacuation decision levels (NRPB 1990, 1997). In the United States, the FDA has published (FDA 1998) PA guides for the early phase of a nuclear accident, recommending a range of 10 to 50 mSv for evacuation, and 50 mSv (lifetime) for relocation. These various recommendations span a range of 10 to 500 mSv of dose averted. These values can be used to evaluate corresponding DILs using Equation (22), which would result in a water concentration range of 2.60E+5 to 1.30E+7 Bq/L.

8.1.5 Threshold Action Levels based on Water Concentration and Exposure Pathway

Based on exposure scenarios, the dose-equivalent Threshold Action Levels of 5, 50, and 500 mSv can be converted to equivalent water concentrations. The following is a summary of the water concentrations that can be used to demonstrate the use of the RRA methodology for surface waters. The equivalent ⁹⁰Sr water concentration action levels corresponding to 5, 50, and 500 mSv by exposure scenario are presented in Table 8.1 for boating/swimming in open water, swimming/shoreline activity on beach, drinking water ingestion, fish consumption, and food consumption. Assumptions on exposure scenarios are summarized as follows. Boating occurs for 2 hours, and swimming occurs for 1 hour. Shoreline and swimming exposure on the beach occur for 1 hour each. Fish consumption is 200 grams, and the fish meat concentration is instantaneous in equilibrium with the water. Drinking water involves intake of 2 liters of water. The food is contaminated by 1-day's worth of irrigation (which may occur in just one hour) onto leafy vegetables. The food ingestion is 200 grams from the contaminated leafy vegetables.

Table 8.1. Summary of Water Concentration Action Levels

Exposure Scenario	Strontium-90 Water Concentration by Threshold Level (mg/L)		
	Level 1 Adverse (5 mSv)	Level 2 (50 mSv)	Level 3 Severe (500 mSv)
Boating/swimming in open water	5.03E-04	5.03E-03	5.03E-02
Swimming/shoreline activity on beach	5.00E-04	5.00E-03	5.00E-02
Drinking water ingestion	1.26E-05	1.26E-04	1.26E-03
Fish Consumption	2.52E-03	2.52E-02	2.52E-01
Food Consumption	2.96E-04	2.96E-03	2.96E-02

8.2 Application of Risk Factors to Zone Water Concentration Predictions - ⁹⁰Sr

Two analyses need to be performed, each of which has a different purpose.

1. When the contamination is first detected, Direct Impact Risk Areas need to be identified. This analysis is preliminary and sets the stage for which calculations are performed. Table 8.1 provides a summary of the water concentration action levels corresponding to the three dose equivalent threshold levels by exposure scenario. Two of these dose equivalent levels are used to determine the Direct Impact Risk Areas. These two threshold levels are Adverse (i.e., 5 mSv) and Severe (i.e., 500 mSv). Because only one value is required for each threshold (i.e., Adverse and Severe) for the initial determination of Direct Impact Risk Areas, the water concentration affiliated with the most restrictive equivalent dose (i.e., “Drinking Water Ingestion”) is used in this determination. So, for

the Severe threshold, the Water Concentration Action Level is 1.26E-3 mg/L, and for the Adverse threshold, it is 1.26E-05 mg/L.

2. The PARs need to be based on the actual scenarios to which people are exposed. For example, the Direct Impact Risk Areas are based on the Drinking Water Ingestion scenario. If people are not ingesting drinking water, then the PA should not be based on the Drinking Water Ingestion scenario; it should be based on the actual scenario to which people are exposed. Hence, this section provides the dose factors that are ultimately used to determine which situations exceed the threshold levels by exposure scenario. In other words, the time varying concentration levels are modified by these dose factors to estimate dose levels, which in turn are then compared to Severe and Adverse threshold levels. The relative location of this comparison (i.e., higher or lower than the threshold) will determine whether the recommendation is to Evacuate, Restrict Access, or Mitigate.

The dose from a predicted water concentration is evaluated using the same dose factors used to generate the action level water concentration values. These factors are provided in Table 8.2 with the reference time period used to develop the dose factors.

Table 8.2. Dose Factors for Evaluation of Risk from Predicted Water Concentrations

Zone	Exposure Pathway	Reference Period (RP) (hrs)	Dose Factor (mSv per mg/L)
Open Water	Boating/Swimming	12	9.94E+03
Shoreline	Swimming/Shoreline	12	1.00E+04
Land	Drinking Water	24	3.98E+05
Land	Fish Ingestion	24	1.99E+03
Land	Food Ingestion	24	1.69E+04

The water transport analysis predicts the water concentration that will exist for a period of time, which is the “Duration of Zonal Impact.” The Duration of Zonal Impact is defined as the time duration when the contaminant level first exceeds a threshold level and last exceeds a threshold level in a zone. Three ranges in time periods are defined:

1. Short: 0 to 2 hours
2. Medium: >2 to 72 hours
3. Long: >72 hours

When the Duration of Zonal Impact is equal to or less than the Reference Period, as given in Table 8.2 (i.e., $RP \leq 12$ hrs for Open Water and Shoreline zones, and $RP \leq 24$ hrs for the Land zone), the dose from a water concentration, averaged over a time period, is equal to the dose factor times the water concentration:

$$\text{Dose} = C_{iw} \cdot \text{DF} \quad (22)$$

where

- Dose = Dose in mSv
- C_{iw} = Integrated Water Concentration in mg/L, averaged over the Duration of Zonal Impact
- DF = Dose Factor in mSv per mg/L.

When the Duration of Zonal Impact is greater than the Reference Period, as given in Table 8.2 (i.e., RP > 12 hrs for Open Water and Shoreline zones, and RP > 24 hrs for the Land zone), the dose is pro-rated using the duration of zonal impact as follows:

$$\text{Dose} = C_w \cdot \text{DF} \cdot (\text{DZI} / \text{RP}) \quad (23)$$

where

- DZI = Duration of Zonal Impact (i.e., time the zone has levels above the threshold) in hrs
- RP = Reference Period in hrs.

The calculated dose is compared to the action levels (e.g., 5 mSv or 500 mSv).

9.0 Protective Action Recommendations Table

A PAR table identifies the response or PA that is implemented. An impact occurs when the contaminant level reaches predefined threshold for a zone or location. The PARs are a function of the following six attributes:

1. **Type of Contaminant** – chemical, biological, radiological, toxic, infectious, etc. For this application, radiological is illustrated with ^{90}Sr as the specific radionuclide.
2. **Type of Zone** – Three types of zones have been identified for this assessment: Open Water, Shoreline, and Land. For each type of zone, zone-specific exposure scenarios have been identified:
 - a. Open Water – Boating/Swimming
 - b. Shoreline – Swimming/Shoreline
 - c. Land – Drinking Water, Fish, and Food IngestionThese exposure scenarios account for the various routes of exposure, including Inhalation, Ingestion, Adsorption, and External (Ionizing).

3. **Threshold Levels (Severity)** – Concentration or Dose that causes an unacceptable human health consequence. Two threshold levels have been identified for this assessment:
 - a. Adverse – Strong likelihood of nonlife-threatening and/or potentially reversible consequence, corresponding to 5 mSv.
 - b. Severe – Strong likelihood of life-threatening, irreversible consequence, corresponding to 500 mSv.

The relationships between Threshold Level, Dose Equivalent, Type of Zone, Exposure Scenario and Water Concentration are presented in Table 8.1. For example, the threshold levels for Drinking Water Ingestion are

- a. Severe: 1.26E-03 mg/L, 1.76E+08 pCi/L, 6.5E+06 Bq/L, 500 mSv
 - b. Adverse: 1.26E-05 mg/L, 1.76E+06 pCi/L, 6.5E+04 Bq/L, 5 mSv
4. **Concentration, Dose, or Risk Level** – The concentration represents the actual or simulated concentration, which can then be converted to dose and risk levels, based on the exposure scenarios.
 5. **Time to Zonal Impact** – Time until contaminant reaches a threshold in the zone:
 - a. Short: 0 to 2 hrs
 - b. Medium: >2 to 72 hrs
 - c. Long: >72 hrs
 6. **Duration of Zonal Impact** – Time duration when the contaminant level first exceeds a threshold level and last exceeds a threshold level in a zone:
 - a. Short: 0 to 2 hrs
 - b. Medium: >2 to 72 hrs
 - c. Long: >72 hrs

Four PARs have been identified for the various combinations of the six attributes: No Action, Mitigate, Restrict Access, and Evacuate. The latter three and their definitions are provided in Table 9.1. The No-

Action recommendation is used when no threshold is reached. The PA Table, which is used in this assessment, is presented in Table 9.2.

Table 9.1. Relationships Between Zone Type, PA Decision, and PA Implementation

Zone Type	Decision	Protective Action Implementation
Water	Evacuate	Immediately Leave Zone (no boating, fishing, swimming)
	Restrict Access	Access to zone is restricted (no boating, fishing, swimming)
	Mitigate	Restrict access, monitor situation
Shoreline	Evacuate	Immediately Leave Zone (no walking, fishing, swimming)
	Restrict Access	Close drinking water intakes, and restrict swimming and access to shoreline
	Mitigate	Restrict Access, clean up soil, treat water at a treatment plant, and evaluate alternatives
Land	Evacuate	Immediately Leave Zone (prohibit non-essential activities)
	Restrict Access	No water use, no ingestion of garden vegetables, no access to watered areas
	Mitigate	Restrict access, clean up soil, treat water at a treatment plant, and evaluate alternatives

Table 9.2. Protective Action Recommendation Table

Sensor Data	Water Model		Human Health Model	Protective Action
Zone Type	Time to Zonal Impact	Duration of Zonal Impact	Severity	Applicable Decisions
Water	Short (0 - 2 hours)	Short (0 - 2 hours)	Severe	Evacuate
			Adverse	Restrict Access
		Medium (>2 - 72 hours)	Severe	Evacuate
			Adverse	Restrict Access
		Long (>72 hours)	Severe	Evacuate
			Adverse	Restrict Access
	Medium (>2 - 72 hours)	Short (0 - 2 hours)	Severe	Evacuate
			Adverse	Restrict Access
		Medium (>2 - 72 hours)	Severe	Evacuate
			Adverse	Restrict Access
		Long (>72 hours)	Severe	Evacuate
			Adverse	Restrict Access
Long (>72 hours)	Short (0 - 2 hours)	Severe	Mitigate	
		Adverse	Mitigate	
	Medium (>2 - 72 hours)	Severe	Mitigate	
		Adverse	Mitigate	
	Long (>72 hours)	Severe	Mitigate	
		Adverse	Mitigate	
Shoreline	Short (0 - 2 hours)	Short (0 - 2 hours)	Severe	Evacuate
			Adverse	Restrict Access
		Medium (>2 - 72 hours)	Severe	Evacuate
			Adverse	Restrict Access
		Long (>72 hours)	Severe	Evacuate
			Adverse	Restrict Access
	Medium (>2 - 72 hours)	Short (0 - 2 hours)	Severe	Evacuate
			Adverse	Restrict Access
		Medium (>2 - 72 hours)	Severe	Evacuate
			Adverse	Restrict Access
		Long (>72 hours)	Severe	Evacuate
			Adverse	Restrict Access
Long (>72 hours)	Short (0 - 2 hours)	Severe	Mitigate	
		Adverse	Restrict Access	
	Medium (>2 - 72 hours)	Severe	Mitigate	
		Adverse	Restrict Access	
	Long (>72 hours)	Severe	Mitigate	
		Adverse	Mitigate	
Land	Short (0 - 2 hours)	Short (0 - 2 hours)	Severe	Evacuate
			Adverse	Evacuate
		Medium (>2 - 72 hours)	Severe	Evacuate
			Adverse	Evacuate
		Long (>72 hours)	Severe	Evacuate
			Adverse	Evacuate
	Medium (>2 - 72 hours)	Short (0 - 2 hours)	Severe	Evacuate
			Adverse	Restrict Access
		Medium (>2 - 72 hours)	Severe	Evacuate
			Adverse	Restrict Access
		Long (>72 hours)	Severe	Mitigate
			Adverse	Mitigate
Long (>72 hours)	Short (0 - 2 hours)	Severe	Mitigate	
		Adverse	Mitigate	
	Medium (>2 - 72 hours)	Severe	Mitigate	
		Adverse	Mitigate	
	Long (>72 hours)	Severe	Mitigate	
		Adverse	Mitigate	

10.0 Summary of the Application of the Rapid Risk Assessment

An example application of this RRA methodology is presented. It involves the release of an unknown contaminant, of unknown strength, of unknown location to a large surface water body, which supplies drinking water and irrigation supplies to a nearby community. Before the assessment, the local and state authorities established an EOC, that

1. identifies PA zones and classifies them as water, shoreline, or land-based zones (see Figure 3.1).
2. establishes surface water sensors (See Figure 6.7).
3. defines exposure scenarios and threshold limits for the exposure pathway, contaminant, and zone type (see Table 8.1).
4. defines PA Thresholds and Recommendations (see Tables 9.1 and 9.2).
5. defines Protective/Response Action Plans.

The approach demonstrates the linkage, application, and implementation of

- contaminant releases to a large surface water body (see Figure 6.1)
- Status Board notification through sensors (see Figure 6.7)
- Incident Identification (i.e., correlation between sensors and Status Board [see Figures 6.10, 6.11, and 10.1])
- three-dimensional surface water modeling, backward calculating an estimate of a given source location and strength (see Figure 6.12)
- three-dimensional surface water modeling, forward calculations estimating where the plume will migrate over time (see Figures 6.13 through 6.16)
- exposure and impact analyses (see Table 8.1 and Figure 10.2)
- an evaluation of threats and determination of PARs (see Tables 9.1 and 9.2).
- choosing and Implementing the best-fit PA Plan (see Figure 10.3).
- evaluating differences between PARs and Final PA Decision (see Figure 10.3).
- re-evaluating in real-time as the assessment requires.

Figure 10.4 provides a 14-step detailed flow diagram that walks through the assessment, illustrating how these components interact with each other..

1. Raw Sensor Data are collected and passed for analysis. As a surrogate for sensors, a Surface Water model, which has been pre-run, will identify locations where contaminant levels have some significance, so an interesting dataset to analyze can be identified. The actual pre-run Surface Water model results will not be known *a priori* by the system (see Figure 6.7).
2. Raw Sensor Data are passed to a Decision Support model.
3. The Raw Sensor Data are consumed by the Decision Support model, and this pre-processor examines the raw data and performs a prognostic to determine a significant “finding,” based on pre-defined scenarios for only those sensor locations initially (See Figures 6.10, 6.11, and 10.5).

- 4a. Sensor locations and contaminant levels are sent to **EMAdvantage**, so significant “findings” can be posted.
- 4b. While **EMAdvantage** displays “findings” on its “findings” story board, a more in-depth analysis will be performed by the Surface Water model. As such, a request is concurrently sent to the Surface Water model for estimated trajectories, potential sources, and plume strength and size.
5. **EMAdvantage** Command & Control 1) coordinates the locations of “raw” sensor data, 2) posts significant Findings for users to review, and 3) displays the “findings” on a “findings” status board. **EMAdvantage** will use a simple simulator (using VB or MATLAB) that uses the User Defined Point API, to package and add the new “findings” to a pre-defined dynamic map layer. By using the API, **EMAdvantage** will receive the necessary notifications and map updates to display the “findings.” By using the user-defined point interface, new “findings” can manually be added. **EMAdvantage** now has some ‘findings’ (either manually or programmatically entered) (see Figure 10.5).
6. Surface Water Model. The Surface Water model is activated to estimate trajectories, potential sources, and plume strength and size. The Surface Water model is run to provide estimates of contaminant levels and locations (i.e., concentration as a function of location and time: $C(x,t)$). There may be multiple “findings” at varying locations. The goal of this box is to show the transition from receipt of findings to a request for multi-thematic model runs to estimate the potential sources, plume size, etc. (see Figure 6.12).
7. A request is sent to a Decision Support model to estimate exposure, risk, or hazard, and identify threat areas (in terms of threat-area polygons).
8. The Decision Support model estimates exposure, risk, or hazard, and identifies threat areas (in terms of threat-area polygons). The modeling information is analyzed, based on a pre-determined set of exposure scenarios, to determine hazard potential. If deemed significant, then the locations and contaminant levels are passed to the Command & Control Center (see Figures 6.13 through 6.16).
9. The Decision Support model packages the threat area polygons and risk levels and sends the information back to the model application shell so that the Threat Area and risk level can be translated, packaged, and sent to **EMAdvantage**. A notification of a new Threat Area is provided to trigger the display of the Threat Area and further processing.
10. **EMAdvantage** displays the Threat Area and then (manually or automatically) runs the Risk Area analysis. The Threat Area is used to identify the response zones that will be impacted. The CSEPP Zones will be used because they already exist and will cover areas on both land and water. Note: To accomplish this, we will need to “morph” South Lake Michigan Geographic Information System (GIS) and modeling information into the Columbia River and North Central Oregon. We will “remove” the Washington land information by creating a new instance of the OR/WA database and simply leave out Washington Counties and State. This is easily done in the database by not including those EOC’s in the new database configuration (i.e., no database, no data). The next step is to remove (or overlay) the existing Washington GIS base maps so that Washington does not exist. We will need to obtain a GIS image of southern Lake Michigan and transition its coordinates to align with the Columbia River. We will also have to go into the Oregon database and modify the

facility database to simulate the special locations required for water-related PA decisions. This will mean deleting some facilities, changing the definition of other facilities, and adding a few new facilities that will be tagged as PA facilities. This is a time and materials problem and will not be a big effort (see Figure 10.2).

11. The results of the Risk Area assessment will be a list of zones and specific facilities that fall within the threatened area. We will want to create some type of a trigger that will pass this information back to FRAMES. The information in the Risk Area table are known locations, object names that will allow a new module to rerun the modeling to determine a preset PAR for each protective action (PA) zone and facility.
12. A Decision Support module will correlate the Risk Area information with an associated PAR. This will really be done by sending back a categorical value that will be used to look up the associated PAR for the PA Decision Matrix. For example, in **EMAdvantage**, the categorical value was impact time (e.g., 0 to 15 min, 15 to 30 min, 30 to 60 min, 60 to 120 min, and >120 min). This step will take the most coding. We will create an API to update the decision variable and then force an execution of the lookup portion of a PAR (see Table 8.1 and Figure 10.2).
13. A categorical value will be passed back to the **EMAdvantage** that will be used to look up the associated PAR for the PA Decision Matrix
14. Once the PAR is set, we can generate a PAD. Then we can use the matrix to select the best-fit plan. This will require that we create some pseudo plans that are different based on the zones and facilities impacted (see Figures 10.2 and 10.5).

** The transition of information between FRAMES, **EMAdvantage**, and new modules within the RRA LDRD will be hard-wired for the demonstration. Once this is complete, we intend to make the transition module more generic. The goal will be to create a more general structure that aligns model output or “finding” with an active guidance element and then relate the element with a PAR or actionable decision. This architecture will be used to replace the hard-wired relationships to demonstrate a method to begin constructing a more generic, interoperable method for linking models with decisions in the field.

INCIDENT IDENTIFICATION (sensors exceed threshold)

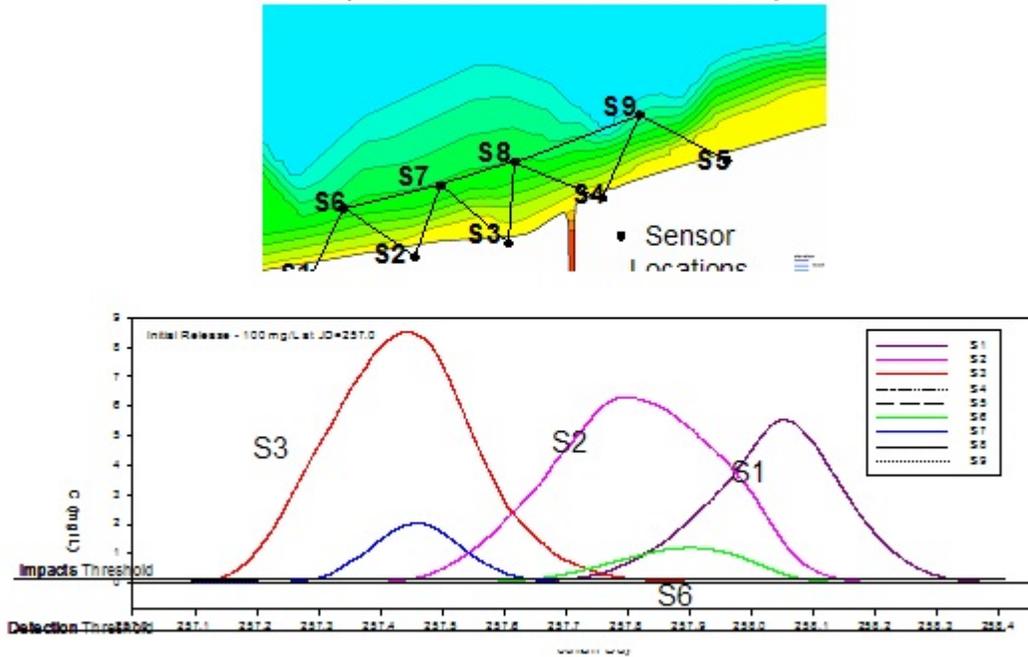


Figure 10.1. Incident Identification and Status Board Notification

Risk Impact Analysis

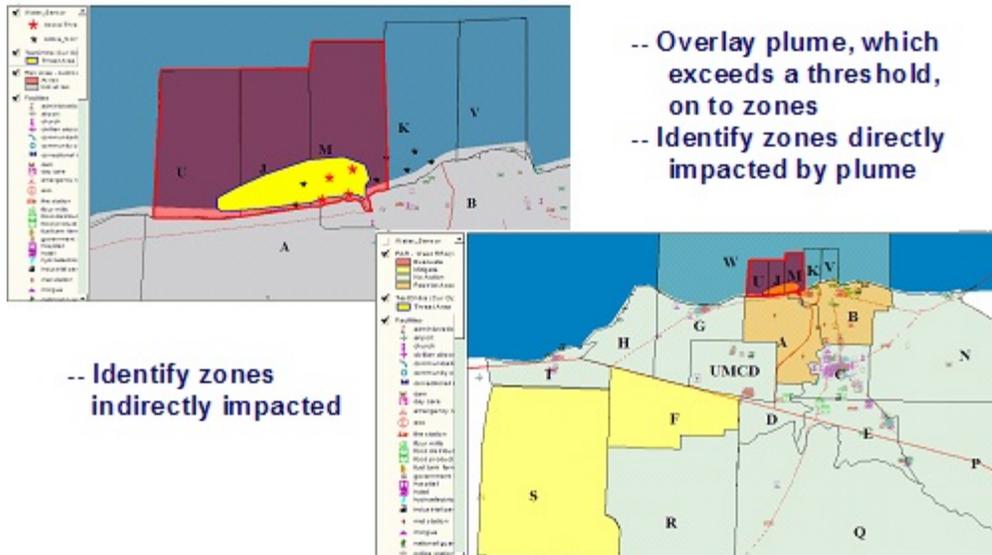


Figure 10.2. Status Board Summation of PA Zones, Impact Areas, and Risk Impact at Zones

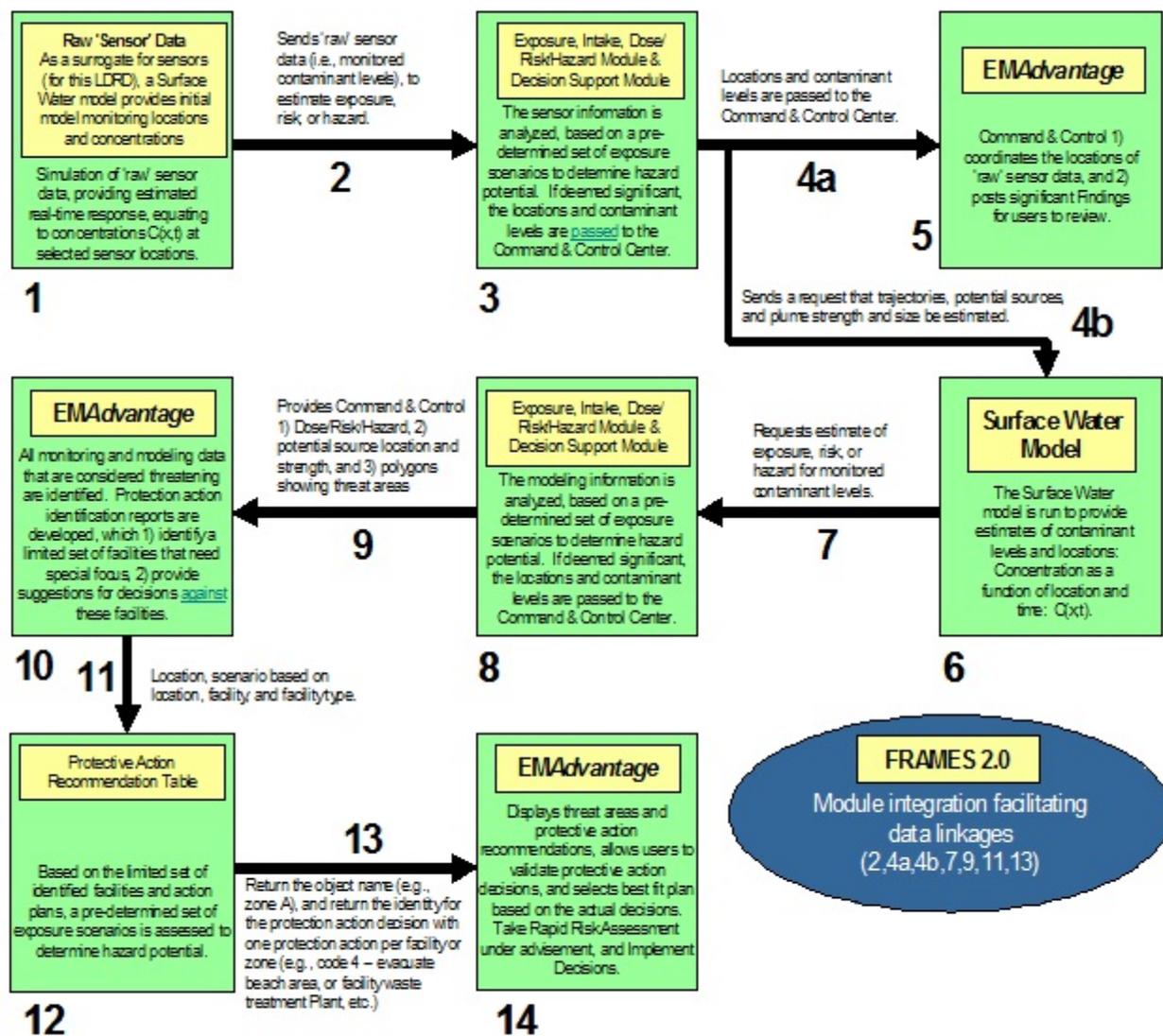


Figure 10.4. Flow Diagram for the Application of the Rapid Risk Assessment

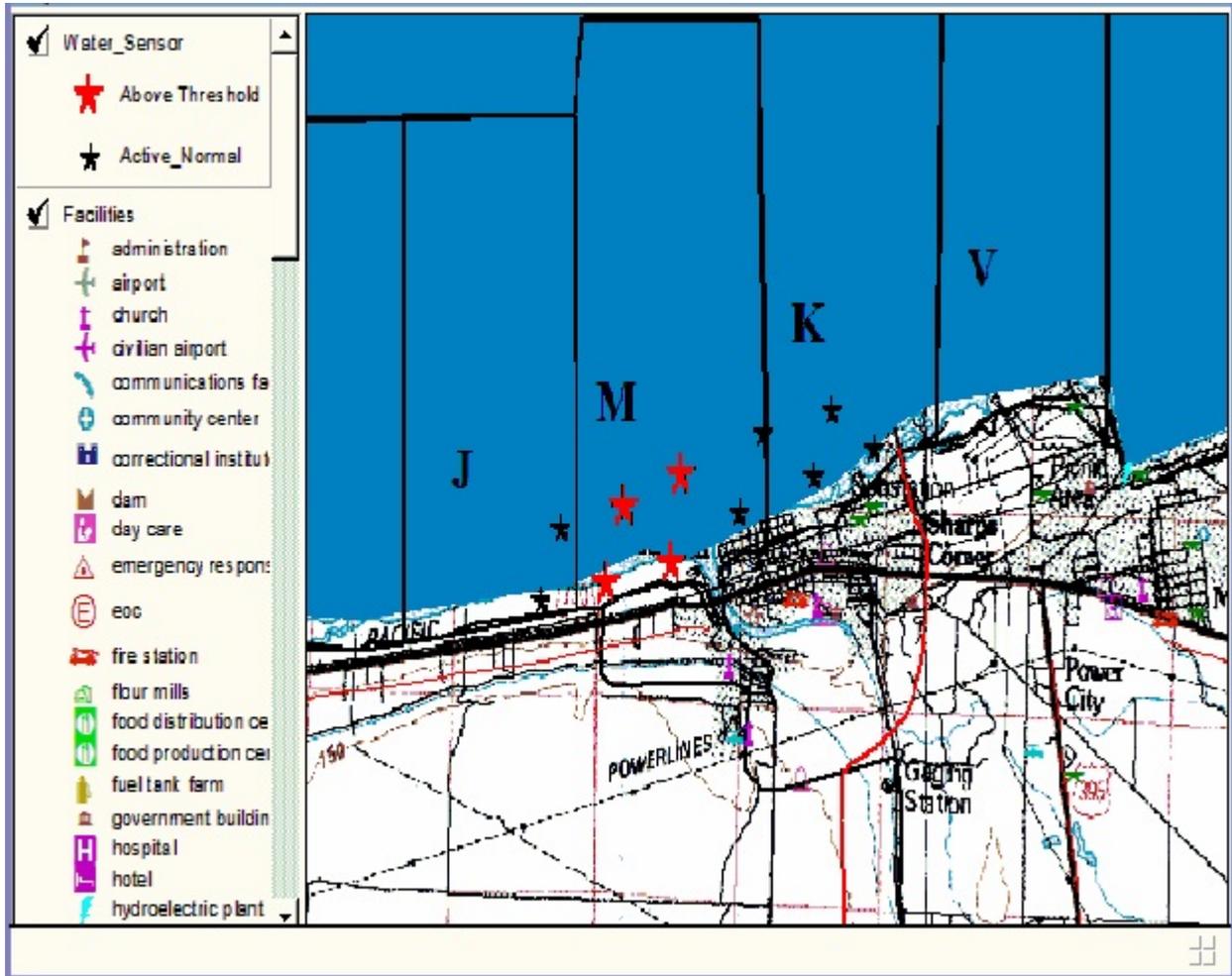


Figure 10.5. Command and Control System Coordinates Sensor Readings with Location for Immediate Communication to Community Decision Makers (Black Stars represent sensors that have not exceeded the acceptable threshold, and Red Stars represent sensors that have exceeded the acceptable threshold.)

11.0 FRAMES

FRAMES-2.0 is a software platform developed by PNNL for selecting and implementing environmental software models for risk assessment and management problems (<http://mepas.pnl.gov/frames2x/>; <http://mepas.pnl.gov/FRAMESV1/index.html>; <http://mepas.pnl.gov/earth/>). This program is a flexible and holistic approach to understanding how industrial activities affect humans and the environment. It incorporates models that integrate across scientific disciplines, allowing for tailored solutions to specific activities, and it provides meaningful information to business and technical managers. FRAMES-2.0 is the key to identifying, analyzing, and managing potential environmental, safety, and health risks. The main FRAMES workspace user interface is presented in Figure 11.1.



Figure 11.1. Main FRAMES Workspace User Interface

FRAMES exhibits four unique attributes that are unparalleled by any other environmental operations and assessment modeling tools produced today. It is user-friendly, flexible, comprehensive, and application-oriented. FRAMES also allows users to view modeling information through text, table, and graphical views to confirm and verify information. In addition, FRAMES provides a method of determining which modeling parameters impact results the most and levels of uncertainty involved in results based on these parameters. This analysis gives managers a critical piece of information missing in many such assessments—what can be changed to lessen the environmental impacts?

FRAMES is the product of sponsorship by the EPA, U.S. Army Corps of Engineers (ACOE), U.S. Nuclear Regulatory Commission (NRC), U.S. Department of Energy (DOE), and American Chemistry Council (ACC) and provides a central development tool to support multiple user communities. The design of FRAMES is based on a memorandum of understanding (MOU) among eight Federal Agencies, establishing a framework for facilitating cooperation and coordination in research and development (R&D) of multimedia environmental models, software, and related databases, including development, enhancements, applications and assessments of site-specific, generic, and process-oriented multimedia

environmental models as they pertain to human health and environmental assessment (<http://iscmem.org/Proceedings.htm>). In addition to EPA, NRC, ACOE, and DOE, the MOU includes the U.S. Geological Survey (USGS), Agricultural Research Service (ARS), National Oceanic and Atmospheric Administration (NOAA), and Natural Resources Conservation Service (NRCS).

FRAMES seamlessly links user-defined disparate models, databases, and modeling systems to transfer data. FRAMES

- represents a deployable system
- provides a means to visually conceptualize the problem
- allows the user to choose the most appropriate models and databases to address the problem
- provides sensitivity /uncertainty analyses
- provides tools to visualize and tabularize the results
- provides a mechanism to document the results
- increases credibility as it automatically provides a mechanism to reproduce the results.

FRAMES provides the following major attributes: 1) PC Windows based, 2) Plug&Play to allow users to import their own models into the system without the aid of a system developer, 3) Drag&Drop real world icon objects to allow analysts to visually display the problem to be solved, 4) minimum data transfer requirements, so models only receive pertinent information, 5) system viewers (graphical & tabular) to provide range managers with a means to view input/output, 6) Monte Carlo sensitivity/uncertainty wrapper to provide all models with a means to perform probabilistic analyses, 7) capability to begin the assessment at any point in the problem to eliminate unnecessary modeling, 8) new classes of models to enter into the system to seamlessly communicate with other models, 9) web accessibility to allow the user to link any model to any database at a remote location, 10) an aliasing capability to allow the user to define surrogates for chemicals and organisms for those databases that lack specific chemical and organism data of interest, 11) import spreadsheet data and user-supplied data to confirm that site-specific information is used, 12) databases, including properties for chemical constituents and radionuclides, human exposure parameters and risk factors, aquatic and terrestrial toxicity reference values, biological species life history profiles, food bioaccumulation factors, and biota sediment accumulation factors.

FRAMES-2.0 supports model and database integration at many levels and across many domains. In addition to sets of DOE (MEPAS), ACOE (Recovery, HELP, TWEM), and EPA (CMTP, ISC3, HWIR) models, which have been linked with FRAMES, PNNL and partner organizations are currently on track to integrate several specific waterborne transport models over the next 12 months, including, for example, HSPF (EPA watershed model), CE-QUAL-ICM (ACOE surface water quality model), and CH3D (ACOE surface water hydrodynamics model). In addition, FRAMES is currently in the process of linking to other waterborne modeling systems, such as the Groundwater Modeling System (GMS), which will provide the approach for linking to the Surface Water Modeling System (SMS) and Watershed Modeling System (WMS). Although GMS would not necessarily be directly used by the National Aquatic Protection Center (NAPC) system, its linkage demonstrates the extensibility of the underlying infrastructure.

The key value that FRAMES provides to our users is the use of a flexible and extensible infrastructure, which enables a team to gather and integrate models and data sources across agencies. In addition to the breadth of model integration, FRAMES can also serve as the platform for disparate data collection, integration, analysis, and visualization. And the flexibility of the framework allows for it to serve as a conduit of more basic research activities as they become ready for deployment and application.

12.0 EMAdvantage^(a)

EMAdvantage is an automated decision support architecture that provides situation planning and response capabilities for a large multi-user environment, as illustrated by Figure 10.3. These capabilities have been used to support the Chemical Stockpile Emergency Preparedness Program. Many components of the **EMAdvantage** architecture are directly applicable to other emergency management efforts. This provides a brief overview of many of these functions as well as the current visual interface used by the application.

The **EMAdvantage** architecture provides the user with the following major capabilities and/or activity:

- Activity Descriptions
- Hazard Modeling
- Threat and Risk Identification
- PA Decisions
- Electronic Plan Generation/Execution
- EOC Activation/Emergency Declaration
- Community Profile
- Evacuation Modeling
- Facility/Resource Management
- Activity Tracking, Reporting, and Status Boards
- User Defined Status Boards
- WebOSB™– Operational Status Boards
- Incident Tracking.

The **EMAdvantage** framework allows EOC personnel to access information and provide operational decisions for each major activity. These capabilities allow an EOC to plan for, perform daily operations, and respond to potential emergencies. They also allow multiple EOC's to better coordinate and communicate between themselves during real-world operations, training, or exercises.

These capabilities allow an EOC to 1) plan for potential emergencies, 2) perform daily operations, and 3) respond to emergencies. **EMAdvantage** allows EOC personnel to access information and provide operational decisions for each major capability. **EMAdvantage** is being used by

- The CSEPP to support emergency management needs at 25 jurisdictions.
- The PEMEX oil refinery in Minatitlán, Mexico, to support emergency management activities. For PEMEX, the user interface and online help were converted to Spanish.
- The National Aeronautics and Space Administration (NASA) to transfer information and decisions to wireless devices called E-Gloves. The E-glove integrates a PDA, wireless modem, and global positioning system (GPS) device into a single unit.
- The Utah Comprehensive Emergency Management in Salt Lake City to provide WebOSB (web-based operational status boards) to disseminate information about CSEPP activities.

(a) Based on <http://www.pnl.gov/EMAdvantage/> and <http://www.gdin.org/wg/EMAdvantage.html>.

12.1 Prevention, Preparedness and Response Management/Hazardous Mitigation

The *EMAdvantage* architecture was developed to support all phases of emergency management. The architecture supports a planning component that allows users to develop “what-if” scenarios based upon activities and their potential threat and risk. Community conditions are used to establish viable PA decisions. The conditions, zones at risk, and desired PA decisions are used to construct an operational response plan. Electronic plans contain emergency management related tasks. These tasks include the action, responsible emergency support function, required resources, location of the task, etc. These scenarios are stored outside of the daily operations database so they can remain static and be reviewed as needed in the future. During daily operations, actual community conditions and hazards are used to identify threatened areas and communities at risk. The hazard, community conditions, and impacted zones are then used to select the closest response plan to be implemented. *EMAdvantage* provides task execution, incident tracking, and other status board reports to assist in implementing the desired actions.

12.2 General Hazard Support

The *EMAdvantage* architecture supports general hazards. There are emergency management functions that are common to all hazards. An EOC uses the same pool of resources, personnel, sirens, traffic control points, shelters, etc., to manage different hazards. *EMAdvantage* has been constructed to allow an EOC to identify the context of the hazard, the PA decisions associated with the hazard, the response zones associated with the hazard, and the community conditions that require the development or selection of a unique response plan. *EMAdvantage* is unique in that it allows a single EOC to simultaneously work multiple hazards and their associated response plans in a coordinated manner.

12.3 Preparedness and Response

The ability to transition between preparedness and response is a key feature of the *EMAdvantage* architecture. The heart of this capability is the generation, management, and application of electronic plans. Using the same system to identify and develop needed plans and perform daily operations and response provides a transition from planning to response that is difficult to achieve with current software products. By expanding this concept to support multiple EOC’s, the ability to support preparedness and response can be expanded from a single EOC paradigm to support multiple EOC’s across multiple jurisdictions.

12.4 Activity Descriptions

Activity descriptions are user-defined status boards that allow a site to provide background information about the world around the EOC. This information can be production activities, weather, or any other information that the site feels may have an impact on their ability to respond to an emergency. The *EMAdvantage* architecture allows a knowledgeable user to construct a status board. A status board is a spreadsheet or form that contains headers and information organized by the user to think of a “super” spreadsheet. It is like a spreadsheet in that the user can identify the title, the headers, and the type of information contained in the spreadsheet. The spreadsheet becomes “super” because it can:

- support multiple user concurrently
- be shared between EOC’s

- can be as open as a view-only bulletin board or limited to only a few privileged users.
- contain location information that directly links to a GIS map
- automatically update and present information as decisions are made in an EOC
- contain links to URL's or other documents and applications.

12.5 Hazard and Evacuation Modeling

The **EMAdvantage** architecture was designed to support hazard modeling. The architecture was created to integrate a user-specified model with emergency-management user interfaces and GIS displays, as well as functions to assist in making PA decision based on the time a potential hazard may impact a response zone or designated facility. An example of how site-defined models may be integrated into **EMAdvantage** is provided in Figures 12.1 and 12.2. To integrate a new model into **EMAdvantage**, PNNL will work with the client to identify the model, the user-oriented interface needed to provide inputs, how the model will graphically and textually display results, and finally how the model will be used in the client's decision making process. The general hazard component of **EMAdvantage** allows a user to "loosely-couple" a model with the **EMAdvantage** architecture. This is done by a direct link to the model from the **EMAdvantage** interface. Additionally, the **EMAdvantage** architecture supports evacuation modeling software. This includes an interface for defining a traffic network, designating traffic flow, establishing evacuation routes, and simulating evacuation activities. Figure 12.3 shows an example screen for the evacuation modeling capability.

12.6 Risk Identification and Protective Action Decisions

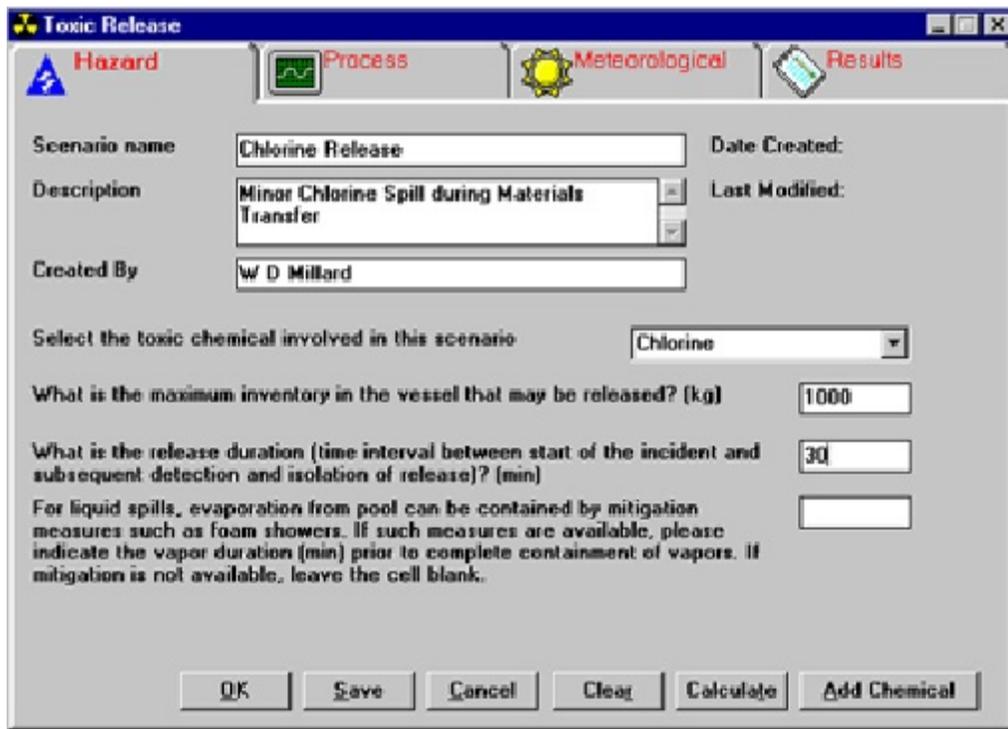
As a result of the modeling integration, **EMAdvantage** can assist the user in identifying the zones and facilities that are at risk. Risk identification also includes identifying sirens, traffic control points, and other key elements of emergency management that are in close proximity to the hazard that will be involved in mitigating the hazard. A sample of emergency planning zones impacted by a chemical hazard is seen in Figure 12.4. PA decisions are made by proximity to the hazard. They can also be based on impact time. Site and community conditions can also be factored into the decision-making process. The general hazard component of **EMAdvantage** allows a site to establish the PA zones associated with each specific hazard. For example, this will allow decisions about fires, traffic accidents, and explosions to be made at the "township" level while decisions about earthquakes, floods, and typhoons may be at a "county" or regional level.

12.7 Electronic Plan Generation/Execution

Electronic plans are selected based upon the PA decisions and the community conditions. The plan contains the activities and tasks that need to be performed to complete the PA decisions. A task within the electronic plan contains general information about who in the EOC is responsible for the task, what actions need to be done, what resources are needed to complete the tasks, etc. The task can also identify the geographical location where the task is to be performed as well as the people to contact outside of the EOC. A log can be made when each task is started and completed for later review. Tasks within a plan can be given desired start and finish times. When a task is executed, the actual start and actual finish times are kept for later review. Many people can view and work an electronic plan at the same time. Figure 12.5 shows an example of an electronic plan as well as some of the information that can be linked to a task.

12.8 EOC Activation/Emergency Declaration

EMAdvantage will allow an authorized user to make an emergency declaration. This is an electronic notification to the EOC and other users outside of the EOC that an emergency has occurred. This notification is automatically sent to other users of the **EMAdvantage** system. Depending on how a site operates, this function can be used as an initial warning system for other EOC's and personnel at the site. A sample of the emergency declaration screens for **EMAdvantage** are provided in Figure 12.6. The General Hazard component of **EMAdvantage** allows the EOC/site to establish a hazard-specific emergency declaration.



The screenshot displays a software window titled "Toxic Release" with a blue header bar. Below the header are four tabs: "Hazard" (selected), "Process", "Meteorological", and "Results". The "Hazard" tab contains the following fields and controls:

- Scenario name:** Chlorine Release
- Date Created:** (empty field)
- Description:** Minor Chlorine Spill during Materials Transfer
- Last Modified:** (empty field)
- Created By:** W D Millard
- Select the toxic chemical involved in this scenario:** Chlorine (dropdown menu)
- What is the maximum inventory in the vessel that may be released? (kg):** 1000
- What is the release duration (time interval between start of the incident and subsequent detection and isolation of release)? (min):** 30
- For liquid spills, evaporation from pool can be contained by mitigation measures such as foam showers. If such measures are available, please indicate the vapor duration (min) prior to complete containment of vapors. If mitigation is not available, leave the cell blank.** (empty field)

At the bottom of the window are six buttons: OK, Save, Cancel, Clear, Calculate, and Add Chemical.

Figure 12.1. Model Integration: User Interface

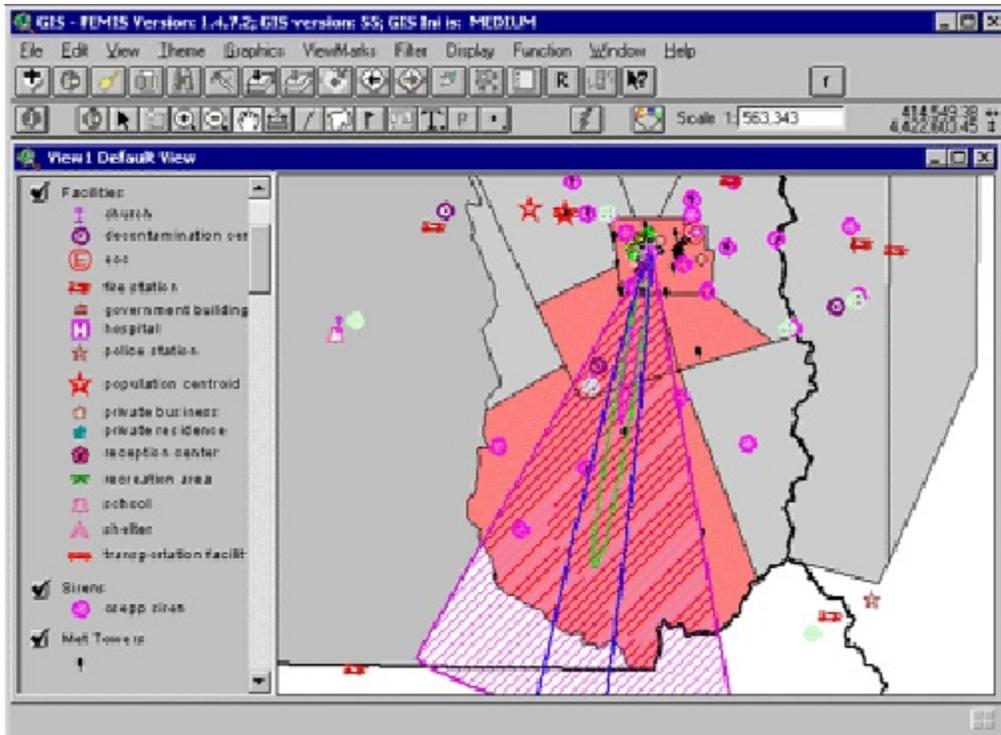


Figure 12.4. Risk Areas and PA

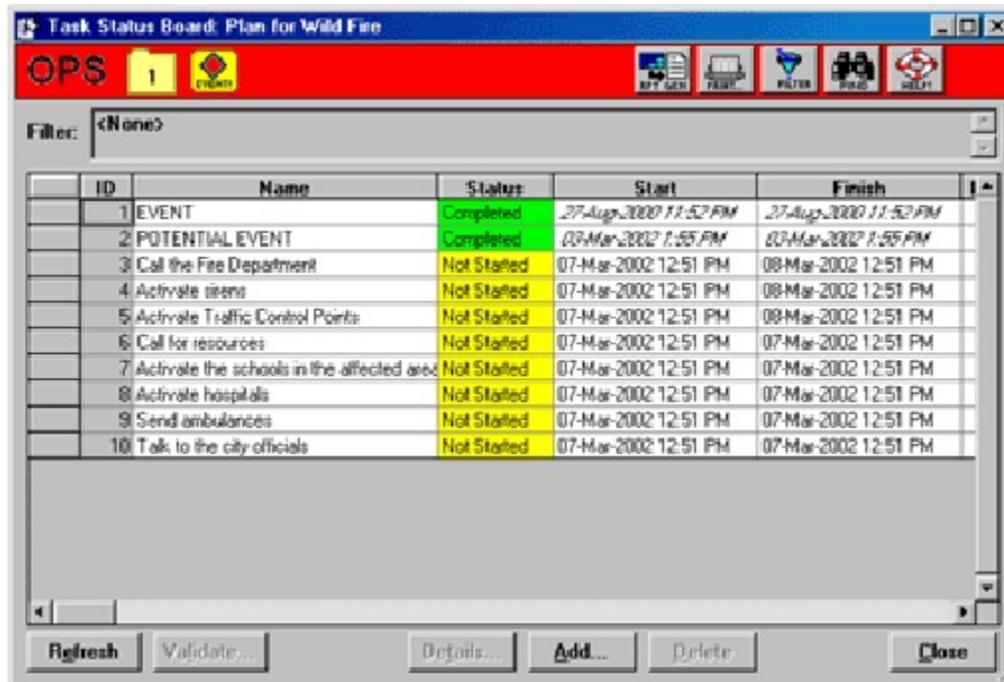


Figure 12.5. Tasks in an Electronic Plan

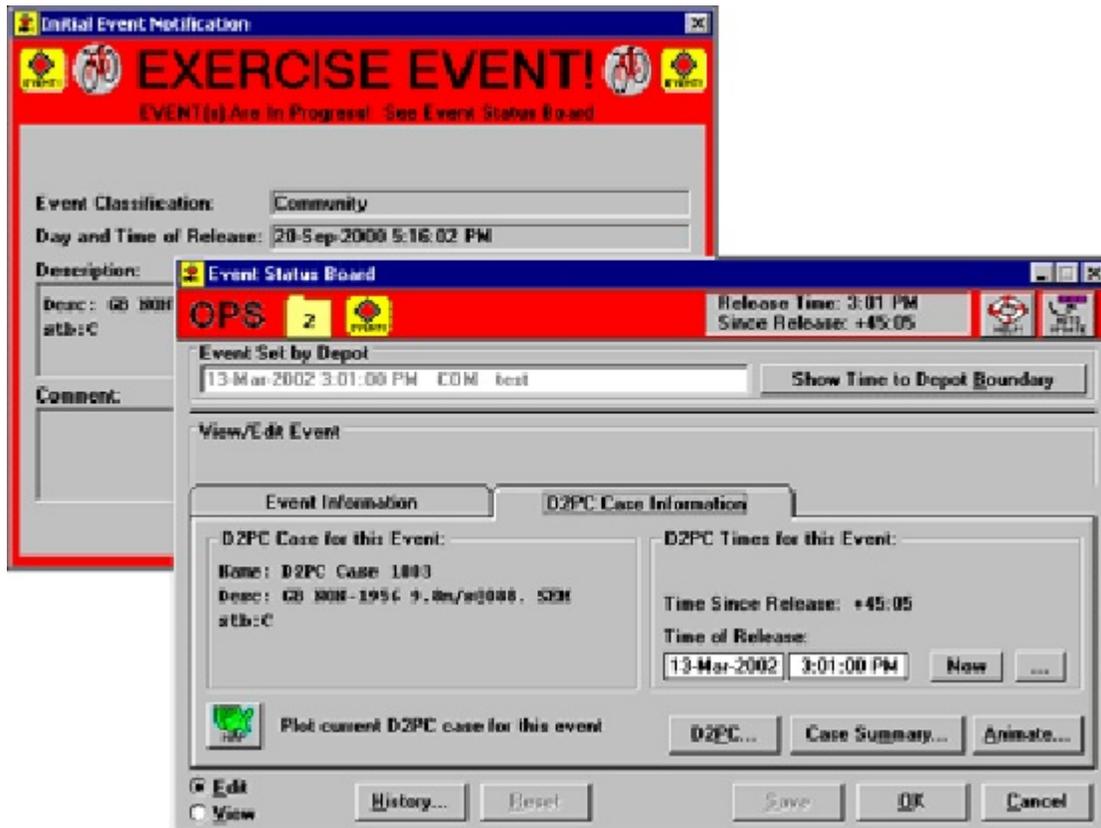


Figure 12.6. Emergency Notification

Information about the emergency is contained in a site defined status board. The notification of an emergency can be limited to a single hazard within an EOC or across all hazards and EOC's at a site. This capability to do multi-hazard, multi-site emergency declaration is unique to the *EM Advantage* architecture.

12.9 Facility/Resource Management

EM Advantage provides the capability to develop, manage, and access information about the facilities, resources, and personnel needed to support a site's emergency management activities. This will allow emergency managers to identify those agencies, departments, and personnel involved in emergency management at the site as well as in the local community. It also allows the emergency managers to track facilities and resources that are of specific interest to the EOC. The information management components of *EM Advantage* include, but are not limited to:

- Agencies involved in emergency management
- Departments involved in emergency management
- Personnel that are responsible for manning the EOC
- Personnel that are responsible for responding to a specific hazard
- Personnel that reside outside of the EOC that provide assistance to the general public during an emergency such as fire, police, and doctors
- People in the community that provide resources
- Facilities that may be affected by the hazard

- Facilities for which special PAs are needed, such as hospitals or schools
- Facilities that are involved in providing emergency management support
- Facilities that are involved in providing resources
- Facilities that are involved in providing shelter to the community
- Traffic Control Points to support evacuation
- Sirens to support public alert and notification
- Meteorological towers to provide real time weather information.

A key component of the **EMAdvantage** architecture is to allow a user to quickly obtain needed information about a facility, traffic control point, siren, or other element of emergency management. This includes the access and display of information directly from the geographic information system. Figure 12.7 is an example of a user obtaining information about a facility that is affected by a chemical plume.

12.10 Activity Tracking, Reporting, and Status Boards

The premise of **EMAdvantage** is to provide both the emergency manager and responder with quick access to information. This includes quick access to information about the emergency, the geographic area at risk, the plan being implemented, and the shelters being activated, as well as the people and materials being used to respond to the emergency. To provide such information, **EMAdvantage** provides predefined status boards and reports as well as single click access to status maps and displays. The list of predefined status boards and maps includes, but is not limited to:

- Emergency Declaration and Status
- Electronic Plan status board
- Casualty Status
- Evacuees Registration and Reunification
- Shelter Activation
- Meteorological and weather status.

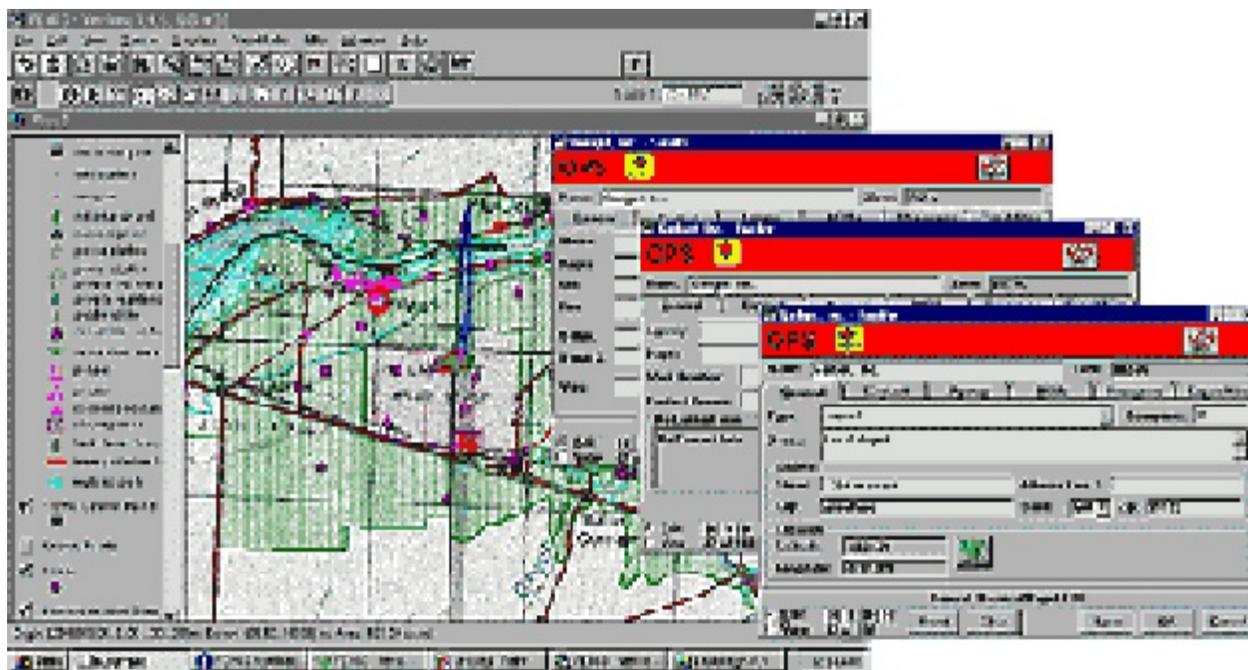


Figure 12.7. Information Management

- PA decisions
- Threat and Risk Area reports
- Current status of other EOCs
- Risk and Threatened area displays
- Chemical plume displays
- PA decision displays.

Figures 12.8 and 12.9 provide samples of the evacuee registration status board and the shelter activation status board. Additionally, **EMADvantage** allows site administrators to develop their own status board and reports. This capability has been used extensively at operational sites and is one of the greatest strengths of the system. User-defined status boards can contain text, numbers, locations, dates, and other types of information that are named and organized by the user. This information can be entered and shared between users as well as between EOCs. This capability allows a site to tailor **EMADvantage** to fit their specific needs.

12.11 Incident Tracking

The **EMADvantage** architecture provides an incident tracking capability. While this capability has been tailored to meet the needs of the CSEPP project, much of the information is directly applicable to other hazards. One key component to the **EMADvantage** incident tracking system is that information about a specific incident can be quickly shared across all EOCs. This allows information about an incident to be easily communicated without the originating EOC losing control.

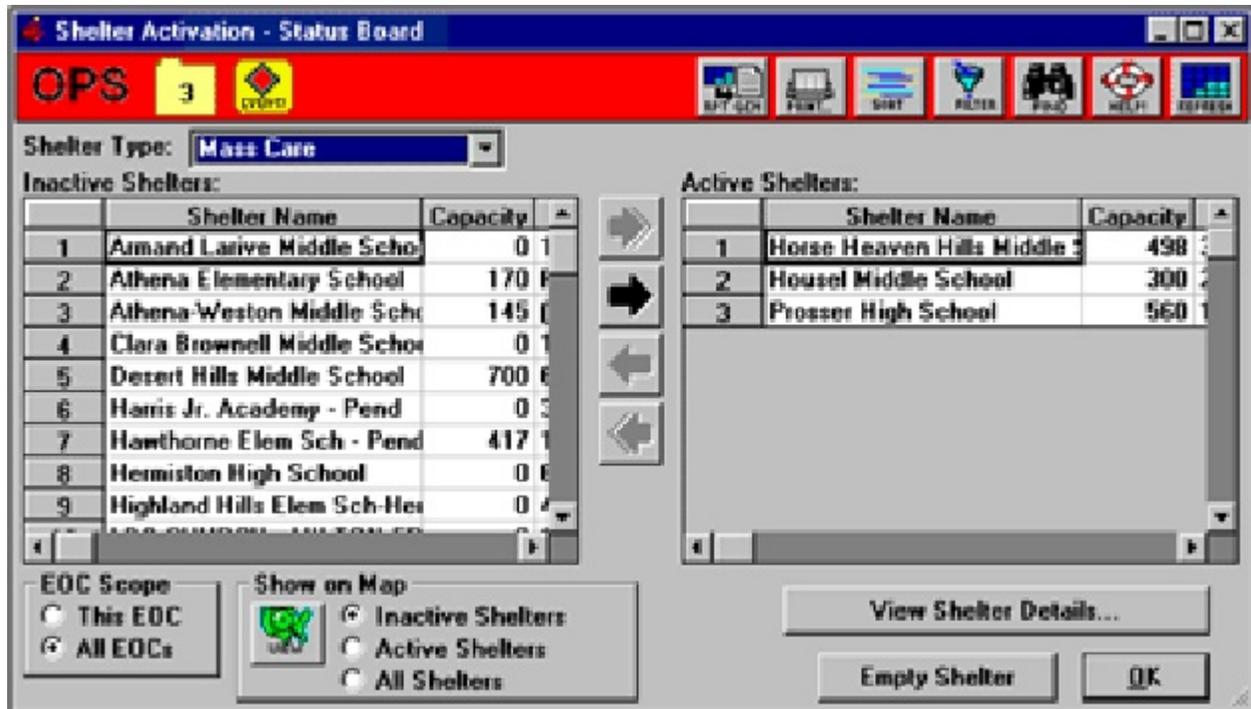


Figure 12.8. Shelter Activation Status Board



Figure 12.9. User Defined Status Board

12.12 Summary

The **EMAdvantage** architecture and supporting software provided by PNNL is directly applicable to the other emergency management communities. It is applicable in three ways:

1. **EMAdvantage** can be used as a general hazard system to assist in identifying and communicating emergency management decisions and information across one or more emergency operation centers.
2. **EMAdvantage** can be used as an initial platform to begin the development of a tailored, site-specific emergency management system. Such a system would include the integration of site-specific models and user interface screens directed to the specific needs of an EOC or site. This development and/or integration effort would be applicable to all EOCs involved in the endeavor.
3. **EMAdvantage** can be used as a prototype to review the information, decisions, activities, and capabilities desired by a site-specific emergency management system. Because **EMAdvantage** is an operational system, with real-world users, there are many capabilities and issues that have already been addressed by this architecture. Because the general hazard component of the **EMAdvantage** architecture can support user defined hazards, it would be an effective starting point to determine what site-specific capabilities are needed. The software, coupled with PNNL's knowledge of emergency management and information technology, can be a significant asset in the effort of providing automation support for emergency management.

13.0 References

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Appendix A: Acronyms

ACC	American Chemistry Council
ACOE	U.S. Army Corps of Engineers
ADA	Ammunition Demolition Area
BRAC	Base Realignment and Closure
CO-OPS	Operational Oceanographic and Products Services
CSEPP	Chemical Stockpile Emergency Preparedness Program
DIL	Derived Intervention Level
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
EFDC	Environmental Fluid Dynamics Code
EOC	Emergency Operations Center
EPA	U.S. Environmental Protection Agency
FDA	U.S. Food and Drug Administration
FRAMES	Framework for Risk Analysis in Multimedia Environmental Systems
GENII	GENeration II
GIS	Geographic Information System
GMS	Groundwater Modeling System
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
JD	Julian Day
MEPAS	Multimedia Environmental Pollution Assessment System
MOU	Memorandum of Understanding
NAPC	National Aquatic Protection Center
NARAC	National Atmospheric Release Advisory Center
NCP	National Contingency Plan
NOAA	National Oceanographic and Atmospheric Administration
NPL	National Priorities List

NRC	U.S. Nuclear Regulatory Commission
NRPB	National Radiological Protection Board
PA	Protective Action
PAR	Protective Action Recommendation
PNNL	Pacific Northwest National Laboratory
RRA	Rapid Risk Assessment
SMS	Surface Water Modeling System
UMCD	Umatilla Chemical Depot
UMDA	Umatilla Depot Activity
WMS	Watershed Modeling System