Risk Assessment for Sites with Volatile Contaminants in Shallow Groundwater

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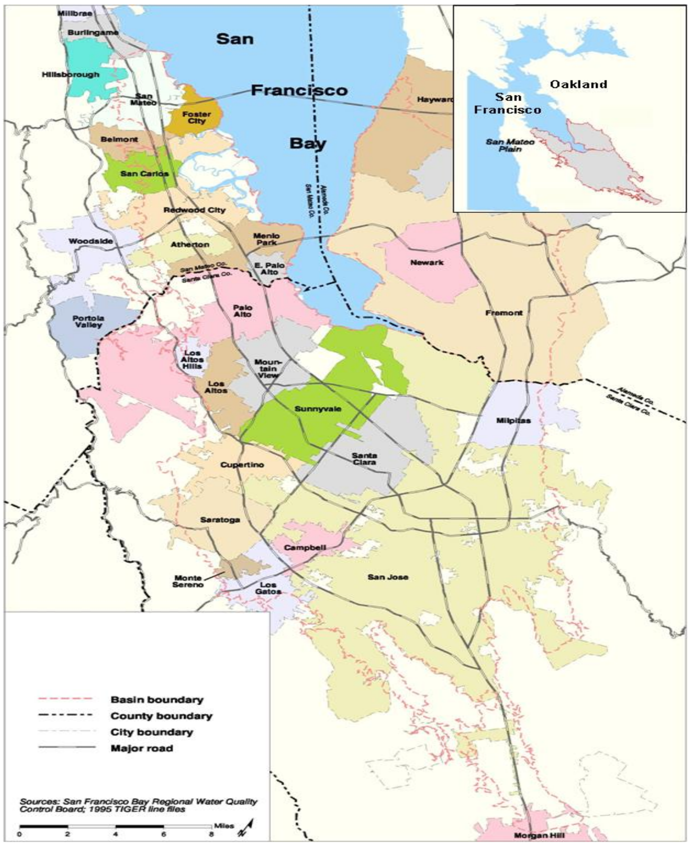
ABSTRACT

A number of hazardous waste sites are present in low-lying coastal areas in California with shallow groundwater (2 to 15 feet below ground surface) contaminated by volatile organic chemicals (VOCs). Shallow groundwater poses complex issues of site characterization and potential exposure pathways. In addition to potential ingestion and dermal contact through domestic water use, exposure can occur through indirect pathways. Inhalation of VOCs can occur via showering and other household uses of groundwater, following volatilization into outdoor air, and through vapor intrusion from soil or groundwater into indoor air. The last pathway currently receives considerable attention in risk assessments. Exposure to VOCs from shallow groundwater can also occur via dermal contact or inhalation by construction workers and uptake of contaminated groundwater into home-grown produce consumed by residents.

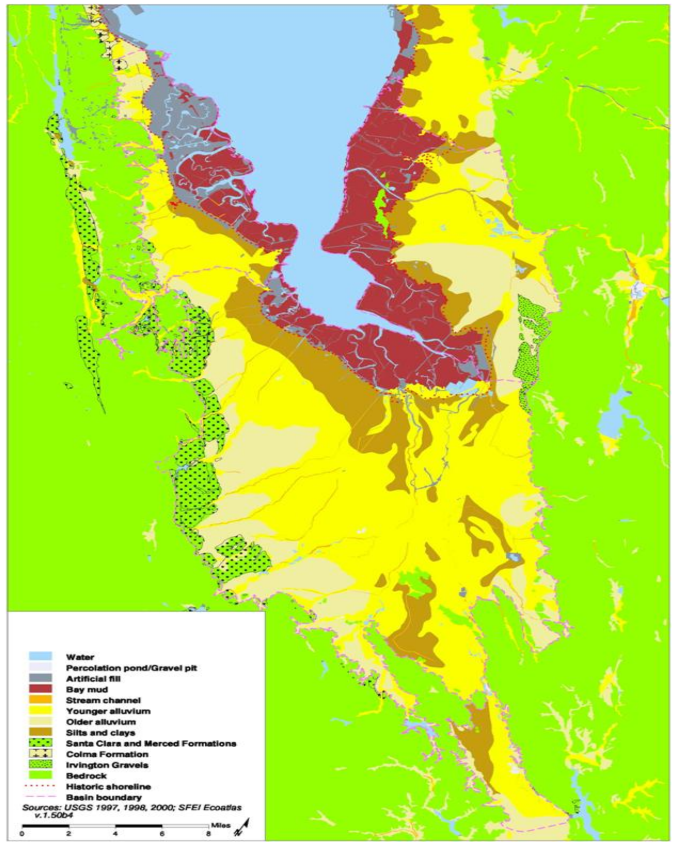
This paper illustrates how these issues were dealt with at a specific site in California. Risk assessment was performed at Site 'A' for groundwater contaminated with benzene and methyl tertiary-butyl ether. A US Department of Energy (DOE) model for home-grown produce predicted cancer risk as high as 3E-3 and a non-cancer hazard index (HI) of 7. However, cancer risk and HI from the CalTOX™ model were much lower (2E-6 and 0.02, respectively), illustrating the uncertainty associated with this pathway. Excluding the food pathway, the highest cancer risk and HI were from the vapor intrusion pathway (2E-5 and 0.08, respectively).

Our experience is that when VOC contamination is at significant concentrations in soil or groundwater, the vapor intrusion pathway usually generates the highest cancer risk and HI. The risk assessment for Site 'A' included an evaluation for construction workers. Although the estimated cancer risk and HI were de minimus for VOCs from groundwater in a trench scenario (3E-7 and 0.03, respectively), inhalation of VOCs from soil generated surprisingly high estimates for the outdoor air pathway (3E-6 and 52, respectively).

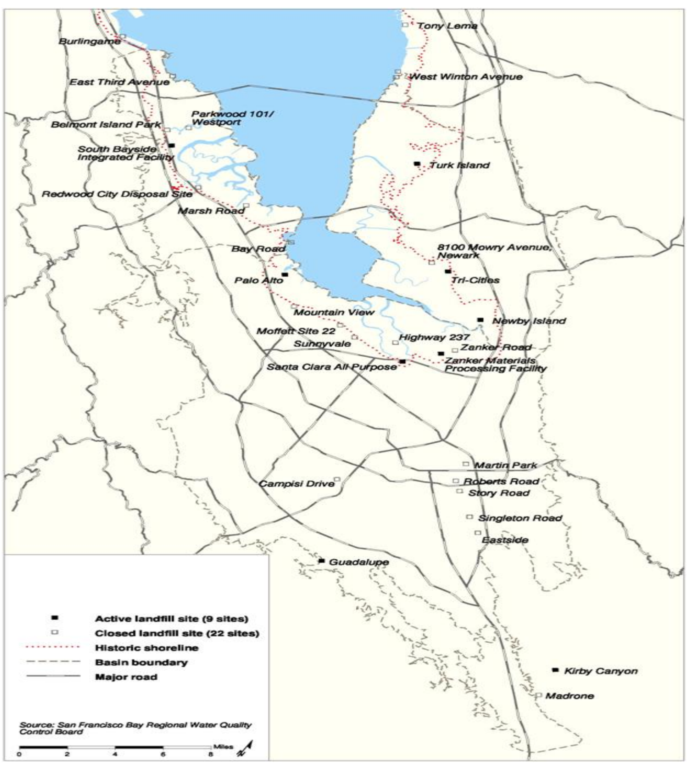
Shallow Groundwater is Common to Low-Lying Coastal Areas of California



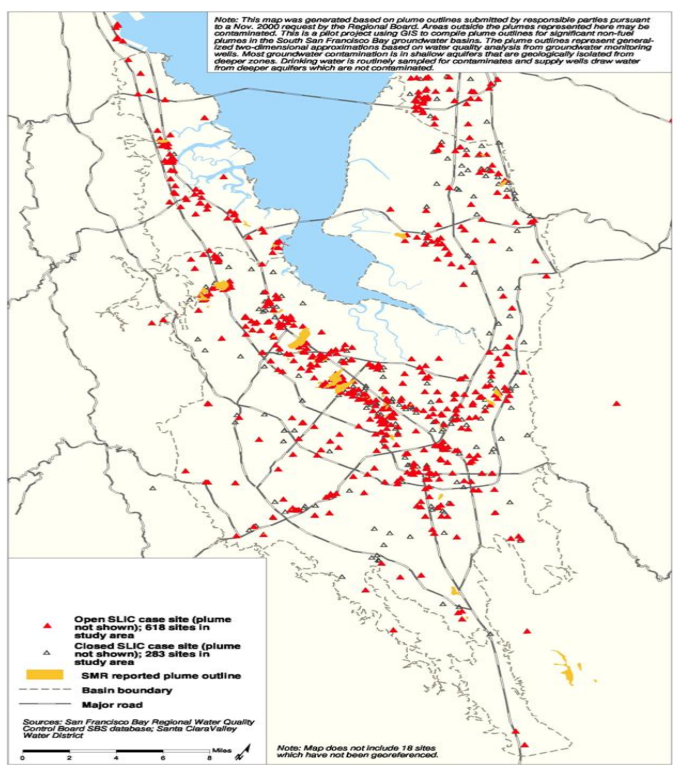
South San Francisco Bay Basin



Shallow Groundwater in Areas with Artificial Fill and Stream Deposition



Change in Historic Shoreline due to Stream Deposition and Artificial Fill



Spills, Leaks, Investigations, and Cleanups (SLIC) Case Sites at the South San Francisco Bay Basin

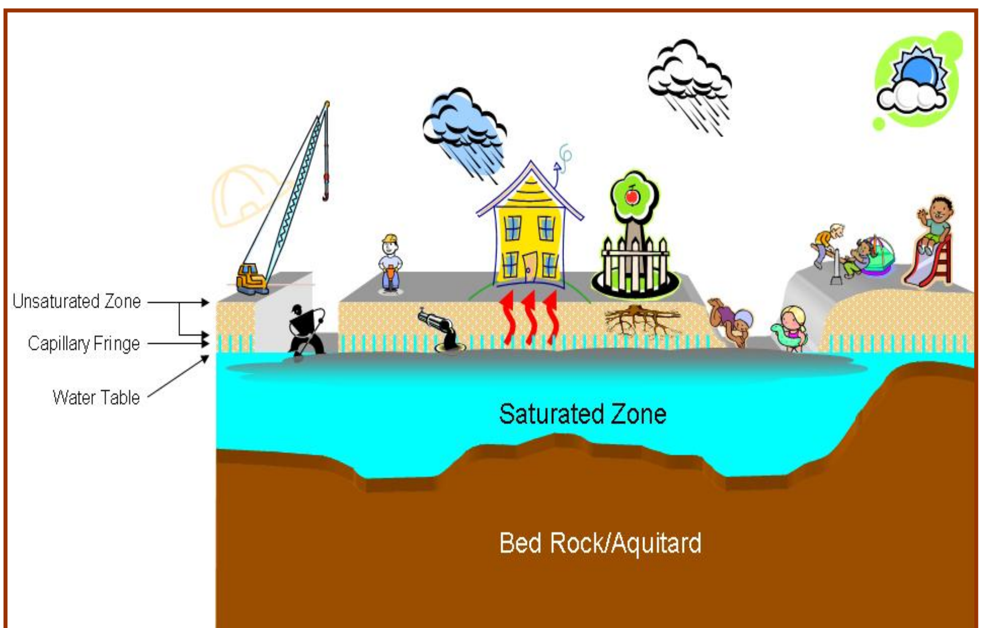
WHAT ARE THE PROBLEMS FOR VOCS IN SHALLOW GROUNDWATER?

1. Indoor Air Issues:

- **Soil gas sampling provides the best data source for modeling vapor intrusion into indoor air.**
  - **Data from either bulk soil or groundwater require partitioning assumptions, thereby increasing uncertainty in modeling.**
  - **Loss of VOCs may occur during soil and groundwater sampling.**
- **Shallow groundwater can make collection of reliable soil gas data problematic.**
  - **A large capillary fringe, the semi-saturated zone above the water table, can reduce the thickness of soil available for soil gas sampling.**
  - **A capillary fringe can extend to the surface, making soil gas sampling nearly impossible.**
  - **Variation in the ambient atmospheric pressure results in subsurface movement of air in pore spaces. This is called barometric pumping, which can potentially bias sampling results.**
  - **Breakthrough of atmospheric air, including volatile chemicals, during sampling can confound the soil gas results. Tracer gases are used to evaluate the magnitude of the breakthrough.**
  - **Tidal influence can reduce the thickness of soil available for soil gas sampling and cause movement of pore air which can bias sampling.**

2. Additional Considerations:

- **Shallow groundwater complicates the exposure assessment.**
  - **Exposure to groundwater during trench activities – dermal contact and inhalation by workers.**
  - **Root uptake of contaminants by home grown produce.**

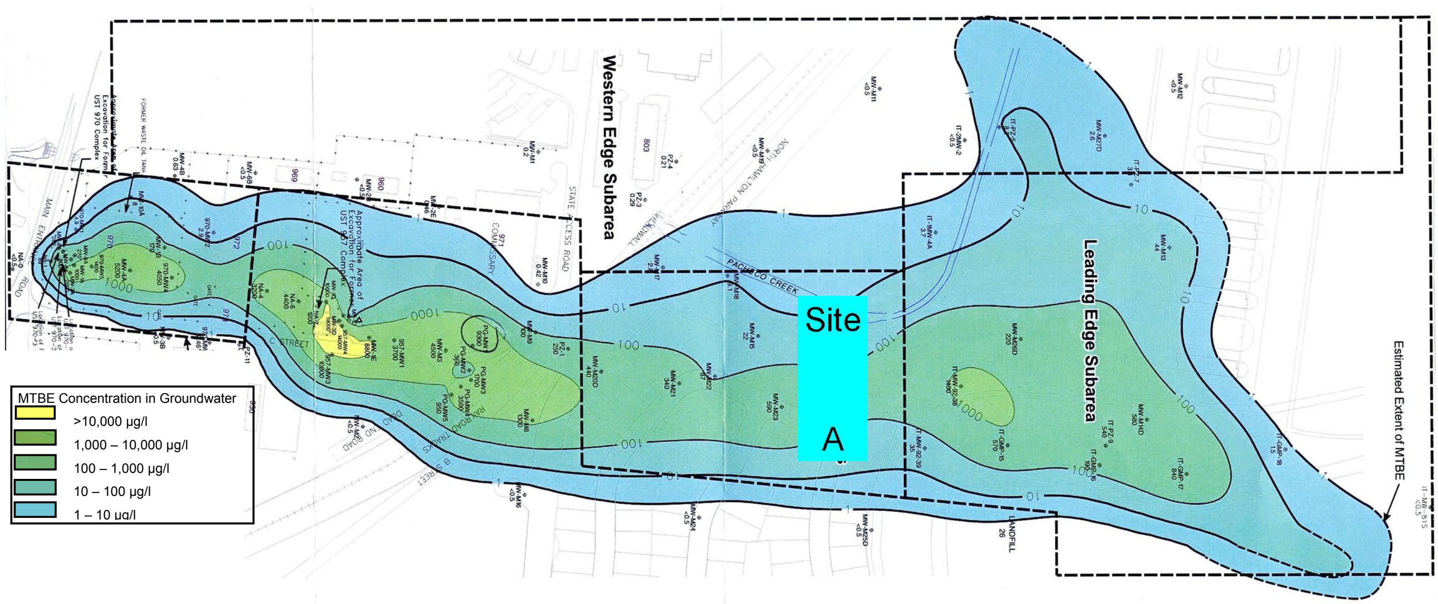


Human Receptor	Construction Workers	Residents	Recreational Receptors
Exposure Pathway	Dermal Contact Inhalation	Ingestion Dermal Contact Vapor Intrusion Inhalation* Home Grown Produce	Ingestion Dermal Contact Inhalation

* Inhalation pathway under the residential scenario includes exposure to VOCs in ambient air and VOCs released during household use of groundwater.

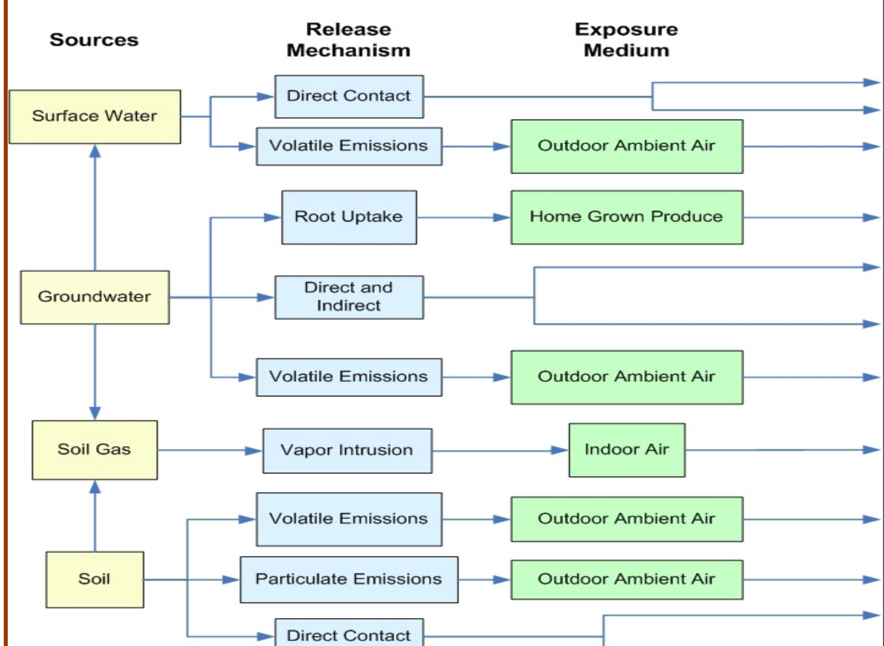
DESCRIPTION OF SITE 'A'

- **A former underground storage tank site.**
- **Shallow groundwater - about six feet below ground surface (bgs).**
- **Sampling probes for soil gas installed at 1.5 to 3 feet bgs.**
- **Groundwater contaminated with volatile organic chemicals (VOCs).**
  - **Benzene**
  - **Methyl tertiary-butyl ether (MTBE)**



Concentration Contour of MTBE in Groundwater at Site 'A'

TABLE 1. CONCEPTUAL SITE MODEL FOR SITE 'A'



Exposure Route	Residents Risk	Residents HI	Construction / Trench Worker Risk	Construction / Trench Worker HI	Recreational Receptor* Risk	Recreational Receptor* HI
Dermal	N/A&		N/A		2.5E-9	1.9E-5
Ingestion	N/A		N/A		Not evaluated	
Inhalation	N/A		N/A		1.8E-9	1.3E-5
Ingestion	See Table 3		N/A		N/A	
	2.4E-6 to 3.4E-3	2.5E-2 to 6.9				
Ingestion & inhalation from residential use	1.5E-3	4.7E-1	N/A		N/A	
Dermal	Not evaluated		See Table 4		N/A	
			1.3E-7	2.1E-2		
Inhalation	1.3E-7	5.1E-4	See Table 4		N/A	
			3.0E-7	2.8E-2		
Inhalation	See Table 2		N/A		N/A	
	2.0E-7 to 2.4E-5	3.2E-3 to 7.5E-2				
Inhalation	4.6E-8	1.1E-2	See Table 4		N/A	
			2.5E-6	52		
Inhalation	N/A		N/A		N/A	
Ingestion	1.3E-7	2.4E-2	2.8E-10	4.0E-4	N/A	
Dermal	N/A		N/A		N/A	
Total	1.5E-3 to 4.9E-3	5.3E-1 to 7.5	2.9E-6	52	4.3E-9	3.2E-5

* Recreational Receptor: Off-site recreational receptor where groundwater daylights.
& N/A: Not applicable due to incomplete or insignificant pathway.

Table 2. Indoor Air Risk Modeled From Shallow Soil Gas as Compared to Groundwater

Source Term	Risk	HI
Shallow Soil Gas (3 ft bgs)	2.00E-07	3.20E-03
Groundwater (9 ft bgs)	2.40E-05	7.50E-02

- Indoor air risk estimated using DTSC modified Johnson and Ettinger vapor intrusion models (DTSC, 2004).
- Indoor air risks estimated from groundwater data are higher.
- Use of groundwater data suffer from modeling considerations:
  - partitioning assumptions in modeling soil gas concentration from groundwater data.
  - degradation of VOCs in vadose zone not accounted for.
- Use of soil gas data suffers from sampling issues:
  - capillary fringe interference.
  - barometric influence during soil gas sampling.
  - possible breakthrough of atmospheric air during sampling.

Table 3. Estimated Risk from Residential Consumption of Home Grown Produce

Model	Risk	HI
CalTOX™ Model	2.4E-06	2.5E-02
US Department of Energy Model	3.4E-03	6.9

- Risk estimated using the DOE model (DOE, 1999) and the CalTOX Eight-Compartment Multimedia Exposure Model (LBNL, 2002) with the assumption of no chemical degradation in groundwater.
- Large differences in risk estimated by these two models.
- The DOE model is based on upper bound estimates of parameters versus central tendency estimates in the CalTOX model.
- The DOE model assumes irrigation as well as root uptake, whereas the CalTOX model assumes root uptake only.

Table 4. Contribution of Construction / Trench Worker Exposure Pathways to Cumulative Risk and Hazard Index from VOCs.

Exposure Pathways in Trench Scenario	Risk	HI
Direct Dermal Contact with Groundwater	1.3E-07	2.1E-02
Inhalation of VOCs from Groundwater	3.0E-07	2.8E-02
Inhalation of VOCs from Soil	2.5E-06	52
Ingestion of Soil	2.8E-10	4.0E-4
Total	2.9E-06	52

- The DOE (PNNL, 1996) trench model and USEPA (1992) excavation model were used to evaluate risks from inhalation of VOCs released from groundwater and soil, respectively

CONCLUSIONS

- For residential development of Site A, the exposure pathways of most concern are:
  - domestic use of groundwater
  - vapor intrusion into indoor air
  - home grown produce
- Although soil gas is generally the preferred sample medium for modeling vapor intrusion into indoor air, it can be problematic when groundwater is shallow.
- Modeling vapor intrusion into indoor air may give very different results based on soil gas or groundwater data.
- Factors such as barometric influence, atmospheric breakthrough, and VOC degradation must be considered.
- Although home grown produce is a common public concern, there is considerable uncertainty in evaluating the associated risks.
- Inhalation of VOCs from soil can present a risk for trench workers.
- Research needs:
  - Validation of home grown produce models and trench models.
  - Validation of the Johnson and Ettinger model under different site conditions, including shallow groundwater.
  - Model modifications for different conditions.
  - Improved sampling techniques for volatile organic chemicals in air and in shallow groundwater.

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DISCLAIMER

The opinions and findings in this paper are those of the authors. They do not represent guidance or policy of the California Department of Toxic Substances Control or California Environmental Protection Agency.

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