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In cooperation with the Department of the Army, Fort Lewis Public Works, Environmental and Natural Resources Division

Innovative Technologies Join the Superfund Cleanup of Ground Water at Fort Lewis, Washington

New information from the Superfund cleanup project at the Fort Lewis Logistics Center, Washington, has prompted an updated, enhanced strategy for cleaning up the site's contaminated ground water. The enhanced strategy brings a suite of innovative technologies to reinforce the standard cleanup technologies already in place. As part of a team made up of the U.S. Army and other cooperating Federal and State agencies and contractors, the U.S. Geological Survey (USGS) is contributing its expertise and experience.

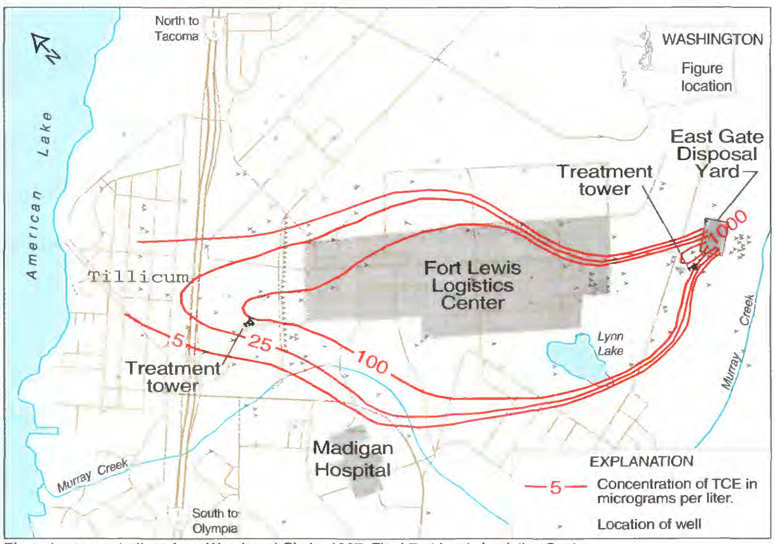
Volatile organic compounds are found in the ground water

In 1985, chlorinated volatile organic compounds (VOCs), especially trichloroethylene (TCE), were detected by the Army in the shallow, unconfined aquifer under the Logistics Center. Then in 1986 and 1987, the U.S. Environmental Protection Agency (EPA) detected VOC contamination in the ground water under the neighboring town of Tillicum, less than a mile to the northwest. Following up, the Army confirmed a plume of VOC-contaminated ground water flowing under the Logistics Center and extending to Tillicum.

In late 1989, the Fort Lewis Logistics Center was designated a Superfund site on the EPA's National Priorities List. Studies, especially the Army's Remedial Investigation from 1987 to 1988, had found that the East Gate Disposal Yard at the southeast end of the Logistics Center was the main source of the VOCs in the shallow aquifer and that the contamination posed an unacceptable risk to the environment and to human health (fig. 1). The federal maximum contaminant level for TCE in ground water used for drinking water is 5 micrograms per liter (5 parts per billion). Through the main body of the contaminant plume, TCE concentrations have ranged from 100 to 200 micrograms per liter, and near the source at the East Gate Disposal Yard, TCE concentrations have exceeded 50,000 micrograms per liter.

TCE was also found in a second, lower aquifer. Today researchers assume that TCE is migrating from the shallow aquifer to the lower aquifer through a window of permeable deposits in the confining layer (fig. 2). Both above and below the window, TCE concentrations are similar—from 100 to 180 micrograms per liter.

The cleanup began in 1990, under an agreement between Federal and State agencies, with the Army leading the work. In the next few years, the U.S. Army Corps of Engineers designed and installed a pump-and-treat system consisting of two fields of extraction wells that pump ground water out of the shallow aquifer and route it to treatment towers. The treatment towers, one for each field, remove the VOCs by exposing the contaminated water to the air and then discharging the treated water back into the ground. One field of extraction wells was installed just downgradient from the East Gate Disposal Yard. The other field was installed at the Fort Lewis boundary immediately southeast of Interstate 5 as a backstop to intercept the contaminant plume before it reached Tillicum and beyond. The completed pump-and-treat system began operating on August 31, 1995. Remediation of the shallow aquifer was estimated at 30 to 40 years.



Plume isoconcentrations from Woodward-Clyde, 1997, Final Fort Lewis Logistics Center Remedial Action Monitoring First Annual Report: Seattle, Woodward-Clyde, [about 100] p.

Figure 1. The TCE plume flows from southeast to northwest under the Logistics Center Superfund site.

New information brings an enhanced strategy

By 1997 and early 1998, in light of evidence from continued monitoring and further investigations, the cooperating agencies considered an enhanced, more effective strategy. New information about the limitations of the pump-and-treat system had indicated that it alone may not be capable of remediating the shallow aquifer and that cleanup may take much longer than originally expected.

Researchers also estimate that at least 110,000 pounds of solvents, mostly TCE, had been dumped between 1948 and 1960 in the East Gate Disposal Yard. The pump-and-treat system, which is now removing and venting 1,400 pounds of solvent per year, will take no less than 78 years to remove enough TCE to restore the ground water to acceptable standards.

Photo by J.R. Lyles, USGS, April 1998

On site at Ft. Lewis, UW and USGS scientists consider phytoremediation possibilities.

An earlier analysis had indicated that cleaning up the shallow aquifer and allowing natural flushing in the lower aquifer would be enough to manage the lower aquifer's contamination. But newer data show that TCE concentrations in the lower aquifer have actually increased. So the plan now calls for closer study of the options.

Finally, new technology options, many still in the experimental stages, are now available to work along with the established pump-and-treat systems. Innovative cleanup technologies like phytoremediation, biodegradation, and permeable reactive barriers may reduce costs by more than 50 percent over 30 years and help close out the treatment plants much sooner than the original estimates allowed.

The USGS has been asked, along with Pacific Northwest National Laboratory (PNNL), to produce a plan that uses the new technologies to restore the ground water to within acceptable limits. While PNNL will mainly apply the new technologies, the USGS will help evaluate how suitable and successful they are at the Fort Lewis site.

Phytoremediation with hybrid poplars

Phytoremediation is so new that it is just now moving from testing in the laboratory to testing in the field. But early research has raised high hopes for this green technology that uses plants, their roots, and associated microorganisms to treat a variety of contaminants in the air, soil, and water. Poplar trees, especially hybrids, are showing remarkable capacities to treat TCE in ground water. The USGS is currently investigating how suitable the Logistics Center site may be for phytoremediation of TCE.

The USGS has found that some of the most up-to-date research on poplar phytoremediation is being conducted by a group of University of Washington (UW) scientists who have been running an experimental hybrid poplar plot at Fife, Washington. USGS scientists are in touch with the UW scientists and have shown them prospective phytoremediation sites at Fort Lewis.

The hybrid trees, crosses between eastern cottonwoods and black cottonwoods, have been dubbed "solar-driven pump-and-treat systems." These hybrids, which grow 10 to 15 feet a year, put out broader leaves than their parents and thus have much more leaf surface area to release water vapor. So the hybrids can take up TCE-contaminated water at accelerated rates.

How much contaminated ground water might an acre-sized poplar stand at Fort Lewis take up in a 180-day growing season? A 1994 field study of a stand of 4-year-old hybrid poplars in Sumner, Washington, gives some indication. The hybrids, which had a nearly full canopy, vented water vapor at a maximum observed rate of 4.8 millimeters per day (Hinckley and others, 1994). In other words, an acre of the Sumner stand pumped as much as 5,100 gallons per day. At Fort Lewis, an acre of poplars could be expected to pump 4 millimeters per day, or 4,300 gallons per day, by the conservative estimate of William Bidlake, who is leading the USGS phytoremediation study.

For comparison, the current mechanical pump-and-treat system at Fort Lewis pumps up to 4 million gallons per day—the equivalent of 790 acres of hybrid poplars pumping at the rate of the Sumner stand. So hybrids are unlikely to replace the current mechanical system, but the hybrids, which run on free sunlight, can supplement the mechanical system at no energy cost.

How well could hybrid poplars treat the TCE-contaminated water that they pump? In the UW group's experimental plot at Fife, poplars planted in individual cells were fed water spiked with 15,000 micrograms per liter of TCE. By the second growing season, the trees were removing more than 97 percent of the TCE from the water.

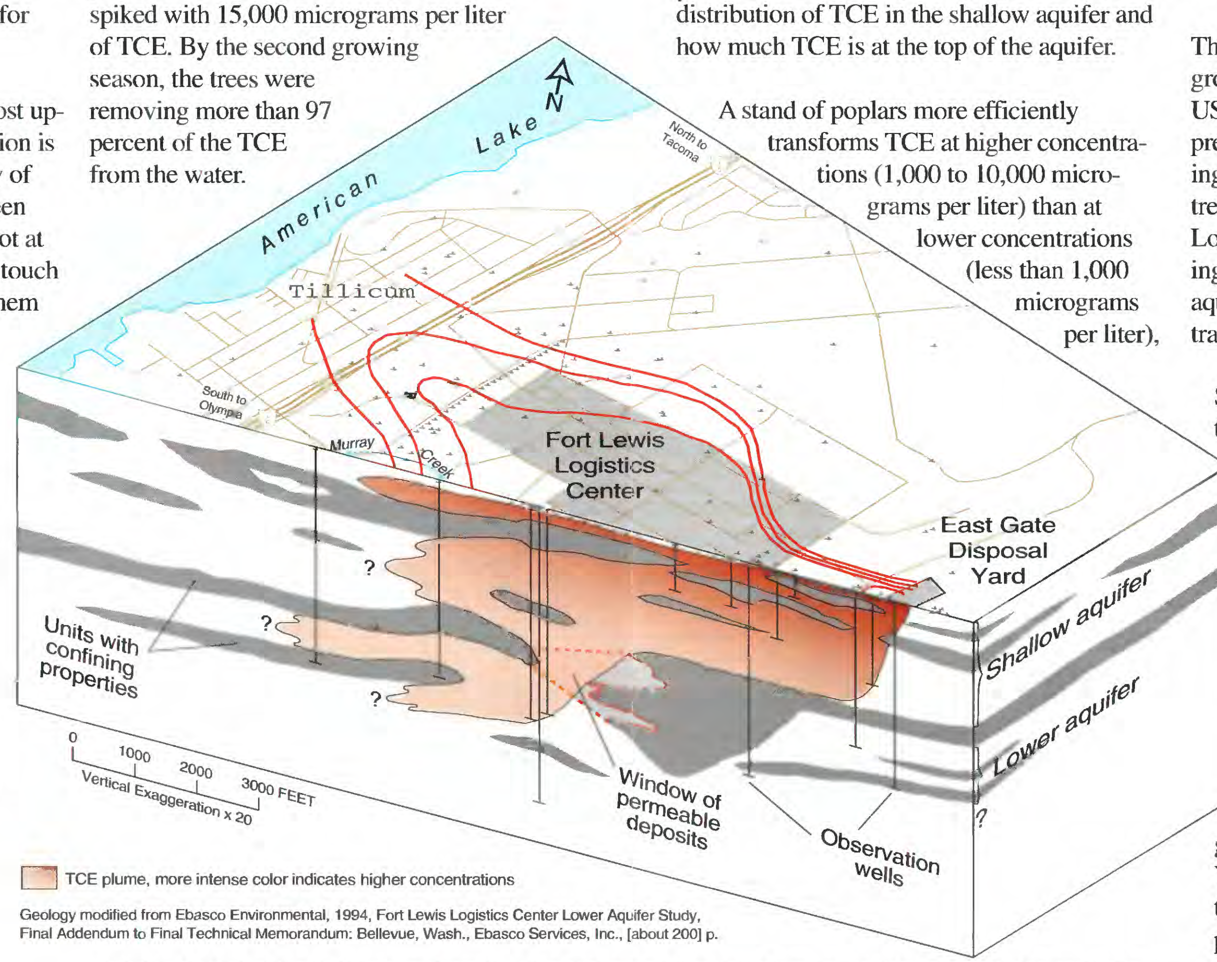


Figure 2. Part of the TCE plume flows from the shallow aquifer through a permeable window in the confining layer and into the lower aquifer.

What happens to the TCE taken up by the trees? How much of it do the trees transpire into the air, store in their tissues, or degrade in some way? Although the trees at Fife stored small percentages (3 to 4 percent) of insoluble TCE residue, the UW scientists have told the USGS that in the third growing season their trees vented no detectable TCE into the air (the pump-and-treat system vents 1,400 pounds per year), and the trees appeared largely to mineralize and metabolize the TCE into carbon dioxide and chloride salts.

Poplar remediation for the Logistics Center site does have its limitations and unanswered questions. For one thing, poplars are active only during the growing season, so for half the year they are not doing any remediation work. For another, poplar roots reach 10 feet or more, and the depth to the water table in the area of the East Gate Disposal Yard ranges from 4 to 12 feet, so the roots can take up TCE present only at the top of the shallow aquifer. The USGS is currently studying the vertical distribution of TCE in the shallow aquifer and how much TCE is at the top of the aquifer.

A stand of poplars more efficiently transforms TCE at higher concentrations (1,000 to 10,000 micrograms per liter) than at lower concentrations (less than 1,000 micrograms per liter), according to recent calculations by Bidlake. (Hybrid poplars tolerate fairly high concentrations of dissolved TCE, surviving TCE concentrations of 50,000 micrograms per liter in greenhouse experiments conducted by the UW group.) So it is possible that hot spots of TCE in the ground water could be pumped from small, inexpensive irrigation wells and routed to irrigate a poplar stand.

Biodegradation with microbes

Some natural attenuation of TCE is taking place at the Logistics Center, says Stephen Cox, who leads the USGS's biodegradation investigation. The TCE in ground water is to some degree diluted, dispersed, or adsorbed; and some of it is degraded by microbes. The USGS is investigating what part the degradation of TCE by microbes—either naturally or with human assistance—may play in achieving remediation goals.

The evidence lies in chemical data about the ground water and the aquifer sediments. The USGS is reviewing chemical data from previous studies and is collecting and analyzing ground-water samples from 12 pump-and-treat wells and 16 observation wells at the Logistics Center and nearby. It is also conducting laboratory studies to determine whether the aquifer sediments can support the chemical transformations needed in biodegradation.

So far, favorable conditions for biodegradation seem to be confined to the area of the East Gate Disposal Yard and a few small areas in the TCE plume, according to Cox. One early indication is that the ratio of TCE to DCE (cis-1,2 dichloroethylene) is much smaller near the East Gate Disposal Yard area than elsewhere in the plume. When microbes work on TCE, they produce DCE as a degradation product, so microbial activity might account for the increase of DCE in proportion to TCE. Another indication is that dissolved oxygen concentrations are generally lowest in the East Gate Disposal Yard area. "Under these anaerobic conditions," according to Cox, "oxidized compounds such as TCE are relatively unstable, and microorganisms can readily exploit this difference for their metabolism."

A third early indication is that iron concentrations, generally small throughout the plume (less than 50 micrograms per liter), are much larger in wells near the East Gate Disposal Yard (up to 280 micrograms per liter). The higher concentrations of iron imply reducing conditions that favor the degradation work by microbes on TCE.

Photo by R.W. Crist, USGS, April 1998

USGS drillers complete the last remaining feet of a monitoring well southeast of the East Gate Disposal Yard.

One ingredient in short natural supply, though, may be organic carbon, which microbes need to fuel their metabolism. Near the East Gate Disposal Yard, organic carbon concentrations (1 to 2 milligrams per liter) may be sufficient for some microbial degradation of TCE, but elsewhere total organic carbon concentrations (less than 1 milligram per liter) may be too low.

The short supply of organic carbon suggests one way that enhanced biodegradation technology might help the microbes do their job—give them what they are missing. By way of injection wells, they could be supplied with organic carbon in any number of forms, from methane to molasses.

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Permeable reactive barrier remediation

The EPA has officially encouraged permeable reactive barrier technology, saying that it has "the potential to more effectively remediate subsurface contamination at many types of sites at significant cost savings compared to other more traditional approaches" (U.S. Environmental Protection Agency, 1997a, p. 3). Plans are underway for PNNL to design, install, and test a new variation of the barrier technology at Fort Lewis.

Applied to TCE, this technology uses iron in an underground permeable barrier to intercept the TCE plume in the ground water and to transform the TCE into ultimately more benign products. The barrier will be constructed by injecting a reagent like sodium dithionite ($Na_2S_2O_4$) through wells into the aquifer in the path of the TCE plume. Injected into the aquifer sediments, the reagent reduces oxidized iron, Fe^{3+}, which is naturally present in the sediments, to Fe^{2+}. When TCE in ground water flows through the barrier, the Fe^{2+} reduces the TCE ultimately to ethane or ethene (also called ethylene) and chloride salts (Pacific Northwest National Laboratory, 1998a). Ethane and ethene biodegrade readily.

A successful barrier must intercept the contaminated ground water and not let TCE escape around it, and the TCE must flow through the barrier slowly enough for the reactive iron to reduce it. To provide supporting knowledge, the USGS is refining and updating what is known about the local hydrogeology and developing a visual numerical model of the local ground-water system. The USGS is also working on a conceptual understanding of the regional ground-water flow system that interacts with the local flow system.

By reviewing and sometimes reconciling existing interpretations of geologic data from previous studies of the East Gate Disposal Yard area, by examining well drillers' logs not used in previous studies, and by scouring other sources of existing data, the USGS aims to define the three-dimensional geometry of the geologic units and their basic hydraulic properties. The existing understanding is based on data from about 90 wells; the USGS intends to analyze data from an additional 180 wells.

The new information will support the numerical model of the local ground-water system on which the permeable barrier design depends. In addition, by knowing where the aquifer is most accessible and thin, the barrier designers can save some of the cost of the reagent. It costs less to treat a thinner unit than a thicker one.

The USGS is also conducting a tracer study, putting a potassium bromide tracer into the injection wells upgradient of the East Gate Disposal Yard and looking for when and where the tracer appears in downgradient monitoring wells. The data from the tracer study of the rates and directions of the ground-water flow will help define the parameters of the local ground-water system's numerical model.

Incorporating new data from the thickness and depth study, the tracer study, and other sources, the USGS has converted an existing numerical model constructed by the Corps of Engineers into a new model with an interactive graphic display. The new model has already tested a 1994 finding of a window of permeable material in the confining layer between the upper and lower aquifers. Upcoming tests will simulate the differences in the ground-water flow system before and after remedial pumping began.

Photo by J.R. Lyles, USGS, April 1998

Raegan Sramek, USGS, lowers a passive diffusion sampler into a monitoring well to detect contaminant concentrations at different depths.

Thanks to the new technologies, "the Army's remediation goals are likely to be met much sooner than was imagined when the problem was first tackled a decade ago," says Sue Kahle, the USGS's project leader. "In addition, because the problem of TCE contamination is not unique to Fort Lewis, the treatment methods developed here will be ready to apply elsewhere."

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Sources

This report is based on talks with the USGS scientists leading the various studies. In addition, University of Washington scientists Lee Newman, Milton Gordon, and Stuart Strand, and Paul Heilman from Washington State University provided rich information about phytoremediation. Finally, the report also relies on these published reports:

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