BOARD OF WATER SUPPLY
KA 'OIHANA WAI
CITY AND COUNTY OF HONOLULU

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MEIA

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December 17, 2024

Roger Babcock, Jr., PhD, P.E.
Director
Department of Environmental Services
City and County of Honolulu
roger.babcock@honolulu.gov

SENT VIA EMAIL

Dear Dr. Babcock:

Subject: Mayor's December 10, 2024 Press Conference Announcing the Selection of Area Northwest of Wahiawā as City's Proposed New Landfill Site

The Honolulu Board of Water Supply (BWS) has reviewed the City and County of Honolulu's (City) December 10, 2024 announcement of a potential landfill site located in an area northwest of Wahiawā on agricultural land to the west of Kamehameha Highway, north of Pa'ala'a Uka Pūpūkea Road (previously referred to as "Area 3, Site 2" in the Mayor's Landfill Advisory Committee (LAC) June 2022 Final Recommendations Report, and reffered to herein as the "Proposed Landfill Site"). While BWS appreciates the difficulties associated with selecting a new landfill site, the position of the Office of the Manager and Chief Engineer (OMCE) on the Proposed Landfill Site has not changed. As you know, by letter dated November 16, 2022, I exercised my authority as Manager and Chief Engineer to formally disapprove the six landfill locations identified by the Department of Environmental Services (ENV), including the Proposed Landfill Site (Babcock, 2022), because operation of a new landfill at any of these locations may impact the quality and/or quanity of the water resources used or expected to be used as drinking water (Lau, 2022). Neither the City nor ENV sought reconsideration of that final decision.

Board of Water Supply's Legal Authority Concerning Plans Proposing Waste Disposal Facilities

BWS is authorized to establish "No Pass Zones," which generally prohibit the installation of waste disposal facilities in sensitive areas in order to protect O'ahu's critical underground drinking water resources from contamination. See BWS Rules and Regulations §3-301(2). BWS' Rules and Regulations further empower the Manager and Chief Engineer to disapprove proposed waste disposal facilities, including landfills, that may affect the quality and/or quanity of water resources used or expected to be

used for domestic water. See BWS Rules and Regulations §3-301(3). All six of the proposed landfill sites in the June 2022 Final Recommendations Report of the LAC are located above the BWS' No Pass Zone and over O'ahu's hydrogeologically-connected drinking water aquifer system. Accordingly, all six proposed landfill sites—including the Proposed Landfill Site—were disapproved in my November 2022 letter.

Never has the importance of this groundwater aquifer been more apparent, and never has our responsibilty to protect it been more paramount. As you know, the people of O'ahu are still coping with what the Hawai'i State Department of Health aptly described as "a humanitarian and environmental disaster," caused by fuel releases from the Navy's Red Hill Bulk Fuel Storage Facility (Red Hill), that resulted in the contamination of O'ahu's drinking water supply and the pollution of this island's irreplaceable sole-source groundwater aquifer. This unfortunate environmental catastrophe is a stark reminder that we all need to be proactive in protecting all of our precious drinking water resources from underground sources of contamination. O'ahu's aquifer cannot be replaced.

As we explained in prior correspondence and presentations to the LAC, BWS understands the need for a new landfill, as well as the challenges associated with finding a new landfill site. We also recognize that modern landfill design and engineering can attempt to reduce the risk that contaminant constituents will adversely impact the environment. However, the Proposed Landfill Site is located above the designated No Pass Zone and sits directly over O'ahu's drinking water aquifer system. The U.S. Geological Survey (USGS), citing EPA studies, has concluded that all landfills eventually will leak into the environment and that the fate and transport of leachate in the environment, from both old and modern landfills, are a potentially serious environmental problem (USGS, 2003).

Available data demonstrates that landfill leachates can and do contain a wide range of harmful inorganic and organic chemical constituents in varying concentrations—such as heavy metals, chlorides, volatile and semi-volatile organic, and per- and polyfluorinated substances (PFAS)—that, if released into the environment, have the potential to adversely affect drinking water resources. For example, the Waimānalo Gulch Sanitary Landfill generates approximately 3.6 million gallons of leachate annually that contains elevated concentrations of heavy metals, chlorides, sodium, total dissolved solids (TDS), phenols, and amines well above their respective EPA drinking water maximum contaminant levels (MCLs). Heavy rainfall can exacerbate landfill leachate containment problems. Indeed, intense storms that occured on O'ahu in December 2010 and January 2011 resulted in the generation of additional leachate at the Waimānalo Gulch Landfill and ultimately gave rise to illegal discharges of municipal debris, medical waste, and leachate to the nearby Waimānalo Gulch stream and ultimately the Pacific Ocean. Thus, leachate from the Propsed Landfill Site would constitute a significant source of potential contamination that could impact O'ahu's groundwater aquifer system.

Since O'ahu's groundwater is hydrogeologically-connected and groundwater is always moving, contamination in one part of the aquifer can spread to and impact other parts of the aquifer. Further, groundwater flow can be unpredictable and can move relatively

quickly (greater than ten feet per day in some instances). Because of this, contaminant migration along preferential flow paths will likely elude even a robust monitoring well network and undetected contaminants could make their way to drinking water production wells before any corrective action can occur. As a result, contamination from landfill leachate poses a considerable risk to both O'ahu's groundwater aquifer and drinking water resources. If such contamination were to occur, it could—as was the case for Red Hill—eventually cause BWS to shut down its water supply wells in the vicinity of the source of contamination at the landfill.

In sum, the No Pass Zone was established to protect O'ahu's drinking water from underground sources of contamination and there is a compelling basis upon which to expect that a landfill situation at the Proposed Landfill Site may impact the quality and/or quantity of the water resources used or expected to be used as drinking water. Accordingly, for the reasons provided in my November 16, 2022 letter (Lau, 2022) and reiterated above, I reaffirm my prior disapproval of the Proposed Landfill Site.

BWS is committed to safeguarding Hawai'i's critical drinking water resources for present and future generations and continues to urge ENV to explore new landfill sites that are below the No Pass Zone. If you have any questions, please feel free to contact me at (808) 748-5061.

Very truly yours,

Ernest Y.W. Lau, P.E.
Manager and Chief Engineer

Attachments:

1. Lau. 2022. Response to November 3, 2022 letter regarding BWS' official position on the six potential landfill sites, November 16, 2022.

2. Babcock. 2022. Request for clarity on BWS' legal authority over landfill siting and whether that authority was exercised and if not exercised, when the City should seek a determination, November 3, 2022.

3. Christenson, Scott C. and Cozzarelli, Isabelle M. Cozzarelli. The Norman Landfill Environmental Research Site: What Happens to the Waste in Landfills? USGS Fact Sheet 040-03, August 2003

cc: The Honorable Rick Blangiardi, Mayor, City and County of Honolulu
Michael D. Formby, Managing Director, City and County of Honolulu
Michael O'Keefe, Deputy Director, Department of Environmental Services
Nā'ālehu Anthony, BWS Board Chair

BOARD OF WATER SUPPLY

CITY AND COUNTY OF HONOLULU
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www.boardofwatersupply.com

November 16, 2022

Roger Babcock, Jr., Ph.D., P.E.
Director
City and County of Honolulu
Department of Environmental Services

Dear Dr. Babcock,

Subject: Response to November 3, 2022 Letter Regarding the Board of Water Supply's Official Position on the Six Potential Landfill Sites

The Honolulu Board of Water Supply (BWS) is in receipt of your November 3, 2022 letter, in which the City and County of Honolulu Department of Environmental Services (ENV) "formally ask[s] for the BWS' official position on the six potential landfill sites" that were evaluated by the Landfill Advisory Committee (LAC)[1] for possible use upon the closure of the Waimanalo Gulch Sanitary Landfill and "clarity on BWS' legal authority over landfill siting."[2] For the reasons set forth below, the BWS does not approve any of the six proposed landfill sites that are located above (or mauka) the No Pass Zone and over Oahu's drinking water aquifer system.

The Board of Water Supply's Legal Authority Concerning Plans Proposing Waste Disposal Facilities

Safeguarding Oahu's water supply from sources of potential contamination is not a matter of discretion; it is constitutionally mandated. The Hawaii Constitution guarantees that "[a]ll public natural resources are held in trust for the benefit of the people" and directs the State, and by extension the BWS, "to protect, control and regulate the use of Hawaii's water resources for the benefit of its people." Haw. Const. art. XI, §§ 1, 7. As the largest municipal drinking water utility in Hawaii, the BWS has a constitutional public trust responsibility to protect the water resources it manages and to preserve the rights of present and future generations in the waters of Hawaii. *See Kauai Springs, Inc. v. Planning Comm'n of Cnty. of Kauai,* 133 Haw. 141, 171, 324 P.3d 951 (2014) (holding

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[1] *See O'ahu Landfill Siting Study & Landfill Advisory Committee Recommendations: Final Report* (June 2022) ("LAC Final Report").

[2] At the October 28, 2022 meeting of the BWS Board of Directors, ENV posed similar questions during an item for information before BWS Board. However, ENV's November 3, 2022 letter is directed to the BWS Manager and Chief Engineer.

that the Hawaii State Constitution "mandates that the 'State and its subdivisions shall conserve and protect' the State's water resources" (emphasis in original)). Specifically, the State and the BWS have "the duty and authority to maintain the purity and flow of our waters for future generations and to assure that the waters of our land are put to reasonable and beneficial uses." *Id.* at 172.[3] Pertinent here, drinking water is among the highest beneficial uses of groundwater. *See In re Water Use Permit Application*, 94 Haw. 97, 136-37, 9 P.3d 409 (2000).[4]

Partially because of its public trust obligation to protect Oahu's drinking water, the BWS was granted the legal authority to "[p]rescribe and enforce rules and regulations having the force and effect of the law to carry out ... the prevention of waste and pollution of water ... and [] other matters having for their object the proper conservation and beneficial use of the water resources available for the city." Revised Charter of the City and County of Honolulu § 7-105(j) (*see also* H.R.S. § 54-33). To ensure that groundwater resources utilized for domestic purposes are protected, the BWS has exercised this authority to require that waste disposal facilities, including municipal landfills, can only be sited if the plans for the same receive written approval from the BWS Manager and Chief Engineer. BWS Rules and Regulations § 3-301(1).

The BWS' Rules and Regulations establish "No Pass Zones" which generally prohibit the installation of waste disposal facilities, including landfills, in areas that may contaminate groundwater resources used or expected to be used for domestic water supplies. *See* BWS Rules and Regulations Definitions, § 3-301(2).[5] The No Pass Zone was derived from the review of geologic maps and borings that define the areas of thick caprock around Oahu. Areas that are below (or makai) the No Pass Zone are primarily located on thick caprock. The caprock formation enables the aquifer to replenish within the No Pass Zone by restricting the seaward movement of infiltrated rainwater that falls on the island. The caprock also serves as a barrier to prevent surface contamination from reaching the underlying geology. Areas that are above the No Pass Zone, have no caprock and are located directly above groundwater that is used for drinking water. When making the decision to approve or disapprove plans proposing certain waste disposal facilities, the No Pass Zone must be considered and the Manager and Chief Engineer may, at his discretion, withhold approval "if there is any basis to expect that

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[3] The Supreme Court of Hawaii has made clear that this responsibility is "unlimited by any surface-ground distinction," extending to all water resources, including groundwater. *In re Water Use Permit Applications,* 94 Haw. 97, 133-135, 139, 9 P.3d 409 (2000).

[4] State policy for water resources in Hawaii is likewise directed toward achieving the highest water quality consistent with maximum benefit to the people of the State and "shall be liberally interpreted to obtain maximum beneficial use of the waters of the State ...." H.R.S. § 174C-2(c).

[5] The BWS Rules and Regulations are clear that the BWS "may establish 'No Pass Zones' which ... shall be used as guidelines in implementing this Section" regulating waste disposal facilities. BWS Rules and Regulations § 3-301(2) (emphasis added). No Pass Zone "means areas in which the installation of waste disposal facilities, which may contaminate groundwater resources used or expected to be used for domestic water supplies, shall be prohibited." *Id.* at Definitions (emphasis added).

the operation of the proposed waste disposal facility and any wastewater therefrom may to any degree affect the quality and/or quantity of water resources used or expected to be used for domestic water." BWS Rules and Regulations § 3-301(2)-(3).

The Board of Water Supply's Response to the Six Potential Landfill Sites Evaluated by the Landfill Advisory Committee

All six of the proposed landfill sites are located above the BWS' No Pass Zone, and all six of the proposed landfill sites are located over Oahu's hydrogeologically-connected drinking water aquifer system.[6] Never has the importance of this groundwater aquifer been more apparent, and never has our responsibility to protect it been more paramount. As you know, the people of Oahu are still coping with what the Hawaii Department of Health aptly described as "a humanitarian and environmental disaster" caused by fuel releases from the U.S. Navy's Red Hill Bulk Fuel Storage Facility that resulted in the contamination of Oahu's drinking water supply and the pollution of this island's irreplaceable sole-source groundwater aquifer. This unfortunate environmental catastrophe is a stark reminder that we all need to be proactive in protecting all of our precious drinking water resources from underground sources of contamination. Oahu's aquifer cannot be replaced.

As we explained in prior correspondence and presentations to the LAC, the BWS understands the need for a new landfill as well as the challenges associated with finding a new landfill site. We also recognize that modern landfill design and engineering can attempt to reduce the risk that contaminant constituents will adversely impact the environment. However, all six of the potential landfill sites evaluated by the LAC are located above the designated No Pass Zone and all six sit directly over Oahu's drinking water aquifer system. The United States Geological Survey (USGS), citing EPA studies, has concluded that all landfills eventually will leak into the environment and that the fate and transport of leachate in the environment, from both old and modern landfills, is a potentially serious environmental problem. USGS Fact Sheet FS-040-03 (Aug. 2003).

Available data demonstrates that landfill leachates can and do contain a wide range of harmful inorganic and organic chemical constituents in varying concentrations—such as heavy metals, chlorides, volatile and semi-volatile organic, and per- and polyfluorinated substances (PFAS)—that, if released into the environment, have the potential to

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[6] Two of these landfill sites also sit directly above Oahu's federally designated sole-source groundwater aquifer, the Southern Oahu Basal Aquifer, from which the BWS supplies 77 percent of the total island-wide water supply. In 1987, the United States Environmental Protection Agency (EPA) determined that this hydrogeologically-connected aquifer is the "principal source of drinking water" for the island, and that "[i]f contaminated, would create a significant hazard to public health." Southern Oahu Basal Aquifer in the Peart Harbor Area at Oahu; Principal Source Aquifer Determination, 52 Fed. Reg. 45496, at 45497 (Nov. 30, 1987).

adversely affect drinking water resources.[7] For example, the Waimanalo Gulch Sanitary Landfill generates approximately 3.6 million gallons of leachate annually that contains elevated concentrations of heavy metals, chlorides, sodium, total dissolved solids (TDS), phenols, and amines well above their respective EPA drinking water maximum contaminant levels (MCLs).[8] Heavy rainfall can exacerbate landfill leachate containment problems. Indeed, intense storms that occurred on Oahu in December 2010 and January 2011 resulted in the generation of additional leachate at the Waimanalo Gulch Landfill and ultimately gave rise to illegal discharges of municipal debris, medical waste, and leachate to the nearby Waimanalo Gulch stream and ultimately the Pacific Ocean.[9] Thus, leachate from any of the proposed landfill sites would constitute a significant source of potential contamination that could impact Oahu's groundwater aquifer system.

Since Oahu's groundwater is hydrogeologically connected and groundwater is always moving, contamination in one part of the aquifer can spread to and impact other parts of the aquifer. Further, groundwater flow can be unpredictable and can move relatively quickly (greater than ten feet per day in some instances). Because of this, contaminant migration along preferential flow paths will likely elude even a robust monitoring well network, and undetected contaminants could make their way to drinking water production wells before any corrective action can occur. As a result, contamination from landfill leachate poses a considerable risk to both Oahu's groundwater aquifer and drinking water resources. If such contamination were to occur, it could—as was the case for Red Hill—eventually cause the BWS to shut down its water supply wells in the vicinity of the source of contamination at the landfill.

Accordingly, there is a compelling basis upon which to expect that any landfill sited at one of the six locations proposed by ENV may impact the quality and/or quantity of the water resources used or expected to be used as drinking water. *See* BWS Rules and

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[7] Aptim. 2021. First Semi-Annual 2021 Monitoring Report, Waimanalo Gulch Sanitary Landfill, Kapolei, Oahu, Hawaii. Prepared for Waste Management of Hawaii. August 2021. Submitted to the State of Hawaii Department of Health, Solid & Hazardous Waste Branch on August 23, 2021 (https://www.honolulu.gov/rep/site/env/envref/envref_docs/WGSL_1SA21_GWMR_Final.pdf); United States Environmental Protection Agency (EPA). 2020. Interim Guidance on the Destruction and Disposal of Perfluoroalkyl and Polyfluoroalkyl Substances and Materials Containing Perfluoroalkyl and Polyfluoroalkyl Substances. Interim Guidance for Public Comment. December 18, 2020 (https://www.epa.gov/system/files/documents/2021-11/epa-hq-olem-2020-0527-0002_content.pdf); Michigan Waste & Recycling Association. 2019. Statewide Study on Landfill Leachate PFOA and PFOS Impact on Water Resource Recovery Facility Influent. Technical Report. Completed in Collaboration with Michigan Department of Environmental Quality. March 1 (Section Revision March 6) (https://www.bridgemi.com/sites/default/files/mwra-technical-report.pdf).

[8] *Id.*

[9] Complaint ¶¶ 20-25, 54-63, 82-88, *United States v. Waste Management of Haw.*, No 19-224 (D. Haw. 2019); Margo Perez-Sullivan, *EPA Resolves Clean Water Act Violations with Honolulu and Waste Management at Waimanalo Gulch Landfill*, EPA (Apr. 29, 2019), https://www.epa.gov/newsreleases/epa-resolves-clean-water-act-violations-honolulu-and-waste-management-waimanalo-gulch.

Regulations § 3-301(3). Upon due consideration of the requisite guidelines and pertinent factors, the BWS must disapprove all six of the proposed landfill sites above the No Pass Zone.[10]

The No Pass Zone was established to protect Oahu's drinking water from underground sources of contamination. The BWS continues to urge ENV to explore new landfill sites that are below the No Pass Zone, including, where appropriate, requesting additional time from the Land Use Commission to explore other siting options.

If you have any questions, please feel free to contact me at (808) 748-5061.

Very truly yours,

ERNEST Y.W. LAU, P.E.
Manager and Chief Engineer

cc.: The Honorable Rick Blangiardi, Mayor, City and County of Honolulu
Michael D. Formby, Managing Director, Department of Environmental Services
Michael O'Keefe, Deputy Director, Department of Environmental Services
Brian Andaya, Chair, BWS
Erwin Kawata, Deputy Manager, BWS

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[10] The City Council of the City and County of Honolulu agreed when it adopted Resolution 03-09, FD1 (April 16, 2003). In that resolution, the Council resolved to establish a policy "of the city that municipal solid waste landfills should not be located anywhere ... within the [BWS'] groundwater protection zone, or over any of the City's drinking water sources." This resolution was partially a result of the Council's finding that "there is no current landfill technology that can guarantee that hazardous or other harmful substances from a ... landfill placed over the city's aquifer will not, over the long-term, enter the city's drinking water sources and pose a risk to the public health and welfare of Honolulu's citizens."

The LAC came to similar a conclusion in its Final Report, specifically noting the importance of the "Board of Water Supply No Pass Zone" in not recommending any of the final landfill sites. Indeed, "[a]ll LAC members expressed concerns related to the location of the proposed sites in the No Pass Zone and, consequently, the potential implications for O'ahu's drinking water resources" (LAC Final Report 1-4) and "[t]he LAC strongly felt that they could not support a landfill sited within the BWS No Pass Zone due to their convictions in ensuring preservation of groundwater resources on O'ahu" (LAC Final Report 6-4).

DEPARTMENT OF ENVIRONMENTAL SERVICES
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RICK BLANGIARDI
MAYOR

ROGER BABCOCK, JR., Ph.D., P.E.
DIRECTOR

MICHAEL O'KEEFE
DEPUTY DIRECTOR

IN REPLY REFER TO:
DIR 22-88

November 3, 2022

SENT VIA EMAIL

Ernest Y. W. Lau, P.E.
Manager and Chief Engineer
Honolulu Board of Water Supply
elau@hbws.org

Dear Ernest:

Thank you for your time and attention during the October 24, 2022, Board of Water Supply (BWS) board meeting. This letter follows up on the item for information, "Briefing by the Department of Environmental Services on their Landfill Siting" that was on that meeting's agenda.

At that meeting we briefed the board that BWS presented on groundwater and landfills to the Landfill Advisory Committee (LAC) and the LAC, based on BWS' presentation, despite evaluating and ranking six sites did not recommend any of the six sites as an alternative to the existing landfill (please see attachment A for final report).

Given this sequence of events, at the October 24 BWS board meeting, I requested clarity on BWS' legal authority over landfill siting and whether that authority was exercised, and if not exercised, when the City should seek a determination.

In order to clarify BWS' position and due to the impending deadline set by the State Land Use Commission Decision and Order for the Department of Environmental Services to "identify an alternative landfill site that may be used upon closure of WGSL [Waimanalo Gulch Sanitary Landfill]" by December 31, 2022, I am writing this letter to formally ask for BWS' official position on the six potential landfill sites (please see attachment B for details on those six sites) the LAC evaluated. Specifically, were Mayor to select any of the six ranked sites off the LAC's list, what would be BWS' official response or position?

Given the timeline before us, I would appreciate a response as soon as possible. Please contact me at 768-3486 if you have any questions with respect to the foregoing.

Sincerely,

Digitally signed by O'Keefe, Michael
Date: 2022.11.03 11:33:02 -10'00'

For Roger Babcock, Jr., Ph.D., P.E.
Director

APPROVED:

Digitally signed by Formby, Michael
Date: 2022.11.03 13:59:17 -10'00'

Michael D. Formby, Managing Director
Office of the Managing Director

Attachments: A - LAC Report Here
B - Sites

cc: Rick Blangiardi, Mayor
Brian Andaya, Chair, Board of Water Supply

Figure 4.9 Location of Area 2, Site 1

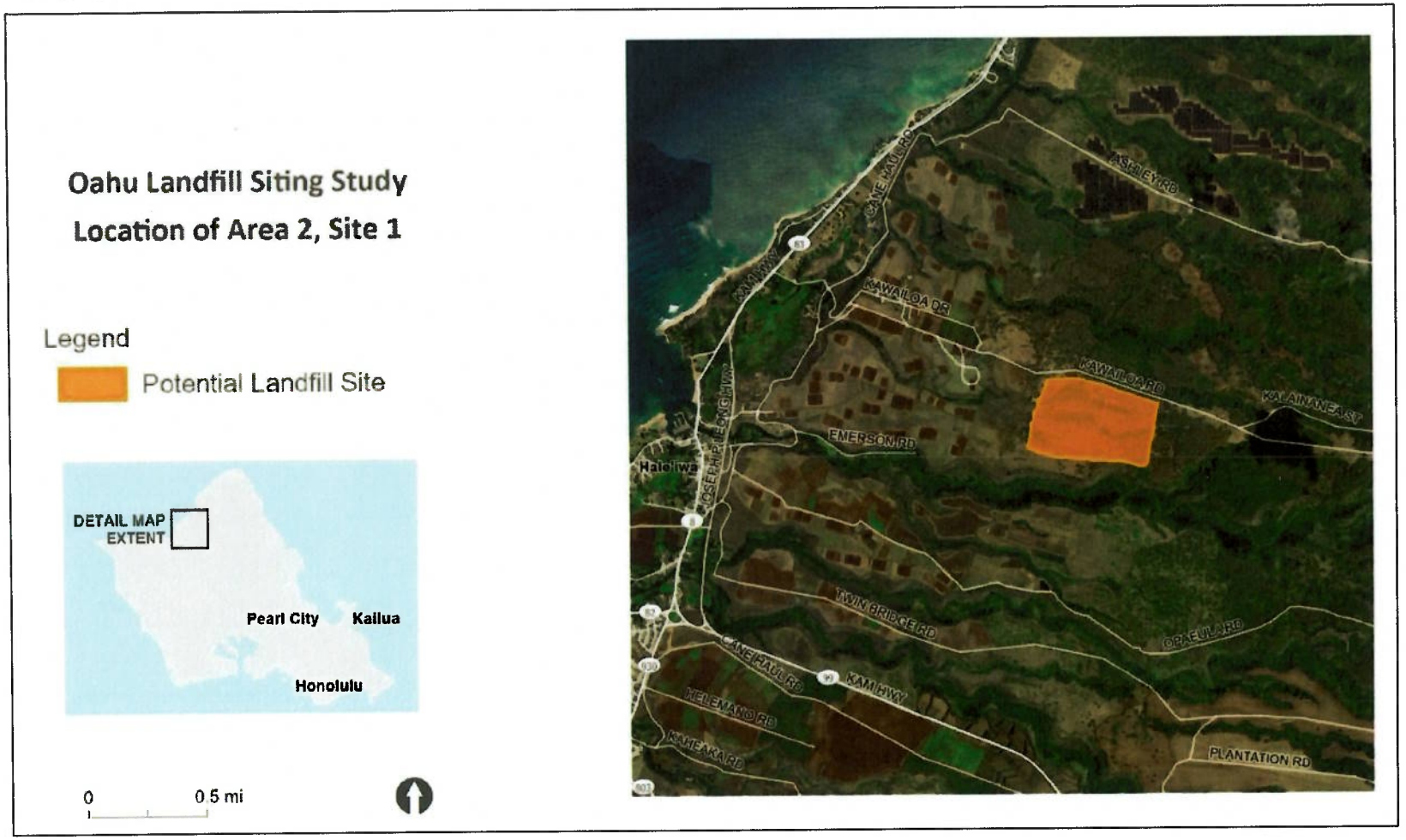


Figure 4.10 Locations of Area 3, Sites 1 through 3

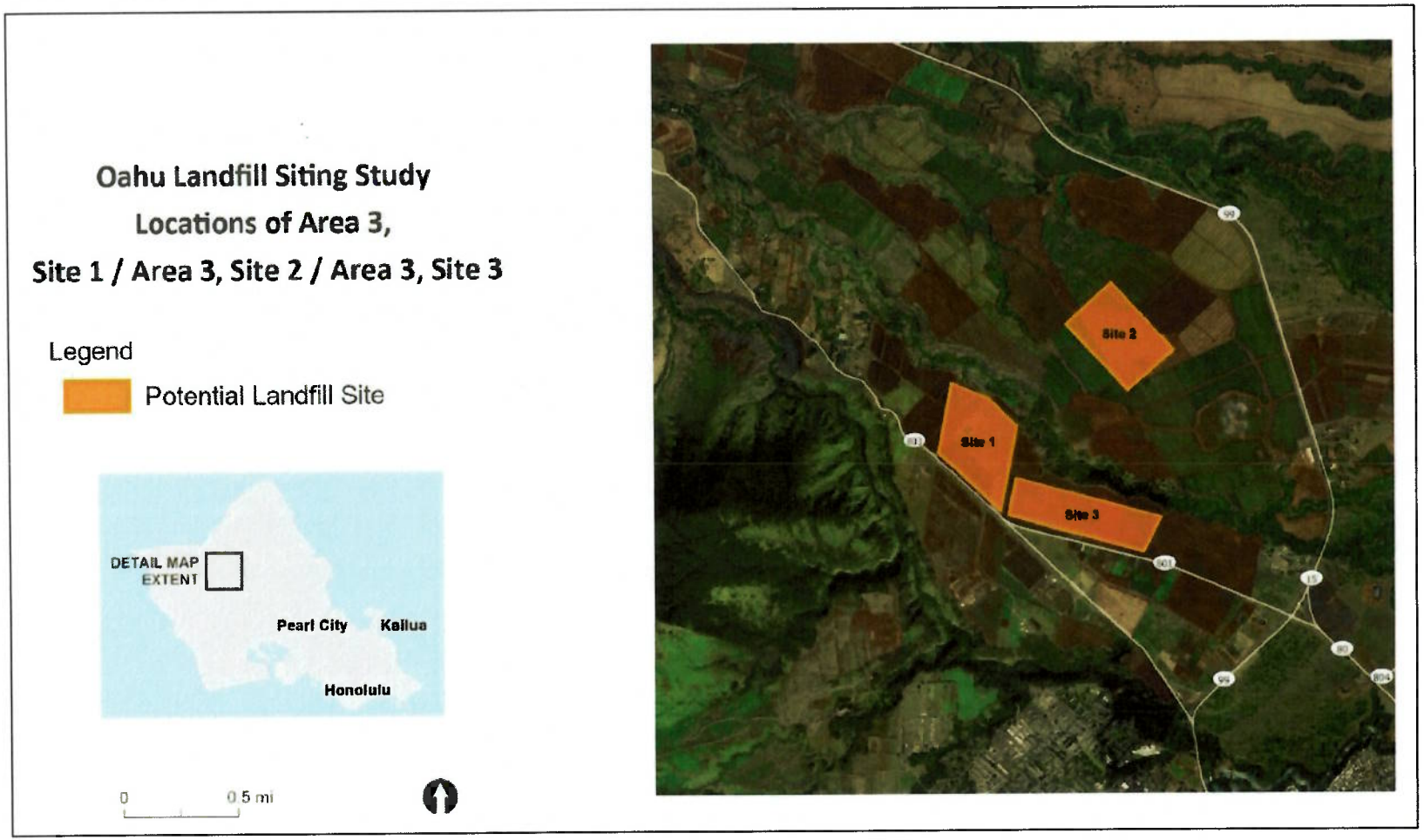


Figure 4.11 Location of Area 6, Site 1

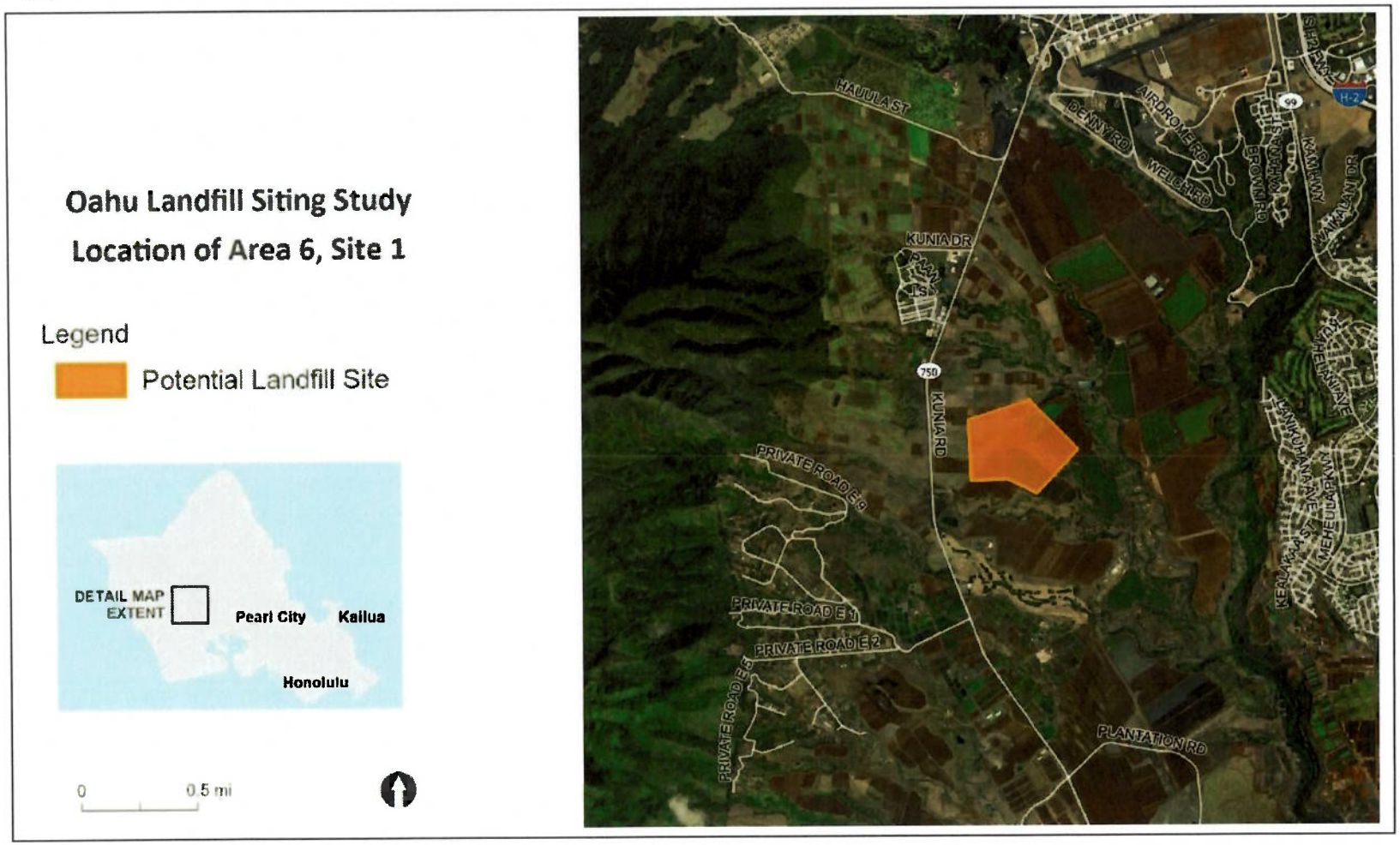
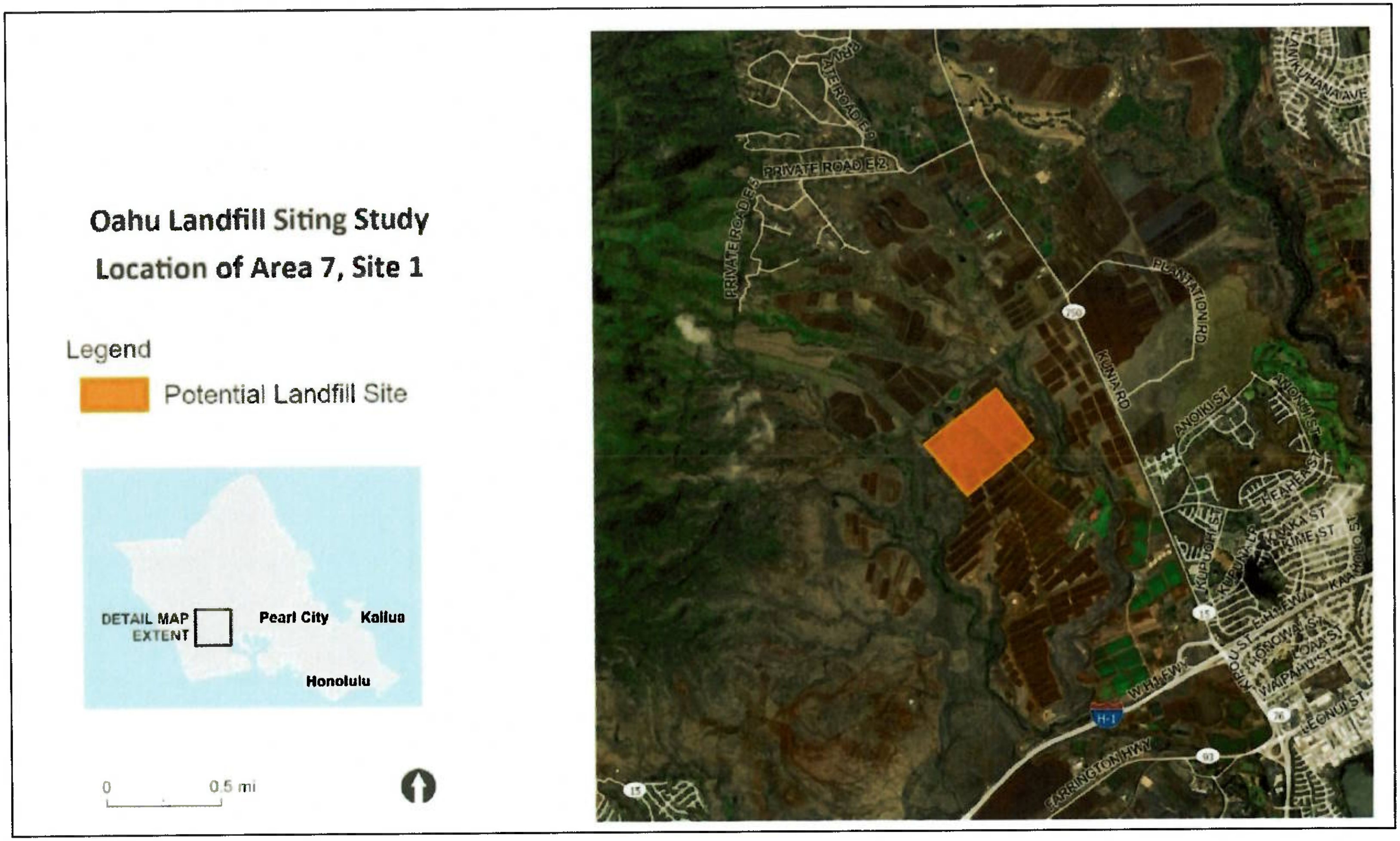


Figure 4.12 Location of Area 7, Site 1



USGS
science for a changing world

The Norman Landfill Environmental Research Site: What Happens to the Waste in Landfills?

By Scott C. Christenson and Isabelle M. Cozzarelli

DO LANDFILLS LEAK?

We call it "garbage" or "trash" but it is "municipal solid waste" to your city government and the waste industry. Municipal solid waste is a combination of non-hazardous wastes from households, commercial properties, and industries. The U.S. Environmental Protection Agency (USEPA) reports that the United States produced about 230 million tons of solid waste in 1999, about 57 percent of which is disposed of in landfills (U.S. Environmental Protection Agency, 1999).

Disposal of municipal solid waste in landfills was largely unregulated prior to the 1970s. Most solid waste was deposited in unlined pits. Precipitation and ground water seeping through this waste produces leachate, which is water contaminated from the various organic and inorganic substances with which it comes in contact as it migrates through the waste. Leachate seeping from a landfill contaminates the ground water beneath the landfill, and this contaminated ground water is known as a plume. The normal movement of ground water causes the leachate plume to extend away from a landfill, in some cases for many hundreds of meters. Many studies have shown leachate plumes emanating from old unlined landfills. Estimates for the number of closed landfills in the United States are as high as 100,000 (Suflita and others, 1992).

Federal and state regulations were passed in the 1980s and 1990s to manage disposal of solid waste. Those regulations require that most landfills use liners and leachate collection systems to minimize the seepage of leachate to ground water. Although liners and leachate collection systems minimize leakage, liners can fail and leachate collection systems may not collect all the leachate that escapes from a landfill. Leachate collection systems require maintenance of pipes, and pipes can fail because they crack, collapse, or fill with sediment. The USEPA has concluded that all landfills eventually will leak into the environment (U.S. Environmental Protection Agency, 1988). Thus, the fate and transport of leachate in the environment, from both old and modern landfills, is a potentially serious environmental problem.

STUDYING LEACHATE PLUMES AT A MUNICIPAL SOLID-WASTE LANDFILL

The Norman Landfill Environmental Research Site

The Norman Landfill (fig. 1) is a closed municipal solid waste landfill, formerly operated by the city of Norman, Oklahoma. The landfill is sited directly on the Canadian River alluvial aquifer and has no liner or leachate collection system, so a leachate plume has developed in ground water in the aquifer. The ground water and leachate plume flow away from the landfill toward the Canadian River, a large tributary of the Arkansas River that drains into the Mississippi River.

The Norman Landfill was designated a research site by the U.S. Geological Survey (USGS) through its Toxic Substances Hydrology Research Program. Monitoring wells and instruments have been installed in and adjacent to the leachate plume. A small stream and wetland overlie the leachate plume, and studies are in progress to determine the fate of leachate compounds that enter the wetland from the ground water. USGS hydrologists and technicians have accomplished comprehensive site characterization, which provides a wealth of information about the site hydrogeology and geochemistry. This site

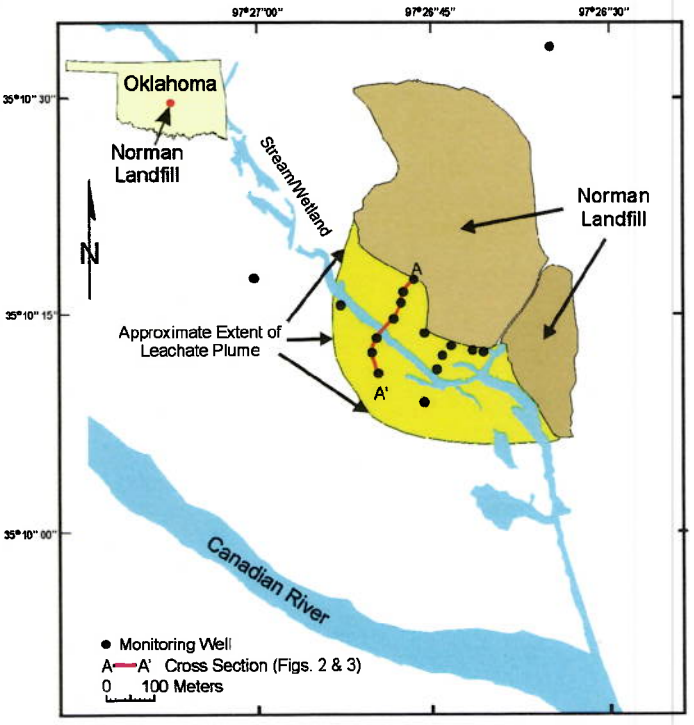


Figure 1. Map of the Norman Landfill Environmental Research Site.

characterization provides essential information to the scientists conducting research about the chemical, biological, and hydrologic processes in ground water and surface water affected by landfill leachate. Research is in progress at the site by scientists from the University of Oklahoma, Oklahoma State University, other universities, the USEPA, and the USGS.

In addition to providing a laboratory for studies of ground and surface water contaminated by landfill leachate, the Norman Landfill Environmental Research Site is used to study other types of contaminant problems. The plume can be used to study microbiological and geochemical processes that are not specific to landfills.

All research at the Norman Landfill Environmental Research

Site is designed to investigate problems and processes that have a high transfer value to other subsurface contamination problems. Comprehensive physical, chemical, and microbial characterizations at this and other USGS Toxic Substances Hydrology Program sites provide fundamental knowledge of the processes that control important types of contamination problems. This knowledge of fundamental processes can be generalized to a wide range of field conditions by comparing results to field and laboratory experiments at other sites with differing conditions and properties. The resulting knowledge and methods improve the effectiveness and reduce the cost of characterization and remediation at contaminated sites across the nation.

NATURAL ATTENUATION

Can Microorganisms Reduce Landfill Contaminants?

Scientists who investigate environmental contamination problems are interested in an environmental cleanup approach known as natural attenuation. Natural attenuation refers to naturally occurring physical, chemical, and biological processes that can reduce concentrations of contaminants. In most contaminated aquifers, one aspect of natural attenuation involves the degradation of contaminants by microorganisms, which in some instances prevents contaminant migration. These microorganisms are naturally present in aquifers, even deep below the surface of the earth.

Natural attenuation can be a better alternative for remediation of certain types of contaminants compared to other methods of remediating contaminated ground water. Natural attenuation can be less expensive and more effective than other methods, such as extracting contaminated ground water with wells and treating it at water treatment plants. Much of the research at the Norman Landfill Environmental Research Site investigates different aspects of natural attenuation.

BIOGEOCHEMICAL ZONES

Where Does Natural Attenuation Occur?

University of Oklahoma and USGS scientists used a combined microbiological and geochemical approach to identify the important processes occurring in the aquifer contaminated by leachate from the Norman Landfill (Cozzarelli and others, 2000, Harris and others, 1999). The combined sciences of microbiology and geochemistry are called biogeochemistry. The Norman Landfill researchers identified zones in the leachate plume at Norman Landfill where different biogeochemical processes are occurring.

One method to identify different biogeochemical zones is to measure the concentration of certain chemicals and minerals, those that are involved in biogeochemical processes, in the ground water and in the aquifer. Electron acceptors are minerals or chemicals that can occur naturally in aquifer solids or ground water, such as iron oxides in the sediments or sulfate dissolved in ground water. These chemicals are called electron acceptors because microorganisms transfer electrons to them during respiration, which is part of the process the microorganisms use to obtain energy. During respiration, an electron is transferred from an electron donor, such as an organic contaminant compound, to an electron acceptor. This electron transfer occurs when microorganisms break down organic contaminant compounds. The availability of electron acceptors in an aquifer is therefore an important factor for evaluating the effectiveness and sustainability of natural attenuation in contaminated aquifers.

Some evidence of natural attenuation at Norman Landfill is shown in figure 2 (Cozzarelli and others, 2000), illustrated as generalized hydrogeologic sections through the leachate plume in the aquifer. The three illustrations within figure 2 show chemical concentrations of important indicators of natural attenuation processes along the same vertical slice of the aquifer. These illustrations demonstrate that the leachate plume begins near

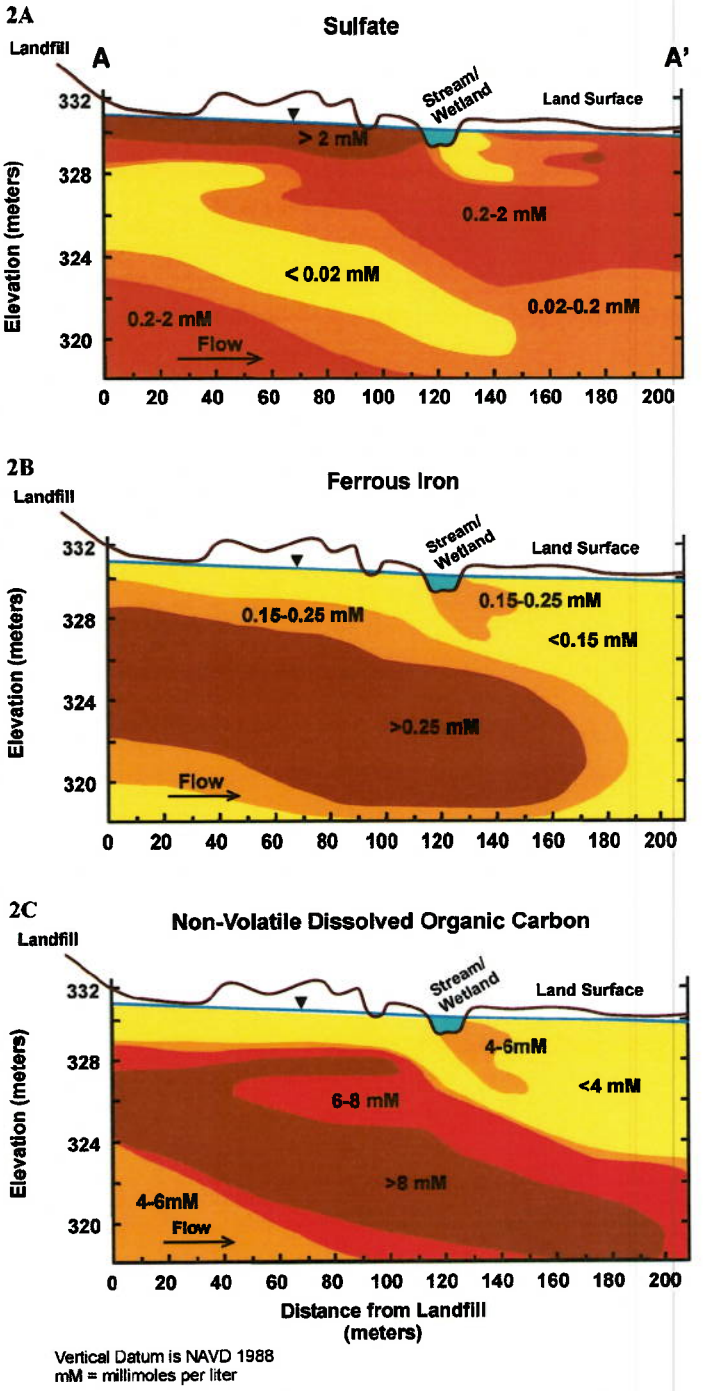


Figure 2. Concentrations of electron acceptors and donors in the Norman Landfill leachate plume.

the surface (on the left side of the figure), where the solid waste is stored in the landfill. Ground water flows to the south toward the Canadian River. The leachate plume migrates toward the bottom of the aquifer as it flows toward the river.

Sulfate occurs naturally in ground water in the Canadian River alluvial aquifer. Sulfate is depleted in the center of the

leachate plume (fig. 2A) because the microorganisms use sulfate as an electron acceptor. When microorganisms transfer electrons to sulfate, sulfate changes chemically to form dissolved sulfide or hydrogen sulfide gas. The highest rates of sulfate reduction have been measured at the plume boundaries, such as where fresh water from rainfall infiltrating the aquifer mixes with the contaminant plume (Cozzarelli and others, 2000), and causes the sharp concentration gradients observed in figure 2A. The degradation of organic contaminants occurs most rapidly at the plume boundaries.

Iron occurs naturally as mineral coatings on sediments in the Canadian River alluvial aquifer. Dissolved iron concentrations increase in the leachate plume (fig. 2B) because microorganisms transfer electrons to the iron on the mineral coatings, which contain insoluble ferric iron, while degrading the organic contaminants. With the addition of an electron, the iron is reduced to ferrous iron, which dissolves in water. Although the solid-phase electron acceptor (ferric iron) cannot be measured in the ground water, the detection of the end product of the reaction (ferrous iron) in water provides evidence that iron reduction has occurred.

The concentration of non-volatile dissolved organic carbon (NVDOC) is shown in figure 2C. NVDOC is a measure of the organic contaminant compounds in the landfill. In the center of the plume, the concentration of NVDOC shows little change with distance, indicating that NVDOC is not efficiently degraded in this zone.

Researchers at Norman Landfill have learned that most of the natural attenuation occurs at the boundaries of the plume where electron acceptors are available. Sulfate concentrations are low in the center of the plume, as are measured rates of iron and sulfate reduction. The natural attenuation capacity of the aquifer, that is, its ability to attenuate contaminants, is depleted in the center of the leachate plume because microorganisms have used all the electron acceptors during migration of the leachate plume.

VOLATILE ORGANIC COMPOUNDS

Evidence for Natural Attenuation

USGS scientists have been investigating volatile organic compounds (VOCs) in the leachate at Norman Landfill (Eganhouse and others, 2001). VOCs are organic compounds that tend to vaporize at room temperature and pressure. Examples of VOCs include some of the compounds in gasoline, lubricants, paints, and solvents. Some VOCs are highly toxic or carcinogenic. VOCs end up in landfills in many ways, including the disposal of ordinary household items such as cleaners or marking pens. Although VOCs make up less than 0.1 percent of the mass of organic carbon in the leachate plume, they are useful indicators of natural attenuation.

At Norman Landfill, USGS scientists compared concentrations of two different alkylbenzene isomers, *n*-propylbenzene and *i*-propylbenzene, in landfill leachate. Isomers of alkylbenzene have the same number and type of atoms, but the molecules have slightly different chemical structures. These different isomers have similar physical properties, so they should be affected by volatilization, dilution, and sorption in a similar manner. The concentration of *n*-propylbenzene decreases much faster as leachate flows away from the landfill than does the concentration of *i*-propylbenzene (fig. 3). This decrease in concentration of *n*-propylbenzene is caused by biological degradation, indicating that biologically mediated natural attenuation is decreasing the concentrations of some contaminants at Norman Landfill. This technique of comparing alkylbenzene isomers as indicators of biological processes can be applied at sites with contaminants other than landfill leachate.

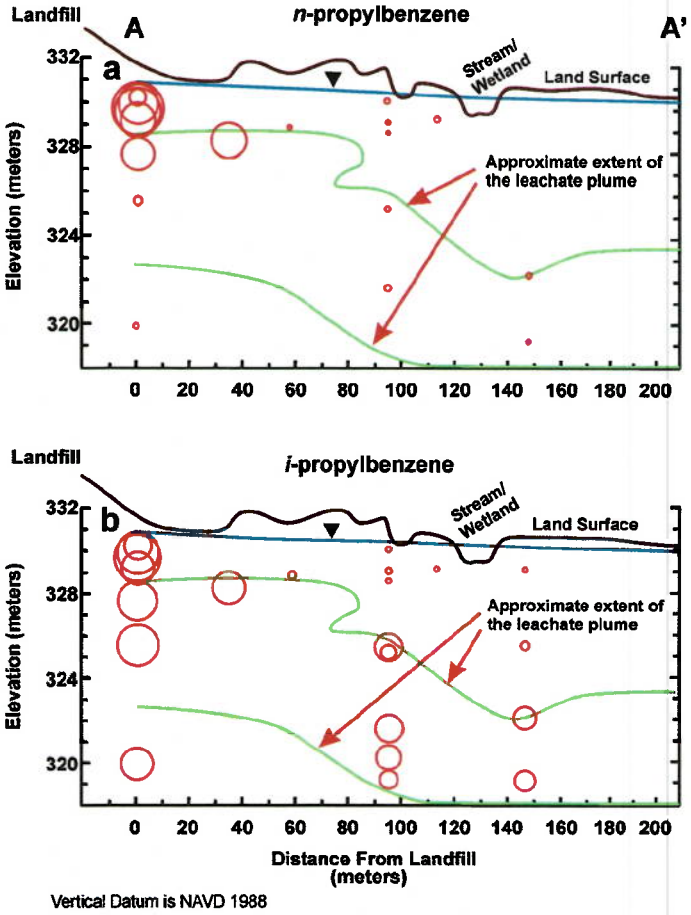


Figure 3. Distribution of the alkylbenzene isomers (a) *n*-propylbenzene and (b) *i*-propylbenzene in the leachate plume at Norman Landfill. Concentrations in micrograms per liter (μg/L) are proportional to bubble diameter. Maximum concentration: *n*-propylbenzene = 0.80 μg/L, *i*-propylbenzene = 1.24 μg/L (from Eganhouse and others, 2001).

INVESTIGATING THE SUBSURFACE TO REVEAL THE RATE OF NATURAL ATTENUATION

Field experiments are being carried out at Norman Landfill to investigate how the rate of natural attenuation may vary with aquifer permeability (permeability is a measure of the ability of a material to transmit fluid). These experiments use push-pull or single-well injection-withdrawal tests (Istok and others, 1997). During the injection phase of the test, a solution consisting of ground water amended with tracers, electron donors, or electron acceptors is injected or "pushed" through a well into the aquifer. During the extraction phase, the test solution is pumped or "pulled" from the same well. Concentrations of tracers, reactants, and possible reaction products are measured as a function of time in order to construct breakthrough curves, measure reaction rates, and to compute mass balances for each solute.

These tests can be conducted anywhere in the aquifer, making it possible to investigate processes and rates in different geologic textures and geochemical environments.

Push-pull tests were conducted at Norman Landfill to measure biodegradation rates of simple organic acids in the leachate plume (Scholl and others, 2001). Wells were drilled into layers of three different types of sediments (medium sand, silt/clay lenses in sand, and poorly sorted gravel), each with a different permeability. Biodegradation rates of two simple organic acids, formate and lactate, were compared in the three different zones in the anoxic leachate plume at the site. These organic acids were used as microbial process indicators because they degrade at different rates depending on the dominant microbial processes. A conservative tracer (bromide) and the two organic acids were added to 50 or 100 liters of contaminated ground water pumped from each test well. The mixture was then re-injected and allowed to mix with the natural ground water. Daily samples were taken from the injection well until organic acids could no longer be detected. Although complete disappearance of the formate and lactate occurred within 7-9 days in all the wells, there were differences in degradation patterns. The results of the test show that the loss of lactate was due to natural attenuation and that there are differences in the rate of natural attenuation in areas of different permeability. These variable degradation rates may be related to microbial community structure, sediment chemistry, and water flow regime.

IMPLICATIONS

Research at the Norman Landfill Environmental Research Site has shown that chemicals leaching from old unlined landfills are contaminating ground water, but that some of the contaminant concentrations are being reduced by natural attenuation. Modern landfills are designed to minimize contamination of ground water, but modern landfills eventually may leak contaminants into the environment. Research results from Norman Landfill will be useful to scientists and regulators trying to determine the effects of landfill leachate on the environment.

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USGS Norman Landfill World Wide Web Sites:
Oklahoma District: http://ok.water.usgs.gov/norlan/
National Research Program: http://water.usgs.gov/nrp/organic/norman.htm