

How to Collect Reliable Soil-Gas Data for Upward Risk Assessments

Part 2: Surface Flux-Chamber Method

by Blayne Hartman

Since Part 1 of this topic, *Active Soil-Gas Method*, was printed in October 2002, U.S. EPA has initiated a series of informational workshops/conferences that address the soil-gas upward-migration risk pathway. (See <http://www.clu-in.org/conf/tio/vapor/resource.cfm> for more information.) While the active soil-vapor method is discussed in detail during these workshops, there is little discussion on the surface flux-chamber method. Yet, based on some of the default approaches recommended by U.S. EPA, the surface flux-chamber method may be the best method to use in some situations. Why is the method not discussed in the guidance? Primarily because of a lack of familiarity, experience, and understanding by the environmental community, including regulators, consultants, and contractors. So, let's take a look at this field technique and see when and how it can aid in the assessment of this risk pathway.

Let me start by making two important points concerning surface flux chambers:

- There is currently no published or official U.S. EPA method for surface flux chambers. There is a published study performed under contract with EPA that gives a recommended protocol, but it is not regulatory guidance.
- There is no one right way to perform a flux-chamber survey. Like any field technique, there are variations of the method—the suitability of each depends on the project goals.

History

Direct measurement of compound fluxes has been commonly performed in the oceanographic, soil science, and natural resource exploration (i.e., petroleum and minerals) communities for many years. The approach has not been as readily applied to environmental risk assessment.

In the mid 1980s, Radian Corporation, under contract to U.S. EPA, performed a series of testing programs on the method that were summarized in a users guide (Kienbusch, 1986). The method described in this document has often been incorrectly labeled as the official U.S. EPA flux-chamber method. While the document gives a thorough treatment of one flux-chamber approach, including a comprehensive treatment of statistical sampling, it is a recommended protocol only, has several limitations for risk-based applications as described further in this article, and is a difficult read for the inexperienced user.

Subsequent documents by Radian for EPA on air emissions at Superfund sites contain more general discussions on flux chamber methods and applications (Eklund & Schmidt, 1990).

Why Use Flux Chambers?

Currently, risk due to the upward flux of vapor-phase contaminants into an overlying structure is assessed either from direct measurements of indoor air or by the collection of groundwater and/or soil-gas data and the application of a predictive transport model or attenuation factor. Both approaches have limitations.

The determination of upward contaminant flux from the measurement of indoor air is subject to such complications as contributions from the natural background of contaminants in ambient air (especially in urban locations), contributions from sources from within the structure, and temporal and spatial variations. Further, the process is often a logistical headache, especially when the measurements are performed in private residences.

For these and other reasons, U.S. EPA currently recommends collecting subsurface groundwater or soil-gas data prior to the measurement of indoor air concentrations (OSWER Draft Guidance for Evaluating the Vapor Intrusion to Indoor Air Pathway from Groundwater and Soils, November 29, 2002, www.epa.gov/correctiveaction/eis/vapor.htm).

The determination of upward contaminant flux using groundwater or soil-gas data requires the application of a predictive model or attenuation factor to compute the contaminant concentration in an overlying room. Attenuation factors, commonly referred to as alpha factors (α), are defined as the concentration of indoor air to either measured soil-gas concentration (soil-gas alpha) or indoor air to a calculated soil-gas



Surface-flux chambers installed on site.

value from groundwater concentrations using the compound-specific Henry's Constant (groundwater alpha).

At present, attenuation factors predicted by the models have yet to be thoroughly validated with field data. Until such time that a sufficient data base is accumulated to test the model-derived values, U.S. EPA is recommending the use of default attenuation factors in its vapor intrusion guidance that are conservative and may be overprotective by up to

several orders of magnitude. The ramification is an increased likelihood of falsely concluding that there may be a risk when the assessment is based on subsurface data, especially if site-specific data are not available.

The flux-chamber approach provides a direct measurement of the subsurface contaminant flux and therefore alleviates the uncertainty introduced from the existing predictive flux models or the use of an overly conservative alpha factor. Assuming proper placement, as described below, fluxes measured by this approach should, in theory, be reflective of all of the subsurface fate and transport processes that are operative and difficult to model (e.g., phase partitioning, bioattenuation, preferential pathways, and advective flow).

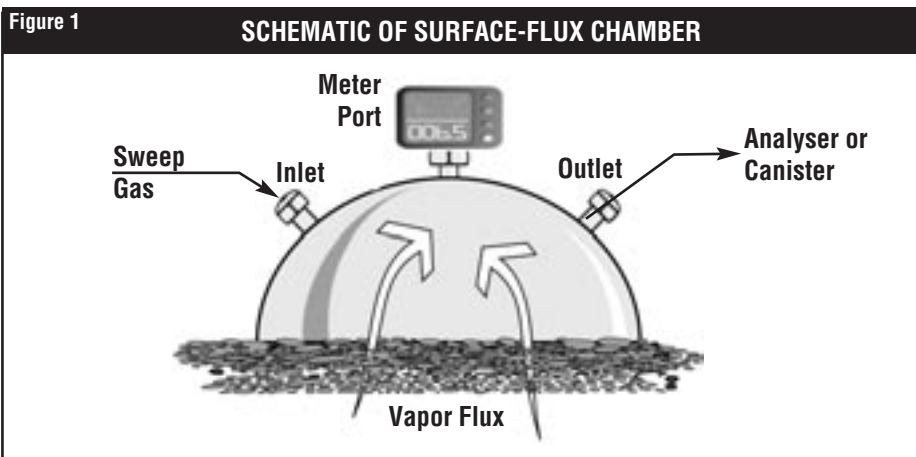
If flux chambers can solve some of the problems of the other approaches, then why not use them? Because, as with any method, flux chambers are not applicable to all situations and they have their share of limitations that must be understood before attempting to employ them on a site.

Flux Chamber Application

Flux chambers are not applicable to every type of structure or site. For example, the use of chambers in basements or any other subterranean enclosure is not practical because the four walls of the basement could also be a source of vapor flux. Also, flux chamber results from undeveloped lots may or may not be representative of fluxes into a future structure. On one hand, the measured flux could be over-estimated because there is no building foundation impeding the flux; on the other hand, the measured flux could be under-estimated for reasons such as the lack of pressure-induced advective flow caused by the heating or ventilation system in the overlying structure.

Flux Chamber Limitations

While factors influencing the results from this method include adequate coverage, measurement time, and temporal variations (these factors also influence indoor air and soil-gas results), the two greatest concerns I have heard voiced from skeptics on this method are:



- Doubt as to whether chambers measure the actual flux into a structure due to our inability to place chambers in the location of highest vapor intrusion. Experience from radon intrusion studies over the years has shown that in many structures, especially older ones, the most permeable zones into basements and slabs are at the junction between the structure footing and the slab/floor (i.e., near the walls) or from conduits (e.g., utility lines and pipes) protruding through the walls or slab. Because chamber designs preclude measurements in such locations, the concern is that measured fluxes will be lower than actual fluxes in such situations.
- Concerns as to whether the air-flow conditions inside a chamber match the air-flow conditions in a room. If the air flow in the chamber is more restricted, fluxes could be reduced. If the air-flow conditions in the chamber are higher than in the room, measured fluxes could be over-estimated if upward advection is created or under-estimated if chamber air is pushed downward into the subsurface.

Employing Flux Chambers

Structures with basements, older construction, and structures containing many conduits through the slab, walls, or floor are not likely to be good candidates for flux chambers. Structures with newer slab-on-grade construction are most applicable for flux chambers. Chambers are applicable to undeveloped lots, as long as effects caused by a future building are considered when interpreting the results. Enough chamber measure-

ments should be made to ensure that spatial variations around the building footprint due to potential preferential pathways (e.g., near the footing and slab junction) are adequately covered. Finally, chamber measurements should be made for a period of time sufficient to ensure that any temporal variations in flux are averaged.

Flux-Chamber Methods

There are basically two different types of flux-chamber methods: (a) the Static-(Closed) Chamber Method and (b) the Dynamic-Chamber Method. Both methods offer advantages and disadvantages as described below.

■ Static-Chamber

In this method, there is no introduction of gas into the chamber during the incubation period. Contaminant flux into the trapped and stagnant chamber volume and the contaminant concentration builds up over time. Discrete samples for analysis are withdrawn either at the end of the incubation period or, preferably, at regular intervals during the incubation period. In essence, the chamber acts like a "mini-room," except there is no air exchange, which provides a time-integrated sample, similar to a Summa canister collected over a specified time period.

The equipment is very simple, consisting essentially of a collection container with sampling ports. (See Figure 1.) Chambers have been made from 55-gallon drums (metal or plastic), Summa canisters, galvanized cans, bowls, and pots. More important than the type of container is the

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chamber material. For most VOCs, the chamber should be constructed of an inert, non-adsorbing material, such as polished stainless steel with a minimum of rough adsorbing sites. (Teflon is not a good choice due to adsorption on its surface.)

Advantages

This method offers many operational advantages over the dynamic method including the following:

- The equipment and procedures are simpler and less expensive, enabling the deployment of multiple chambers over the same time period, giving better coverage of the site/structure.
- The method gives a time-integrated sample for long periods, reflecting any flux variations due to temporal effects.
- The simpler system and procedures minimize potential false positives from equipment blanks (e.g., blanks from inlet gas, chamber hardware, or sample containers).
- The absence of flowing inlet and outlet gases minimizes potential disturbances of the natural flux conditions (i.e., creation of advective flow or pressure gradients in the chamber).
- The method is more sensitive (i.e., can detect lower fluxes) as there is no inlet gas diluting/sweeping the contaminant concentration inside the chamber, and contaminant concentrations build-up over time. For example, for a 1 in 100,000 risk the "chamber fail concentration" for benzene would be approximately 25 $\mu\text{g}/\text{m}^3\text{-hr}$ or 200 $\mu\text{g}/\text{m}^3$ over eight hours. This offers the following additional benefits: (a) Required analytical detection limits increase, enabling less expensive measurements and the potential for on-site, real-time measurements. (b) Higher detection limits reduce the potential for false positives.
- Measured values are easier to interpret for the inexperienced

user. Measured chamber concentrations can be compared directly to tabulated acceptable indoor air values or converted easily to a flux as follows:

$$C_{\text{room}} = C_{\text{chamber}} * H_{\text{chamber}}/H_{\text{room}}$$

$$\text{Flux} = C_{\text{chamber}} * V_{\text{chamber}}/A_{\text{chamber}} * T$$

Where: C refers to concentration
H refers to height
V refers to volume
A refers to area
T refers to incubation time

For example, a measured concentration of 10 $\mu\text{g}/\text{m}^3$ after an 8-hour period in a 10-inch high chamber would be equivalent to a concentration of 1 $\mu\text{g}/\text{m}^3$ in an 8-foot high room. This value can be compared directly to tabulated acceptable room concentrations for the applicable risk level and allowed room air-exchange rate. Or the value can be easily converted to a flux for input into an exposure model.

Disadvantages

There is one major disadvantage to the static method: If chamber concentrations build up to a significant fraction of the subsurface concentration, the flux will be impeded. By Fick's Law, the flux is directly related to concentration gradient; hence, for example, a 20 percent reduction in concentration gradient will lead to a 20 percent reduction in flux.

For sites where emissions are known to be high (e.g., near landfills, compost piles), the flux reduction caused by concentration build-up could be significant. But, for most upward risk applications, concentration build-up will most likely not be significant. For example, existing case studies indicate that the attenuation factors are less than 0.01 for chlorinated solvent sites and less than 0.001 for hydrocarbon sites. The corresponding concentration build-up in a static chamber would be 20 percent and 2 percent of the subsurface soil-gas concentration, respectively, for these two attenuation factors.

Any reduction in the measured flux can be identified and corrected for by measuring the chamber concentration periodically during the incubation period. If required detection levels can be achieved, I recommend on-site analysis to enable

real-time feedback. Alternatively, multiple samples can be collected from the chamber over the incubation time for off-site analysis. If the measured concentration in the chamber is within 25 percent of the subsurface soil-gas concentration, then it is possible the measured flux was underestimated.

■ Dynamic-Chamber

This is the method described in the Radian's Users Guide. In this method, an inlet gas (sweep gas) is continuously introduced into the chamber during the incubation period and an equivalent amount of the chamber gas is allowed to escape. The system is assumed to reach a steady-state concentration after four or five chamber-residence times, where one residence time equals the chamber volume divided by the sweep-gas flow rate.

At steady state, the contaminant concentration in the outlet gas is equivalent to the concentration in the chamber. The concentration in the outlet gas is monitored with a meter, or a sample of the outlet gas is collected for analysis, depending on the required detection level for the contaminants of concern. For risk-based applications requiring low detection levels, the typical approach is to collect a batch sample of the outlet gas for off-site analysis after steady-state conditions have been reached (approximately 30 minutes for the nominal conditions given in the Radian report).

Advantages

The major advantage this method offers is that, except in the most extreme cases, there is little chance for the chamber concentration to build up to a significant fraction of the subsurface concentration due to the inflow and outflow of the sweep gas. Hence, there is very little chance that the measured flux will be impeded by concentration build-up in the chamber.

Disadvantages

This method has a number of operational and technical disadvantages, including the following:

- This more complex procedure requires more complicated equipment. In addition to the chamber,

required equipment includes gas tanks, flow regulators, tubing connections, pressure gauges, and larger sample containers, typically canisters with flow chokes. The potential for false positives from equipment blanks is higher than the static method, especially if the equipment is reused on the same site on the same day.

- The more complicated and expensive equipment limits the deployment of multiple chambers covering long time periods at the same time.
- The high dilution of the chamber volume due to sweep gas results in a loss of sensitivity by a factor of 60 to 500 versus static chambers, requiring lower detection limits for the collected sample. For a 1 in 100,000 risk, the allowable benzene flux is less than $0.05 \mu\text{g}/\text{min}\cdot\text{m}^2$, corresponding to a measured concentration of less than 0.5 ppbv. Hence, expensive off-site indoor air (e.g., TO-14) methods are typically required. Finally, all equipment must be ultra clean and field procedures must be conducted with great care to ensure method blanks below these very low levels.
- Direct comparison of the measured concentration in the collected sample to tabulated acceptable room concentrations is not possible, and the conversion is difficult for all but the sophisticated user.
- The inflowing and outflowing sweep gas creates a potential disturbance of the natural flux (e.g., creation of advective flow in the chamber). In the typical application of this method, there is no measure of the air flow out of the exit ports. Without such a measurement, there is no knowledge or control on where the sweep air is going—out the exit ports or out the bottom. Since the air will take the path of least resistance, it is only reasonable to expect that some portion of the air will escape out the bottom—the portion depending on the soil permeability. If this happens, it is a major impediment to the natural flux. Pressure measurements, which are often performed to address this issue, do not give an indication of

the direction of flow, and hence do not solve the uncertainty. In my opinion, this is a major disadvantage of this method and raises doubt over any flux measurements obtained by this method if the output flow is not measured.

- Another major disadvantage of this method is the inability of the method, as generally practiced, to measure any temporal variations over the course of the day due to the assumption of a constant flux (i.e., steady state conditions). Case studies in the literature clearly document that emissions from soil vary, and even the Radian report acknowledges this as a limitation of the method. Because the residence time of the air in the chamber is so short, a discrete sample collected at the end of an incubation period only reflects the last 30 minutes of time, despite the length of the incubation period. This limitation can be eliminated if a split of the outlet gas is collected continuously over a longer incubation period using a canister equipped with a flow choke.

■ Methods Summary

As discussed, reliable flux measurements can be made with both chamber techniques. For vapor intrusion applications, where low fluxes are likely to be detected, the static-chamber method offers more advantages and fewer disadvantages over the dynamic-chamber method.

This conclusion was also stated in a subsequent document by Radian to EPA Superfund group (Eklund and Schmidt, 1990). If high fluxes are expected (e.g., chlorinated solvent concentrations near the surface greater than 1,000 times allowable ambient air values), collect multiple samples from static chambers over the deployment period to detect any flux reduction due to potential concentration build-up.

If the dynamic method is used, the output-gas flow (not pressure) must be measured to ensure that the sweep air is not escaping underneath the chamber and impeding the natural flux.

If previous soil-gas data do not exist, the collection of corresponding soil-gas samples near the flux chambers is advised to substantiate the

presence of target contaminants in the subsurface, especially at chlorinated solvent sites, where vapor clouds are more common.

Key Factors of Concern

The following are some of the key factors to consider when using either flux-chamber method:

- **Coverage** The Radian document gives a statistical approach for determining adequate coverage. However, in practice, similar to choosing the number and location of borings for site assessment, this decision will likely be made based on site-specific issues, such as size of the site/structure, surface features, and budget.

Deploy multiple chambers in any program to provide representation of the area of interest and to determine precision. Chambers should be located in areas where surface features suggest possible conduits to the subsurface (e.g., cracks, drains) and close to the external walls near the junction of the footings and slab. At least one chamber should be deployed in the area of maximum subsurface contaminant concentration, if it has been identified from a previous subsurface investigation.

Keep the following in mind: You wouldn't consider proposing or accepting a site-assessment report with only one analysis from one or two borings, would you? So why would you accept only one or two flux-chamber measurements to *characterize this risk pathway?*

- **Deployment Period** Chambers should be deployed for a long enough period of time to ensure that temporal variations are measured. I recommend a minimum of eight hours. Longer exposure times, on the order of 24 hours, may be more appropriate since they give a time-integrated result that is more representative of the actual flux into a surface structure. This is especially relevant if climatic variations are extreme from day to night (barometric pressure or temperature).

If the dynamic method is used, samples should be collected con-

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tinuously over the incubation period in a canister equipped with a flow regulator.

- **Chamber Purging and Blank Samples** Purge static chambers after emplacement with clean gas (i.e., air or nitrogen), and immediately collect a sample after the purging is complete. This gives an initial concentration at the start of the flux measurement that should not be included in the final value. For dynamic chambers, collect at least one method blank at the start of the program per chamber and prior to reuse, as recommended in the Radian report.
- **Environmental Conditions** It is well known that emission rates from soil immediately after a rain-fall will be lower than from drier soils. A flux chamber program should wait at least several days after a minor rain event. (The Radian report recommends waiting seven days after a rain event exceeding 0.3 inches of rain.)

Barometric pressure has also been documented to have an effect on emission rates—highest emission rates are found during periods of lower atmospheric pressure. Programs should be avoided during any period of extreme high or low barometric pressure.

Temperature effects have been found to be relatively minor on emission rates, unless the flux is from soil contamination immediately at the surface. The greater effect of ambient temperature will likely be due to changes in the vapor flow below a structure caused by heating/cooling or ventilation systems in the building. Due to this latter issue, flux measurements collected over one or more seasons may be appropriate for locations with large seasonal variations in temperature (high or low).

Special Concerns

The following are some of the special concerns associated with using either flux-chamber method:

- **Use of On-Site Analysis** In my

opinion, on-site analysis is always advised to enable real-time decisions to be made. This is especially helpful for static chambers, where concentration build-up could impede the flux. The applicability of on-site analysis will depend upon required detection levels and the sensitivity of the on-site instrumentation. For example, the acceptable ambient benzene value for 1 in 100,000 risk is 0.84 $\mu\text{g}/\text{m}^3$. For a static-flux chamber concentration with a 20 to 1 height ratio, this is equivalent to approximately 20 $\mu\text{g}/\text{m}^3$. If a nominal room air exchange rate of 1 every 2 hours is used, the allowable chamber concentration will be 20 $\mu\text{g}/\text{m}^3$ every 2 hours, or 80 $\mu\text{g}/\text{m}^3$ over an 8 hour incubation. This detection level can be reached on-site by laboratory-grade photoionization detectors or GC/MS.

- **Petroleum Hydrocarbons and UST Sites** Petroleum hydrocarbons are known to actively biodegrade in the vadose zone if oxygen is present, hence resulting fluxes can be expected to be low unless near surface soil-gas values exceed 1,000 times allowed ambient values. On-site instruments can typically detect required levels in static chambers.
- **Methane Sites** Fluxes of methane gas into overlying homes near landfills, petroleum contaminated sites, and dairy farms are of extreme interest to fire departments and building departments around the country. Required methane levels can be easily measured with on-site instruments, hence the static method offers advantages over the dynamic.
- **Solvent Sites** Chlorinated hydrocarbons are not as biodegradable in the vadose zone and, at sites with surface sources of solvents (e.g., dry cleaners, vapor degreasers), vapor clouds may exist. Hence, the potential exists for higher fluxes as substantiated by the higher attenuation factors reported in published studies. If soil-gas data exist and are greater than 1,000 times acceptable ambient air concentrations, ensure that multiple samples are taken if the static method is used.

Published Protocols and References

Unfortunately, there are no regulatory guidance documents governing flux-chamber protocols. The Radian document, referenced previously, is the most comprehensive document, but it only deals with the dynamic method. San Diego County has some limited guidance regarding flux chambers in its Site Assessment Manual, most of which I included in this article (http://www.co.san-diego.ca.us/cnty/cnty_depts/landuse/erv_health/twq/sam/pdf_files/presentations/soil-vapor_guide.pdf). Most other papers on flux chamber methods are case studies from vendors supplying the service, conference proceedings, or from other disciplines. Three recent papers comparing fluxes measured with chambers to fluxes estimated by models are by Menatti and Fall (2002), Richter and Schmidt (2002) and Frez et. al (1998).

Another Valid Tool

Flux chambers should be considered to be another valid tool for upward vapor risk assessment, in addition to soil-gas data and indoor-air data. Which method to use on a given site depends upon the site-specific goals and the logistical limitations. In my view, the active soil-gas method described in *LUSTline* #42 offers less uncertainty and more versatility than the other methods for most situations. However, in situations where active soil-gas data are not definitive or can't be collected, and reliable indoor air samples cannot be collected due to background issues or other logistical reasons, then flux chambers may be the best approach.

Several reviewers of this article prior to publication raised the issue as to whether burial of adsorbent tubes into the cracks of the slab, utility conduits, or room edges might be another viable alternative. In my opinion, such an approach is not useful for quantitative results because one does not know the volume of air that passes through the adsorbent while it is emplaced. Without this knowledge, concentrations cannot be computed. However, one could use this approach as a screening method to decide where the areas of highest flux into a structure are to assist in locating the chambers. ■

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California Updates Guidance on ELD and SIR

In May 2003, the California State Water Resources Control Board (SWRCB), Underground Storage Tank (UST) Program updated two local-guidance (LG) letters. The SWRCB sends LG letters to local UST agencies to clarify program requirements. Two LG letters, one on enhanced leak detection (ELD) and one on statistical inventory reconciliation (SIR), were updated.

ELD is a third-party-certified test method capable of detecting both liquid and vapor releases at a leak rate of 0.005 gallons per hour. The original ELD LG (LG 161) discussed the requirement for UST systems with a single-walled component to be tested using ELD within 18 months of notification from the SWRCB and every 36 months thereafter. The SWRCB has now revised the LG (LG 161-2) to incorporate expanded ELD requirements (Assembly Bill 2481, Statutes 2002, Chapter 999). As of January 1, 2003, ELD is required at ALL UST systems located within 1,000 feet of a public drinking water well; double-walled UST systems

must be tested *once* using ELD by January 1, 2005. For additional information on the ELD requirement, visit: <http://www.swrcb.ca.gov/ust/docs/eld/index.html>.

Although not widely used in California, SIR is a monitoring method that may be used when approved by a local agency as part of a non-visual monitoring program [California Code of Regulations, title 23, section 2643(b)(3)]. The SWRCB has now revised the SIR LG (LG 139-2) to clearly identify the SIR reporting requirements, explain how to respond to fail/inconclusive results, and explain additional requirements that may be overlooked by SIR vendors or owners/operators. Additionally, updated monthly and annual SIR summary report forms clarify the SIR requirements and the importance of reporting the SIR provider, method and version number, and SIR test results. SIR vendors and UST system owners/operators may use these forms to comply with reporting requirements (CCR, title 23, sec-

tions 2646.1[c] & [j]). For additional information on SIR, visit: http://www.swrcb.ca.gov/ust/docs/lgs/LG139_2.html.

Be sure to visit the California UST Program Web site (<http://www.swrcb.ca.gov/ust>) in the future to stay up-to-date on new guidance and requirements. You can subscribe to receive updates by visiting the California UST Program Web site and using the "Subscribe To" feature. ■

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California Water District Sues Oil Companies for MTBE Contamination

The Orange County Water District (OCWD) is suing more than a dozen oil companies, MTBE manufacturers, and other responsible parties firms to recover funds needed to investigate, monitor, and remove MTBE and other gasoline oxygenate contamination in the soil, groundwater, and drinking water supplies within its service area. Leaking underground fuel storage tanks were identified as the primary source of the contamination.

The groundwater basin managed by OCWD provides most of the water supply for north and central Orange County—the most populous and developed part of the county. This water meets the needs of approximately 2.3 million residents. The District maintains that MTBE has significantly contaminated parts of the basin's shallow aquifer zone.

The suit contends that defendants named in the action "knowingly and willfully promoted and marketed gasoline containing MTBE and other oxygenates, when they knew or reasonably should have known that these compounds would reach groundwater, pollute public water supplies, render drinking water unusable and unsafe, and threaten the public health and welfare as they have done within the District." ■