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Use of geographical maps to manage risk from groundwater contamination

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Abstract

Risk inherently involves a geographical component. It occurs at locations in space where receptors (human or environmental) and hazards come together. For this reason, maps provide a tool for visually displaying information about the distribution of risk. This tool helps an analyst to fully understand the nature of a situation, to evaluate alternative ways to reduce or manage the risk, and then to convey the results of the analysis to the affected stakeholders, including the public. The focus of this paper will be on the use of maps to address the risk to the local community owing to a plume of contaminated groundwater emanating from a chemical plant. In this case, maps have proven to be invaluable in: (1) evaluating the existing data, and developing a site conceptual model of the nature and extent of the contamination; (2) determining what additional data needed to be collected; (3) evaluating the effectiveness of remedial options; (4) educating the public to provide them with understandable information to shape their perception of risk; and (5) achieving public acceptance of the plan for remediating the contamination and managing the residual risk. © 1998 Elsevier Science B.V. All rights reserved.

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1. Introduction

The risk of exposure to a chemical in the environment involves three components: presence of the chemical at a harmful concentration; a transport pathway for the chemical to reach a receptor; and the duration of exposure. To define these components and calculate the potential risk resulting from a site, scientists, engineers and managers must collect and evaluate various types of information, such that an appropriate action

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can be developed to mitigate such risks. Of the tools available, mapping and imaging of these data prove to be highly valuable in the evaluation, communication and management of these risks.

In the recent past, the risk analyst and manager were limited by the number and variety of maps which could be developed within the constraints of the project. The risk manager was forced to be very selective regarding the images produced. The full value of the environmental data which had been collected was not being realized. Fortunately today, due to the availability of progressively advanced computer software, the risk manager has at his or her disposal many options to utilize environmental risk data. These tools include but are not limited to electronic data management systems, numerical modeling programs, geographically based information systems (such as Geographical Information System or GIS), and advanced 2-dimensional and 3-dimensional visualization systems. When these tools are effectively applied, environmental information can be quickly and efficiently managed, accessed and visualized without putting pen to paper, providing new and innovative ways to use and interpret data while saving time and money. This paper explains how the integration of these mapping tools resulted in the successful outcome of a risk assessment, mitigation and communication project.

The application of mapping to risk assessment and communication benefits many people, including the following.

- *Scientists and Engineers*. Mapping of data which has been collected at a remediation site assists in the development of a site conceptual model which describes the nature and extent of the problem (i.e. where risk is considered to be unacceptable), and identifies where additional data need to be collected. It allows data to be used effectively for decision-making.
- *Environmental Risk Manager*. Mapping provides a valuable tool for evaluating the effectiveness of alternative remedial strategies. It aids in selecting and designing the strategy that will achieve the greatest reduction in risk. It can be used to monitor the performance of the strategy, and determine when the clean-up objective has been met. It also provides a useful tool for communicating the risk, and the effectiveness of the remedial strategy, to regulatory agencies, the public and to senior management.
- *Financial Risk Manager*. The ultimate objective of remediation is to clean up contamination to a risk level that is acceptable, while minimizing financial and environmental liabilities. For the financial risk manager, the use of maps provides guidance on which remedial options are most cost-effective for achieving this objective.
- *Liability Risk Manager*. The visual display of data afforded by maps is a very powerful tool that can assist lawyers in defense of a lawsuit. It can also reveal the presence of contaminants from other sources, and result in assigning some of the cost to other potentially responsible parties.

2. Tools for mapping of risk

A number of tools are available to assist in managing and mapping of environmental and risk data, including advanced computer software. If wisely selected and integrated, these tools allow for a greater range of options, higher quality and lower costs. The basic tools that aid in the analysis of risk at a site can be placed in three categories: (1) relational databases, (2) numerical modeling programs and (3) geographically based visualization platforms such as GIS. Under a fourth category, 3-dimensional and animated presentations of data are proving to be powerful risk communication tools. To get the most value out of your data, the manager should establish the suite of programs to be used early in the life of a given project.

It is important to recognize that an organized way is needed to store and retrieve the large amounts of data that will be generated during the investigation and remediation of the site. *Database programs* such as Woodward-Clyde's SiteManagerPro™ and Microsoft's Access™ are suitable tools for this purpose. A good data management platform should allow quick efficient access to available data in multiple formats, and produce output which is compatible with other applications.

In risk assessment, *modeling programs* are often used to take current site data and estimate potential future conditions and risks. The results of these models may be the generation of tables of numbers representing predicted changes in various parameters.

Tables of information, such as those obtained from a database or a model, are useful to store, sort, and select information, but they do not help in developing a spatial feel for the distribution of chemicals or risk across a site. For this, a good site map or base map is needed showing the locations of the sampling points and the other features important to the site. Commonly, computer aided design (CAD) programs such as AutoCAD™ are used to create these base maps.

But maps by themselves are limited. If a contouring package such as Surfer™ or a *geographically based visualization platform* such as GIS or SitePlanner™ is used to combine maps with data and contours, then the picture of what is going on becomes much clearer. In other words, these tools working together can help create a conceptual model that describes what is actually happening. It is possible to see where the chemicals are located, their concentrations, and how they might contribute to risk. Places where additional measurements may be needed can be easily identified.

For groundwater contamination problems, sometimes it is important to understand the dynamics of water flow and contaminant transport at a site and numerical models such as Modflow and MT3D are used to calculate water velocities, hydraulic heads, and plume movement. With these tools, the results of various postulated remediation schemes can also be projected and compared. Changes in the location and intensity of the chemicals (and thus the risk) can be estimated as a function of time. Here again, the use of visualization programs to display the output of these numerical modeling programs helps the analyst to illustrate the effect a particular scheme will have on the site. The output of these integrated applications can be used as a communication tool that aids in explaining the estimates of risk to stakeholders less familiar with the details.

Computer generated *3-dimensional and animated imaging* is now more affordable and user friendly than ever, and is now becoming commonly used in environmental applications. A leading software package, EVS (or Environmental Visualization System™) developed by C-Tech can take spatially distributed concentration measurements and create true 3-dimensional images showing the size and shape of an object such as a plume relative to the geologic, geographic and anthropomorphic setting. It also animates changes in time and spatially dependent data. By coupling this tool to an historical database, it is possible to create an animation that simulates the changes in the plume with time. Likewise, by coupling to the output of a numerical modeling program, you can create a visual representation of what the plume may look like in the future. This visual simulation is a very powerful communication tool for illustrating how a site situation is expected to change with time.

3. Example application

In 1994, contaminated groundwater was discovered extending beyond the boundaries of a chemical plant and beneath the homes of the community near the facility. Management was concerned about the potential risks to the public associated with this contamination. Fortunately, sampling of air and groundwater in the community and a risk assessment indicated there was no risk to human health as a result of the plume. Although this groundwater is not used as a source of drinking water and posed no health risks, the presence of the plume posed a potential impact to property values (economic risk) and public perception. Management made the decision to remediate by reducing the groundwater concentration of volatile organic compounds (VOCs) to below residential groundwater standards at all locations beyond the fenceline.

A series of actions, each involving the use of maps, was taken to deal with this situation.

- *Determine the actual extent of the contamination*. VOC concentrations were measured at a number of monitoring wells. Before the advent of visualization software, tables would have been prepared showing the concentrations (Table 1) and hand contoured plots of compounds would be generated. Tabular data display does not show which houses could be potentially at risk, nor does it show where the source of the contamination originated from. The facility had the foresight to have developed an electronic database for the site early in the project. Visualization software was utilized to quickly produce high quality maps and images depicting the extent of the plume in the residential area. In contrast to Table 1, Fig. 1 readily shows the extent of the plume (the 1 mg/l concentration contour), and suggests the facility as a source. It, therefore, quickly provided a conceptual model, from which we could evaluate the effectiveness of alternative remedial strategies. These images were used to communicate the facility's knowledge of the problem to the community.
- *Evaluate and select alternative remedial actions*. Several remedial options were evaluated using a groundwater flow and contaminant transport model to predict how

Table 1
Tabular data display

Parameter	Unit	IW-101	IW-102	IW-103
Ethylbenzene	mg/l	ND	1.020	0.283
Xylene	mg/l	0.039	5.363	1.558
Toluene	mg/l	ND	0.123	0.049
Total volatiles	mg/l	0.059	6.506	1.910

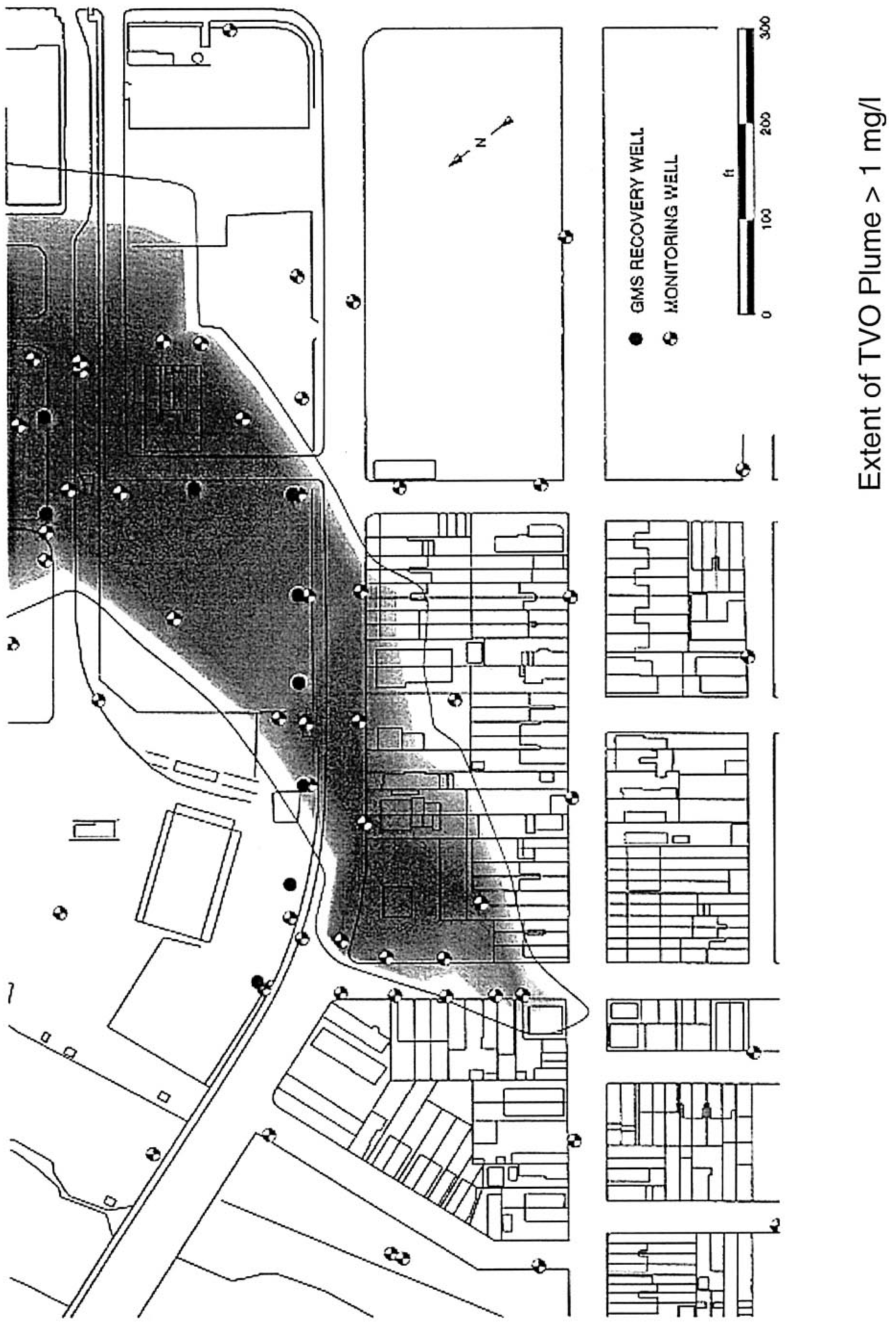


Fig. 1. Extent of TVO plume > 1 mg/l.

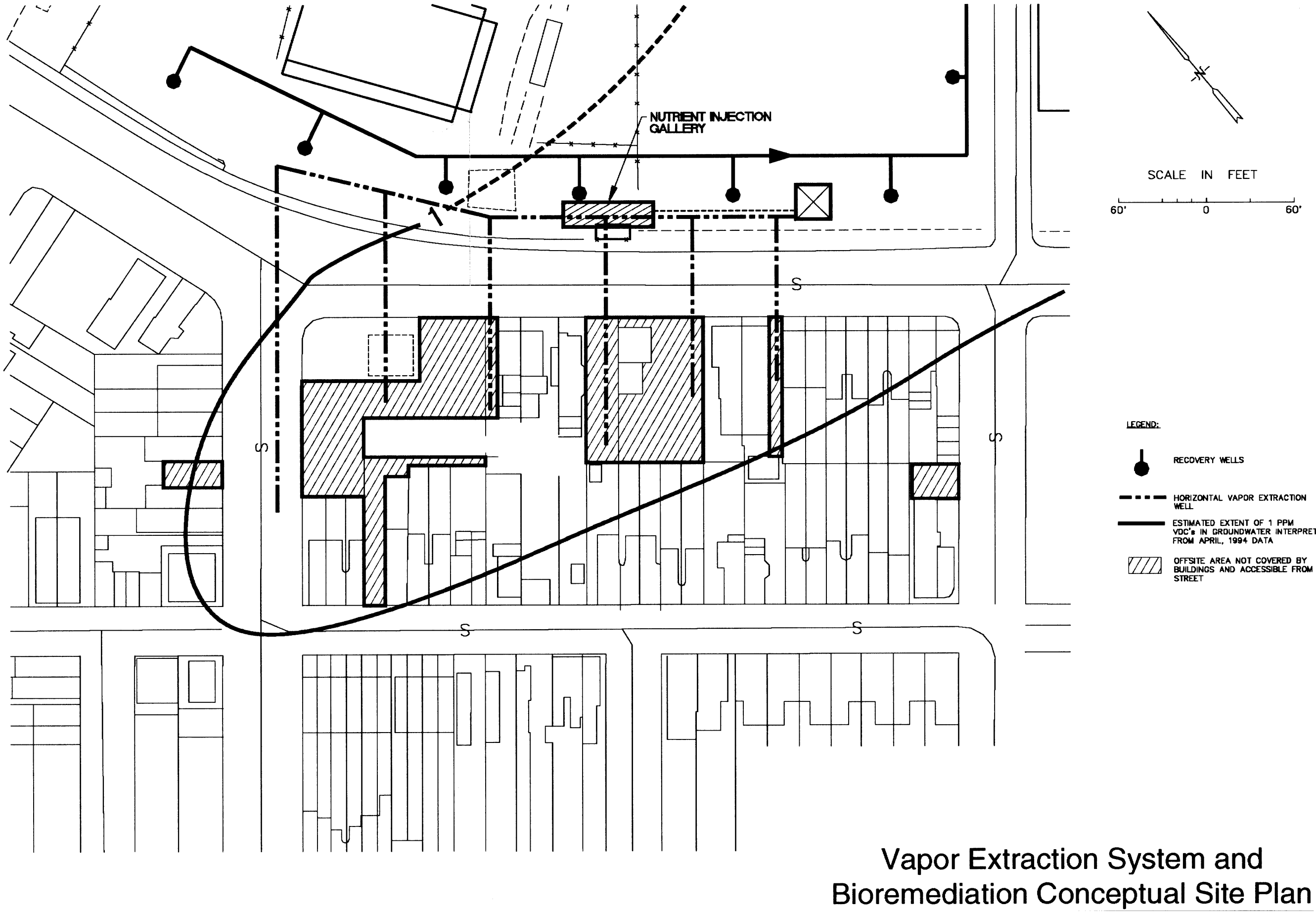


Fig. 2. Vapor extraction system and bioremediation conceptual site plan.

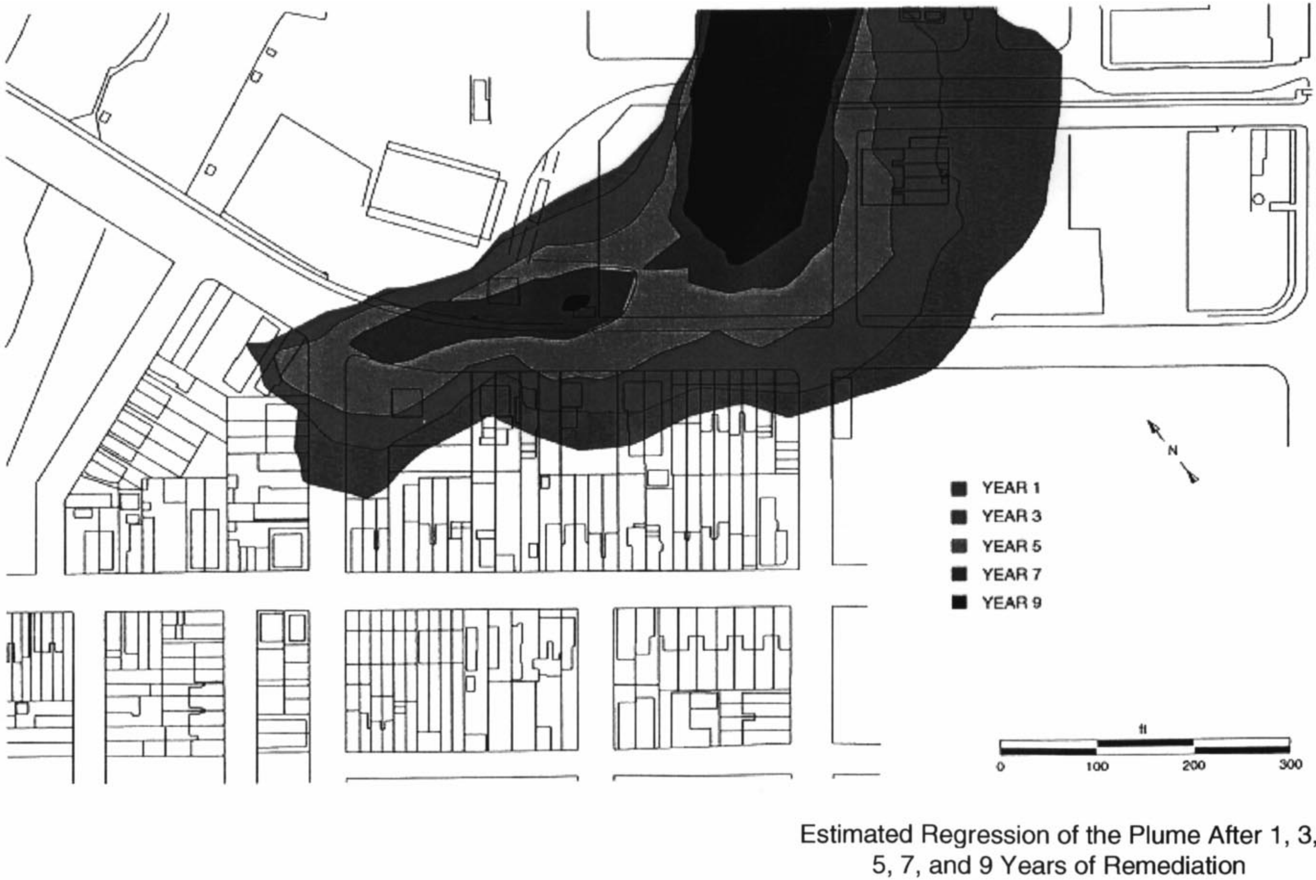
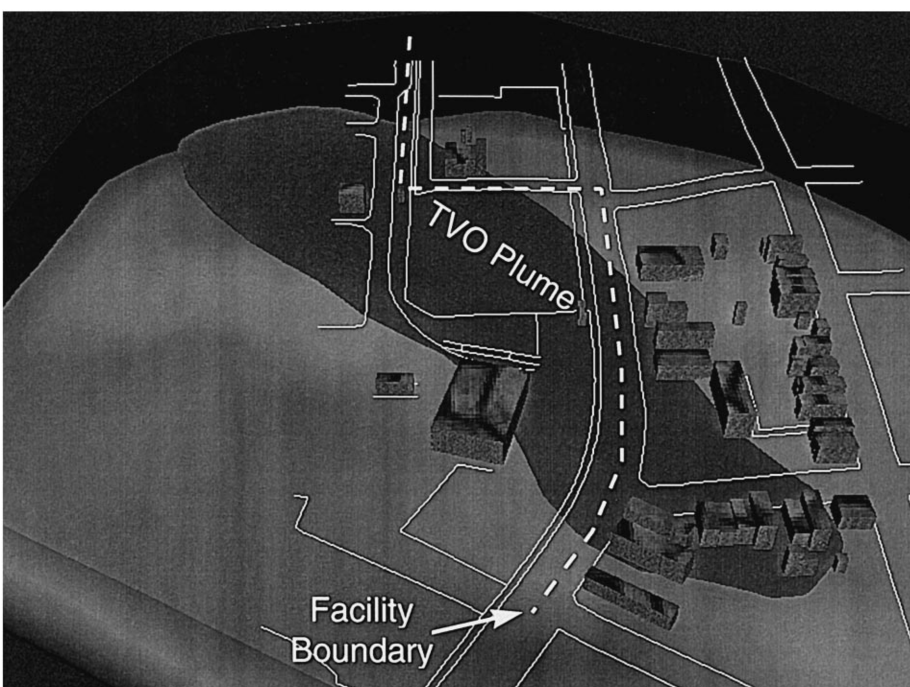


Fig. 3. Estimated regression of the plume after 1, 3, 5, 7, and 9 years of remediation.

quickly the VOC concentration would be reduced to below the target level beyond the fenceline. Again, visual displays of the locations of recovery wells and their predicted affect on the plume allowed us to quickly determine if these options would effectively meet our remedial objectives. Figs. 1 and 2 show two of these options, a series of vertical groundwater recovery wells located on the property, and horizontal soil vapor extraction wells extending into the community. As a result of the evaluation, a series of vertical recovery wells coupled with source removal was selected as the remedy. Fig. 3 visualizes the regression of the plume over a 9-year period as predicted by the model. The plots along with estimated costs were presented to management for selection of the most appropriate option. In this case, the option which resulted in the shortest time to reduce the VOC concentration to meet residential groundwater standards was selected. This is the multiple recovery wells system shown in Fig. 1.

• *Communicate with the public*. A number of public meetings were held to share with the community the nature of the contamination and the actions being taken to remediate it. Several maps, such as those in Figs. 1 and 3, were provided to the public. The facility chose to illustrate to the public the conceptual model and predicted performance of the remediation using a computer generated 3-dimensional animated model. The animated model was developed by Woodward-Clyde using EVS, converted



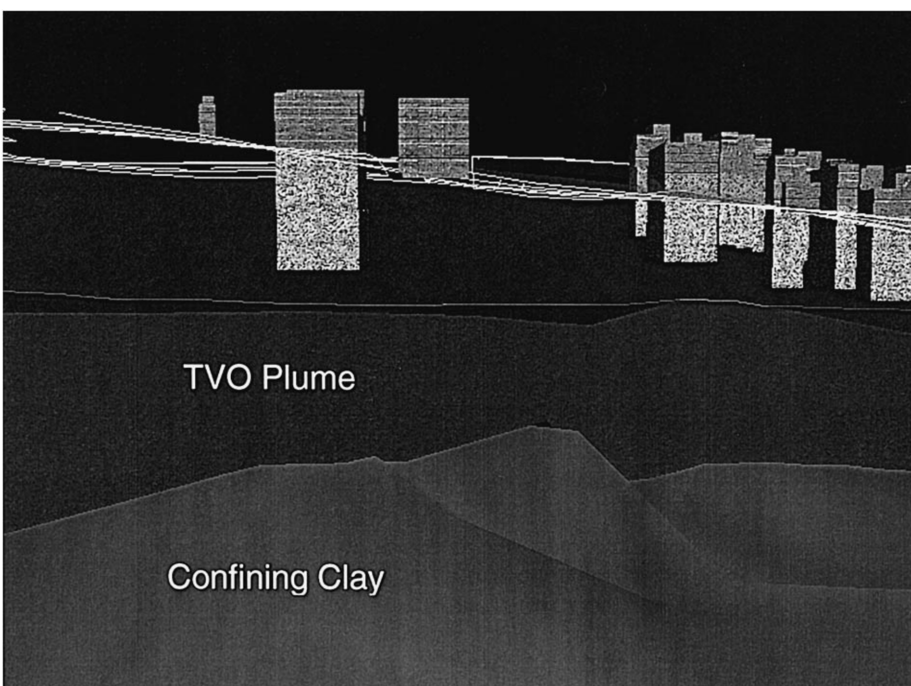
Aerial View of TVO Plume > 1 mg/l

Fig. 4.

to video tape and shared with the community in an open house forum. This film showed (1) the dimensions of the plume in 1994 relative to the houses, (2) the actual measured progress of the remediation, and (3) the predicted future changes in the plume location and dimension with the recovery wells operating. Fig. 4 is an aerial snapshot from the film showing the original extent of the plume. Fig. 5 is a side view snapshot showing the location of the plume relative to the basements. Specifically, it demonstrated that the plume was not in contact with the basements of any houses and gave the public a simple understanding of a complex problem.

- *Evaluate performance of the system*. Concentration data continue to be collected and the extent of the plume mapped, in order to evaluate how well the recovery system is working. This information is routinely shared with the community. Data management and visualization software are being used to quickly and efficiently produce images depicting the progress of the remediation. The latest data indicate that the concentrations are reducing even faster than we originally predicted.

The use of visual tools allowed us to mitigate the fears and concerns of the public, and to demonstrate the facility's commitment to reducing the potential risk of groundwater contamination to its neighbors.



View of TVO Plume > 1 mg/l
looking east

Fig. 5.

4. Summary and conclusion

Mapping, the visual display of information, is an extremely powerful tool for understanding and managing risk. It assists us with remediation in several ways: (1) evaluating data, and developing a site conceptual model of the nature and extent of the contamination; (2) evaluating the effectiveness of remedial options, and selecting the one which will minimize future liabilities for the least overall cost; (3) refining the perceptions of the public as to their actual, as opposed to their perceived, risk; and (4) achieving public acceptance of the plan for remediating the contamination and managing the residual risk. New tools for data management, modeling and visualization have value in the evaluation, communication and management of risks. When these tools are effectively applied, environmental risk information can be quickly and efficiently managed, accessed and visualized without putting pen to paper, providing new and innovative ways to use and interpret data while saving time and money. These mapping tools were useful in developing a solution to a groundwater contamination problem, communicating the situation and solution to the community, and mitigating the perceived risks associated with the problem.

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