From: Joel Geier
To: Benton Public Comment
Subject: LU-24-027 Document on issue of landfill liner failures and difficulty of leak detection
Date: Tuesday, July 1, 2025 11:23:19 AM
Attachments: Landfill_Failures_-_PUB_009.pdf

CAUTION: This email originated from outside of the organization. Do not click links or open attachments unless you recognize the sender and know the content is safe.

Dear Chair Fowler and members of the Planning Commission:

I apologize for dropping this nearly 200 page document (Center for Health, Environment & JusticeFactPack - PUB 009) on you, at this late point in the process. But it contains several articles describing general problems with landfill liners, as well as the difficulty of leak detection, which are written in lay terms that might be more accessible than more specialized scientific literature on these topics.

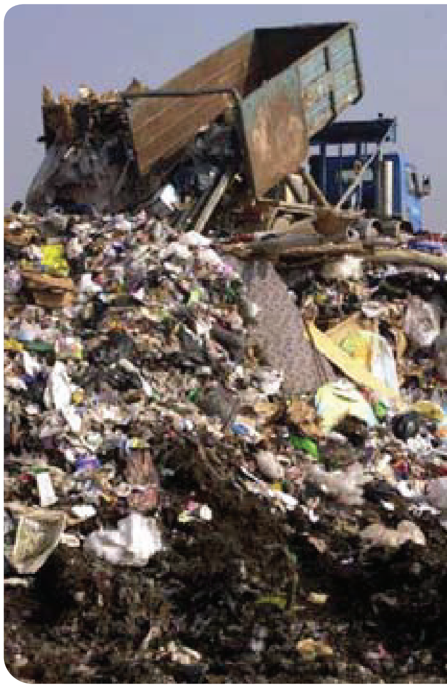
I will be referencing several of these articles in more detailed technical testimony (likely submitted by hand, due to the county's cutoff of e-mail submissions) regarding the effectiveness of the Applicant's groundwater monitoring program, and the inadequacy of their proposal to add a few "sentinel wells." Of particular interest are the articles that summarize peer-reviewed scientific research on the difficulty of detecting contaminant plumes with a few widely spaced wells.

These issues arise even for relatively uniform sediments (such as the Willamette Basin sediments east of Coffin Butte Landfill), but become worse in fractured rock (such as under Tampico Ridge) where flow paths for groundwater are much more irregular and essentially unpredictable, without very detailed geoscientific investigations.

Yours sincerely,
Joel Geier, Ph.D (geology/hydrogeology)
38566 Hwy 99W
Corvallis OR 97330

Landfill Failures
The Buried Truth

FactPack – P009



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Landfill Failures
the Buried Truth

Center for Health, Environment & Justice
FactPack - PUB 009

August 2019

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Mentoring a Movement

Empowering People

Preventing Harm

About the Center for Health, Environment & Justice

CHEJ mentors the movement to build healthier communities by empowering people to prevent the harm caused by chemical and toxic threats. We accomplish our work by connecting local community groups to national initiatives and corporate campaigns. CHEJ works with communities to empower groups by providing the tools, strategic vision, and encouragement they need to advocate for human health and the prevention of harm.

Following her successful effort to prevent further harm for families living in contaminated Love Canal, Lois Gibbs founded CHEJ in 1981 to continue the journey. To date, CHEJ has assisted over 15,000 groups nationwide. Details on CHEJ's efforts to help families and communities prevent harm can be found on www.chej.org.

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WHAT IS A LANDFILL?
A secure landfill is a carefully engineered depression in the ground (or built on top of the ground, resembling a football stadium) into which wastes are put. The aim is to avoid any hydraulic [water-related] connection between the wastes and the surrounding environment, particularly groundwater. Basically, a landfill is a bathtub in the ground; a double-lined landfill is one bathtub inside another. Bathtubs leak two ways: out the bottom or over the top.

WHAT IS THE COMPOSITION OF A LANDFILL?
There are four critical elements in a secure landfill: a bottom liner, a leachate collection system, a cover, and the natural hydrogeologic setting. The natural setting can be selected to minimize the possibility of wastes escaping to groundwater beneath a landfill. The three other elements must be engineered. Each of these elements is critical to success.

THE NATURAL HYDROGEOLOGIC SETTING:
You want the geology to do two contradictory things for you. To prevent the wastes from escaping, you want rocks as tight (waterproof) as possible. Yet if leakage occurs, you want the geology to be as simple as possible so you can easily predict where the wastes will go. Then you can put down wells and capture the escaped wastes by pumping. Fractured bedrock is highly undesirable beneath a landfill because the wastes cannot be located if they escape. Mines and quarries should be avoided because they frequently contact the groundwater.

WHAT IS A BOTTOM LINER?
It may be one or more layers of clay or a synthetic flexible membrane (or a combination of these). The liner effectively creates a bathtub in the ground. If the bottom liner fails, wastes will migrate directly into the environment. There are three types of liners: clay, plastic, and composite.

WHAT IS WRONG WITH A CLAY LINER?
Natural clay is often fractured and cracked. A mechanism called diffusion will move organic chemicals like benzene through a three-foot thick clay landfill liner in approximately five years. Some chemicals can degrade clay.

WHAT IS WRONG WITH A PLASTIC LINER?
The very best landfill liners today are made of a tough plastic fi lm called high density polyethylene (HDPE). A number of household chemicals will degrade HDPE, permeating it (passing though it), making it lose its strength, softening it, or making it become brittle and crack. Not only will household chemicals, such as moth balls, degrade HDPE, but much more benign things can cause it to develop stress cracks, such as, margarine, vinegar, ethyl alcohol (booze), shoe polish, peppermint oil, to name a few.

WHAT IS WRONG WITH COMPOSITE LINERS?
A Composite liner is a single liner made of two parts, a plastic liner and compacted soil (usually clay soil). Reports show that all plastic liners (also called Flexible Membrane Liners, or FMLs) will have some leaks. It is important to realize that all materials used as liners are at least slightly permeable to

liquids or gases and a certain amount of permeation through liners should be expected. Additional leakage results from defects such as cracks, holes, and faulty seams. Studies show that a 10-acre landfill will have a leak rate somewhere between 0.2 and 10 gallons per day.

WHAT IS A LEACHATE COLLECTION SYSTEM?

Leachate is water that gets badly contaminated by contacting wastes. It seeps to the bottom of a landfill and is collected by a system of pipes. The bottom of the landfill is sloped; pipes laid along the bottom capture contaminated water and other fluid (leachate) as they accumulate. The pumped leachate is treated at a wastewater treatment plant (and the solids removed from the leachate during this step are returned to the landfill, or are sent to some other landfill). If leachate collection pipes clog up and leachate remains in the landfill, fluids can build up in the bathtub. The resulting liquid pressure becomes the main force driving waste out the bottom of the landfill when the bottom liner fails.

WHAT ARE SOME OF THE PROBLEMS WITH LEACHATE COLLECTION SYSTEMS?

Leachate collection systems can clog up in less than a decade. They fail in several known ways: they clog up from silt or mud; they can clog up because of growth of microorganisms in the pipes; they can clog up because of a chemical reaction leading to the precipitation of minerals in the pipes; or the pipes become weakened by chemical attack (acids, solvents, oxidizing agents, or corrosion) and may then be crushed by the tons of garbage piled on them.

WHAT IS A COVER?

A cover or cap is an umbrella over the landfill to keep water out (to prevent leachate formation). It will generally consist of several sloped layers: clay or membrane liner (to prevent rain from intruding), overlain by a very permeable layer of sandy or gravelly soil (to promote rain runoff), overlain by topsoil in which vegetation can root (to stabilize the underlying layers of the cover). If the cover (cap) is not maintained, rain will enter the landfill resulting in buildup of leachate to the point where the bathtub overflows its sides and wastes enter the environment.

WHAT ARE THE PROBLEMS WITH COVERS?

Covers are vulnerable to attack from at least seven sources: 1) Erosion by natural weathering (rain, hail, snow, freeze-thaw cycles, and wind); 2) Vegetation, such as shrubs and trees that continually compete with grasses for available space, sending down roots that will relentlessly seek to penetrate the cover; Burrowing or soil- dwelling mammals (woodchucks, mice, moles, voles), reptiles (snakes, tortoises), insects (ants, beetles), and worms will present constant threats to the integrity of the cover; 3) Sunlight (if any of these other natural agents should succeed in uncovering a portion of the umbrella) will dry out clay (permitting cracks to develop), or destroy membrane liners through the action of ultraviolet radiation; 5) Subsidence--an uneven cave-in of the cap caused by settling of wastes or organic decay of wastes, or by loss of liquids from landfilled drums--can result in cracks in clay or tears in membrane liners, or result in ponding on the surface, which can make a clay cap mushy or can subject the cap to freeze-thaw pressures; 6) Rubber tires, which “float” upward in a landfill; and 7) Human activities of many kinds.

Prepared by: Environmental Research Foundation

THE NORMAN LANDFILL ENVIRONMENTAL RESEARCH SITE WHAT HAPPENS TO THE WASTE IN LANDFILLS?

U.S. Geological Survey Fact Sheet 040-03
August 2003

By Scott C. Christenson and Isabelle M. Cozzarelli

This Factsheet is also available as pdf (949KB).

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 house holds, 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.

SOLID WASTE LANDFILL TECHNOLOGY
A DOCUMENTED FAILURE

HIGH DENSITY POLYETHYLENE LINERS (HDPE) ARE NOT EFFECTIVE BARRIERS TO LANDFILL LEACHATE.

Two major classes of chemicals are responsible for HDPE failure. Aromatic hydrocarbons such as benzene and naphthalene, "permeate excessively and cause package deformation," and halogenated hydrocarbons such as trichlorethylene and methylene chloride can permeate HDPE and cause,"softening, swelling, and part deformation."

Marlex Polyethylene TIB 2 Packaging Properties, Plastics Division, Phillips 66 Company, Bartlesville, OK 74004

The "best demonstrated available technology" for composite liners (clay and plastic) allow leakage rates from .02 to 1.0 gallons per acre per day. This would result in 730 to 36,500 gallons per year from a 100 acre landfill.

Geoservices Inc. Background Document on Bottom Liner Performance in Double-lined landfills and Surface Impoundments, April 1987

LANDFILL CAPS ARE SUBJECT TO NATURAL ELEMENTS AND LEAKAGE

Lightning bolts striking the ground typically five million volts and 2,500 to 220,000 amperes can bore holes in the ground eight inches in diameter and fifteen feet deep. In western North Carolina, an average number of lightning strikes per hundred acres is 2.96 per year.

AT&T Telecommunication Electrical Protection, AT&T Technologies, Inc. 1985

Burrowing animals can move 5.3 tons of soil to the surface per acre per year. "Similar activity would have a dramatic impact on landfill cap integrity...synthetic liners, measured in mils are not likely to impede these same animals." Clay presents little barrier to such animals.

Johnson & Dudderar, WASTE AGE, March 1988, p.108-111

LEAK TESTING OF NEW LANDFILL LINERS REVEALS MAJOR FLAWS

Tests of the new municipal solid waste liner after burial by an Arizona contractor revealed that even with the most careful construction and quality assurance testing at every stage of emplacement, the liners had holes and punctures. *American City and County, July 1991*

EVEN EPA PREDICTS FAILURE OF THE NEW LANDFILL TECHNOLOGY

"First, even the best liner and leachate collection systems will ultimately fail due to natural deterioration…" *Federal Register p.33345 August 30, 1988*

BLUE RIDGE ENVIRONMENTAL DEFENSE LEAGUE

PO Box 88 Glendale Springs, North Carolina 28629 ~ Phone 336-982-2691 ~ Fax 336-982-2954 ~ Email BREDL@skybest.com October 2002

www.BREDL.org

Rachel's Environment & Health News

#316 - New Evidence That All Landfills Leak

December 15, 1992

Starting in the 1970s and continuing throughout the 1980s, U.S. Environmental Protection Agency [EPA] funded research which showed that burying household garbage in the ground poisons the groundwater. On several occasions, EPA spelled out in detail the reasons why all landfills leak. (For example, see RHWN #37, #71, and #116)

Then in late 1991, after several years of deliberation, EPA chief William Reilly issued final landfill regulations that allow the continued burial of raw garbage in landfills. (See RHWN #268.) EPA's 1991 regulations require an expensive landfill design: two liners in the ground and an impervious plastic cover over the landfill after it has been filled with garbage. This is "state of the art" technology, the very best that modern engineers can build. However, EPA officials still expect such landfills to fail and eventually poison groundwater.

As early as 1978, EPA knew why all landfills eventually leak. The main culprit is water. Once water gets into a landfill, it mixes with the garbage, producing a toxic leachate ("garbage juice"), which is then pulled downward by gravity until it reaches the groundwater. Therefore, the goal of landfill designers (and regulators) is to keep landfills dry for the length of time that the garbage is dangerous, which is forever.

Now a 1992 report from a California engineering-consulting firm, G. Fred Lee & Associates, has examined recent scientific studies and has confirmed once again why modern "dry tomb" landfill technology will always fail and should always be expected to poison groundwater.[1]

The new report, authored by Fred Lee and Anne Jones, reviews recent evidence--much of it produced by government-funded research--that landfill liners leak for a variety of reasons; that leachate collection systems clog up and thus fail to prevent landfill leakage; that landfill leachate will remain a danger to groundwater for thousands of years; that even low-rainfall areas are not safe for landfill placement; that gravel pits and canyons are particularly dangerous locations for landfills; that maintaining a single landfill's cap for the duration of the hazard would cost hundreds of billions, or even trillions, of dollars; that groundwater monitoring cannot be expected to detect landfill leakage; that groundwater, once it is contaminated, cannot be cleaned up and must be considered permanently destroyed; and that groundwater is a limited and diminishing resource which modern societies grow more dependent on as time passes.

A 1990 examination of the best available landfill liners concluded that brand-new state-of-the-art liners of high density polyethylene (HDPE) can be expected to leak at the rate of about 20 gallons per acre per day (200 liters per hectare per day) even if they are installed with the very best and most expensive quality-control procedures.[2] This rate of leakage is caused by pinholes during manufacture, and by holes created when the seams are welded together during landfill construction. (Landfill liners are rolled out like huge carpets and then are welded together, side by side, to create a continuous field of plastic.) Now examination of actual landfill liners reveals that even the best seams contain some holes.

In addition to leakage caused by pinholes and failed seams, new scientific evidence indicates that HDPE (high density polyethylene, the preferred liner for landfills) allows some chemicals to pass through it quite readily. A 1991 report from University of Wisconsin shows that dilute solutions of common solvents, such as xylenes, toluene, trichloroethylene (TCE), and methylene chloride, penetrate HDPE in one to thirteen days. Even an HDPE sheet 100 mils thick (a tenth of an inch)--the thickness used in the most expensive landfills) is penetrated by solvents in less than two weeks.

Another problem that has recently become apparent with HDPE liners is "stress cracking" or "brittle fracture." For reasons that are not well understood, polyethylenes, including HDPE, become brittle and develop cracks. A 1990 paper published by the American Society for Testing Materials revealed that HDPE liners have failed from stress cracks in only two years of use. Polyethylene pipe, intended to give 50 years of service, has failed in two years. Lee and Jones sum up (pg. 22), "While the long-term stability of geomembranes (flexible membrane liners) in landfills cannot be defined, there is no doubt that they will eventually fail to function as an impermeable barrier to leachate transport from a landfill to groundwater. Further, and most importantly at this time, there are no test methods, having demonstrated reliability, with which to evaluate long-term performance of flexible membrane liners."

Recent scientific studies of clay indicate that landfill liners of compacted clay leak readily too. For example, a 1990 study concludes,

[I]F A NATURALLY OCCURRING CLAY SOIL IS COMPACTED TO HIGH DENSITY, THEREBY PRODUCING A MATERIAL WITH VERY LOW HYDRAULIC CONDUCTIVITY, AND IF IT IS MAINTAINED WITHIN THE SAME RANGES OF TEMPERATURE, PRESSURE, AND CHEMICAL AND BIOLOGICAL ENVIRONMENT, IT WOULD BE EXPECTED TO FUNCTION WELL AS A SEEPAGE BARRIER INDEFINITELY. IN WASTE CONTAINMENT APPLICATIONS, HOWEVER, CONDITIONS DO NOT REMAIN THE SAME. THE PERMEATION [PENETRATION] OF A COMPACTED CLAY LINER BY CHEMICALS OF MANY TYPES IS INEVITABLE, SINCE NO COMPACTED CLAY OR ANY OTHER TYPE OF LINER MATERIAL IS EITHER TOTALLY IMPERVIOUS OR IMMUNE TO CHEMICAL INTERACTIONS OF VARIOUS TYPES

The 1992 study by Lee and Jones is an excellent resource for anyone wanting to understand why landfills always fail. In their footnotes, they cite 18 other studies of landfill problems that they themselves have authored, so their expertise is unquestionable, their information reliable, their arguments solid.

There has been sufficient scientific evidence available for a decade to convince any reasonable person that landfills leak poisons into our water supplies, and are therefore anti-social.

The question remains: what will it take to convince government--specifically EPA--to base policy on its own scientific studies and its own understanding?

The new EPA administrator is Carol M. Browner, an avowed environmentalist from Florida. Asked to describe Ms. Browner's style, John Sheb, head of Florida's largest business trade association, said: "She kicks the door open, throws in a hand grenade, and then walks in to shoot who's left. She really doesn't like to compromise."

Maybe Ms. Browner could start with a wake-up grenade in the Office of Solid Waste.

--Peter Montague

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[1] G. Fred Lee and Anne R. Jones, MUNICIPAL SOLID WASTE MANAGEMENT IN LINED, "DRY TOMB" LANDFILLS: A TECHNOLOGICALLY FLAWED APPROACH FOR PROTECTION OF GROUNDWATER QUALITY (El Macero, Calif.: G. Fred Lee & Associates, March, 1992). Available from: G. Fred Lee & Associates, 27298 East El Macero Drive, El Macero, CA 95618-1005. Phone (916) 753- 9630. 67 pgs.; free.

[2] Rudolph Bonaparte and Beth A. Gross, "Field Behavior of Double- Liner Systems," in Rudolph Bonaparte (editor), WASTE CONTAINMENT SYSTEMS: CONSTRUCTION,

REGULATION, AND PERFORMANCE [Geotechnical Special Publication No. 26] (New York: American Society of Civil Engineers, 1990), pgs. 52-83.

CLARIFICATION: RIGHTS OF CORPORATIONS

Last week we suggested the need for a Constitutional amendment declaring that a corporation is not a natural person and is therefore not protected by the Bill of Rights and the 14th amendment to the Constitution. Such an amendment would level the playing field somewhat, giving communities and individuals a greater chance of controlling anti-social corporate behavior. As we noted in earlier newsletters (RHWN #308, #309), corporations are now literally out of control. Shareholders cannot control them; boards of directors cannot control them; workers cannot control them; in a competitive world market, even managers have lost control. In some cases, of course, management doesn't care about the environment or the community. But even when managers, as individuals, want to do the right thing, the logic of corporate growth and short-term gain often dictates choices that do not serve the environment or the community. Since corporate behavior is at the root of nearly all environmental problems, stripping corporations of some of their rights (such as the Constitutional protections guaranteed to individual citizens, which the Supreme Court extended to corporations in 1886), would help communities assert control over corporate behavior. Merely DEBATING such an amendment would get people thinking about power in the modern world, asking who has a legitimate right to control what. Ask yourself: who ever gave private corporations the right to manufacture and sell products that can destroy the planet as a place suitable for human habitation? In suggesting such a Constitutional amendment, we omitted reference to the original source of the idea, author Richard Grossman.

For historical background on control of corporations, get: Richard Grossman and Frank T. Adams, TAKING CARE OF BUSINESS; CITIZENSHIP AND THE CHARTER OF INCORPORATION (Cambridge, Mass.: Charter, Inc., 1992). For a copy, send $4.00 plus a self-addressed, stamped envelope containing 52 cents postage to: Charter, Inc., P.O. Box 806, Cambridge, MA 02140.
--Peter Montague

Descriptor terms: corporations; constitution; us; landfilling; landfill liners; leachate collection systems; groundwater; epa; waste disposal technologies; high density polyethylene; waste treatment technologies; msw;

Rachel's Environment & Health News

#217 - Plastics -- Part 2: Why Plastic Landfill Liners Always Fail

January 22, 1991

In the landfill business, government and industry say plastic liners are going to save the day. For example, U.S. Environmental Protection Agency (EPA) and industry both argue that incinerator ash can be safely "disposed of" in a double-lined ash "monofill." A "monofill" is a landfill that contains only ash, no raw garbage. Like any other landfill, the basic design is a bathtub in the ground. The bottom of the bathtub is formed by a huge sheet of plastic. In an expensive landfill, you have two sheets of plastic separated by about two feet of sand and gravel--thus creating one bathtub inside another bathtub. Therefore, a doublelined ash monofill is a landfill (which is really just a polite word for a dump) in the form of a bathtub created by two plastic liners, containing incinerator ash and nothing else.

The theory behind the monofill is that ash contains only small amounts of aggressive organic chemicals that might eat a hole in the plastic liner, so the plastic liner will remain intact and protect us against the lead and cadmium and other toxic metals contained in the ash. (See RHWN #92.) As always, the key question is: what is the duration of the hazard and what is the duration of the protection provided by the plastic liner? (The "cap" or umbrella covering a landfill will also be made of the same plastic, so a landfill is really a "baggie" in the ground, containing toxins. What is the lifetime of this baggie? How long will it protect us?)

What is the duration and nature of the hazard from metals in incinerator ash? As we saw earlier (in RHWN #92) incinerator ash is rich in toxic metals. For example, it typically contains anywhere from 3000 parts per million (ppm) to 30,000 ppm of lead. U.S. Environmental Protection Agency Region (Boston), and the Harvard University School of Public Health have recommended a cleanup action level of 1000 ppm for lead in soil--in other words, they recommended that remedial action, as would be needed at a Superfund site, should be undertaken wherever lead in soils exceeds 1000 ppm.[1] In recommending the 1000 ppm action level, EPA and Harvard wrote, "While we believe a greater margin of safety would be achieved with an action level of 500 ppm, we think it necessary to set priorities for remedial activity." (What they meant was that there are so many places in urban America where there is 500 ppm lead in soil that EPA would be overwhelmed with work if 500 ppm were set as the threshold for remedial action--so 1000 ppm is a more "realistic" cleanup action level even though it's not as safe as the nation's children really need it to be.)

Given that EPA Region I and the Harvard School of Public Health have recommended that Superfund-type cleanup be initiated whenever soils contain more than 1000 parts per million (ppm) of lead, we know immediately that every ash monofill will have to be cleaned up at some time in the future because all incinerator ash contains more than 1000 ppm lead. (Ash also contains dangerous amounts of other toxic metals-- cadmium, arsenic, chromium, and perhaps others, so lead is not the only reason why a cleanup might be needed.) Therefore, when we create ash monofills we know we are creating Superfund sites that our children will pay for--either in damage to their brains and nervous systems, or in enormous outlays of money--or both.

Because lead and cadmium and other metals never degrade into anything else, but remain toxic forever, the duration of the hazard is perpetual, everlasting, eternal. The danger will never go away.

The incineration industry, and its acolytes in government, argue that the plastic liners will protect us and our children forever. Unfortunately, this idea is based on a misunderstanding (or more likely an intentional misrepresentation) of what happens to plastics as they get older. Plastics are not inert; they do not stay the same as time passes. They change. They come apart spontaneously.

A recent book by Deborah Wallace, Ph.D., describes this process well. [2] The book is about the dangers of plastics in fires, but in telling the story of "Why today's fires are so dangerous," (the answer is because burning plastics give off toxic gases that kill people who breathe them), Dr. Wallace included a section on the makeup of plastics at the molecular level, which helps us understand why all plastics eventually fall apart.

The building blocks of plastics are found in natural gas, coal, and wood, but the major source is oil. Oil (like coal and natural gas) is a mixture of molecules of different sizes and structures. To separate out the different molecules, crude oil is distilled in an oil refinery. The oil is boiled and smaller, lighter molecules are separated from the larger, heavier molecules. The heavier molecules are then "cracked" to break up the large, heavy molecules into smaller, lighter molecules.

The result of this distillation and cracking is organic chemicals, which is the name for chemicals containing carbon and other elements (chiefly hydrogen, oxygen, and nitrogen). These organic chemicals form the building blocks of pesticides, glues, and plastics. Other chemicals (such as chlorine and lead) are added to give the raw materials new characteristics (strength, stiffness, color, and so forth).

After the building blocks are manufactured, they are turned into plastic resin by a process called polymerization. A polymer is a large, organic, chain-like molecule made of repeated units of smaller molecules. Polymerization usually requires heating the raw materials in the presence of helper chemicals called catalysts, until the building blocks form long chains. Even with the catalysts, a great deal of heat is used in the polymerization process. "Because of this heat, the long chains, even during manufacture, may decompose slightly and have defect points along them," Dr. Wallace explains. The defect points are in the chemical bonds, which absorb the energy used in the manufacturing process. The law of conservation of energy states that the amount of energy in a system after the reaction is the same as the amount of energy before the reaction. The large amounts of energy (heat) thus must go somewhere; they go into the bonds between the atoms of the plastic and are stored there. But nature does not favor this gain of energy--nature favors low energy chemical bonds, and high energy bonds tend to release their energy by breaking spontaneously. These are defect points. Although polymer scientists have striven to reduce the number of defect points, they have not been able to completely eliminate them from synthetic polymers.

Dr. Wallace continues, "The physical and chemical defects that are produced by ordinary processes in the manufacture and use of plastics demonstrate the fragile and unstable character of these long chains of molecules that are joined by high energy chemical bonds. When the resin is further processed to become the finished marketable product, additional defect points are created because the product is again heated and handled."

As time passes, plastics decompose--their molecules come apart spontaneously--beginning at the defect points. Polymer scientists refer to this decomposition as "aging." All plastics "age" and there is nothing that can be done about it. Within a few years (at most a few decades), all plastics degrade, come apart, and fail. They become brittle, lose their strength, crack, break into fragments. At that point, any protection the plastic may have afforded against the toxic dangers lurking in an ash monofill is gone. By that time, the people who created the ash monofill will have taken their profits and left town, but the deadly residues they leave behind--the ash--will remain to plague the community forever, poisoning the community's children with toxic lead and other metals.

The only affordable solution to this problem is a simple one: prevent the creation of incinerator ash.

--Peter Montague

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[1] P.L. Ciriello and T. Goldberg, "Lead-contaminated Soil Cleanup

Draft Report" which appears as Appendix E in: Agency for Toxic Substances and Disease Registry, THE NATURE AND EXTENT OF LEAD POISONING IN CHILDREN IN THE UNITED STATES: A REPORT TO CONGRESS (Atlanta, Ga: Agency for Toxic Substances and Disease Registry, Public Health Service, U.S. Department of Health and Human Services [1600 Clifton Rd. -Mail Stop E-33, Atlanta, Ga 30333; phone (404) 639-0730], July, 1988). Free while supplies last."

[2] Deborah Wallace, IN THE MOUTH OF THE DRAGON (Garden City Park, NY: Avery Publishing Group [120 Old Broadway, Garden City Park, NY 11040; phone (516) 741-2155], 1990). $17.95.

Descriptor terms: epa; landfilling; plastic liners; harvard university school of public health; studies; remedial action; ash monofills; heavy metals; deborah wallace; polymerization; leaks;

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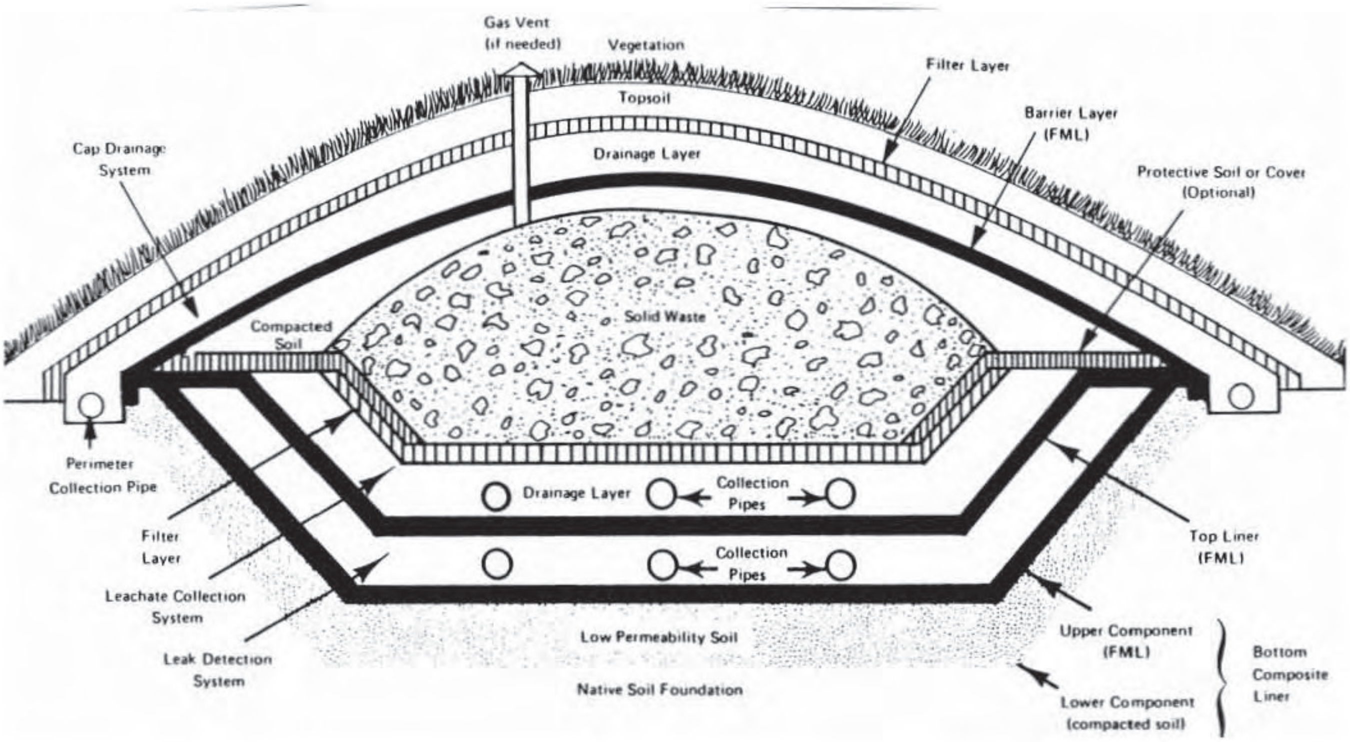
Rachel's Environment & Health News
#119 – Leachate Collection Systems: The Achilles' Heel Of Landfills
March 7, 1989



A landfill is a bathtub in the ground, and a bathtub can leak two ways: it can leak through a hole in the bottom (failure of its bottom liner), or it can fill up with fluid and spill over its sides. Either way, it's bad news. The basic problem is the fluid. If a landfill begins to fill up with fluid, the weight of the fluid puts pressure on the bottom of the landfill, increasing the likelihood of bottom liner failure, so any fluid inside a landfill is a potential source of trouble.

To prevent fluid from causing problems, every modern landfill has a system for draining liquids out of the landfill. This is called a leachate collection system. What is leachate? Think of a landfill as being like a drip coffee maker. The dry coffee is the garbage, the water you pour in the top is rainwater, and the dark, brewed coffee dripping out the bottom is leachate. You might want to drink coffee, but you definitely do not want to drink leachate: it has many toxic and dangerous characteristics. It is badly polluted with chemicals and with micro-organisms (bacteria and viruses) that would make you sick.

The picture below represents a closed landfill; the heavy dark line represents the plastic baggie (bottom liner and top cover) that is supposed to keep leachate from entering the environment. The round circles between the two bottom liners represent collection pipes which have many holes drilled along their length (making these pipes resemble a swiss cheese); they are supposed to collect any leachate that flows to the bottom of the landfill. In theory, these pipes carry off the leachate to a wastewater treatment plant, where the leachate is processed to remove the toxic chemicals. (At the wastewater treatment plant, some of the chemicals are released into the air, and the remaining ones are collected [they're now in a mud-like sludge] and they are sent to another landfill somewhere.)

One of the least-studied aspects of landfill design is how to make a leachate collection system that will work for many decades (much less many hundreds of years). The fact is, leachate collection systems can clog up in less than a decade and, when that happens, fluids begin to build up inside the landfill—a dangerous situation, as we have noted above.

Leachate collection systems fail in several known ways. First, they can clog up from silt or mud. Second, they can clog up because of the growth of microorganisms in the pipes. Third, they can clog because of a chemical reaction leading to the precipitation of minerals in the pipes; anyone who has boiled a pot of "hard" water and seen the whitish crusty residue in the bottom of the pot knows what "precipitated chemicals" look like. Fourth, the pipes themselves can be weakened by chemical attack (acids, solvents, oxidizing agents, or corrosion) and may then be crushed by the tons of garbage piled above them.

The book, AVOIDING FAILURE OF LEACHATE COLLECTION AND CAP DRAINAGE SYSTEMS, by Jeffrey Bass, discusses these four failure mechanisms. The first problem (silt) can sometimes be avoided, or at least reduced, by installing a "filter layer" above the leachate collection system. The filter layer may be made up of gravel or of a rug-like plastic material called "geotextile." Since the oldest leachate collection systems date from the early 1970s, humans have very little experience with the long-term performance of leachate collection systems. The hope is that a “filter layer” will solve the siltclogging problem, but after many decades the entire filter layer itself may clog. Only time will tell.

The growth of microorganisms seems to be an uncontrollable problem. The conditions for growth of slime-forming microorganisms are not well understood. Even if they were understood, we could not control chemical and physical conditions (temperature, pH, etc.) at the bottom of a landfill because of the thousands of tons of wastes heaped up in the landfill.

The problem of chemical precipitation also appears to be uncontrollable. The chemical conditions that lead to precipitation may be knowable, but again the conditions in the leachate collection system cannot be controlled because the system is not accessible once wastes have begun to be dumped into the landfill.

The last problem—chemical attack on the leachate collection pipes, leading to destruction of the pipes themselves—also appears to be an unsolvable problem. Mr. Bass suggests, in best ivory tower fashion, that the way to control chemical attack on the pipes is to select pipes that are resistant to the chemicals that you know will make their way into the landfill. In principal, this is a good idea. But in the real world, how do you know what’s going to be put into your landfill next week? Next year? With 1000 brand new chemicals being put into commercial use each year, over the next 10 years, today’s leachate collection pipes may come into contact with 10,000 new chemicals that don’t even exist today. Any of those chemicals may attack the pipes. In addition, chemicals mixing together inside a landfill will create new chemical combinations that may produce heat or may otherwise attack the pipes.

Mr. Bass’s book is misnamed because it seems to suggest that the failure of leachate collection systems can be avoided. However, as the text of Mr. Bass’s book makes abundantly clear, if such failures were to be avoided, it would be by dumb luck, not by engineering design. Only a fool trusts dumb luck.

Mr. Bass’s book is overpriced at $36.00 from: Noyes Data Corporation, Mill Road, Park Ridge, NJ 07656. No telephone orders accepted.

--Peter Montague

Descriptor terms: landfilling; landfill failure mechanisms; leachate collection systems; msw;

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Rachel's Environment & Health News
#109 - The Catch-22s Of Landfill Design
December 25, 1988

The waste hauling industry knows that all landfills will eventually leak because their own industry trade journals are now telling the story. WASTE AGE is the main magazine for the waste industry. The editors of WASTE AGE are not sympathetic to environmental groups. For example, it was in WASTE AGE'S columns that you may have read,

"The NIMBY [not in my back yard] syndrome is a public health problem of the first order. It is a recurring mental illness that continues to infect the public.

"Organizations that intensify this illness are like the viruses and bacteria which have, over the centuries, caused epidemics such as the plague, typhoid fever, and polio.

"....It is time solid waste management professionals stopped wringing their hands and started a campaign to wipe out this disease." (WASTE AGE, Mar., 1988, pg. 197.)

Clearly WASTE AGE is no friend of the grass roots environmental movement. Yet it has been publishing articles that say what we've been saying all along: the security and safety of landfills is dependent upon the landfill cap, and the landfill cap is inevitably destroyed by natural forces.

WASTE AGE has run a series of articles over the past two years saying why landfills will inevitably leak, and suggesting that the only solution to the problem is perpetual maintenance of the closed landfill. Since humans have no experience maintaining anything in perpetuity, perpetual maintenance is an untested and unproven, and, one can only say, silly non-solution. If we took it seriously, perhaps we would develop a large army of landfill maintainers whose only job in life will be to maintain the toxic garbage left behind by their parents and their parents' parents and their parents' parents' parents and so on for generation after generation.

Despite the silly suggestion that perpetual maintenance of landfill caps is a way out of our present garbage problem, these articles contain much good information about why landfills leak.

Remember, a landfill is nothing more than a bathtub in the ground (perhaps, in the case of a double-lined landfill, one bathtub inside another). A bathtub will leak if its bottom develops a hole, or it can simply fill up with water (for example, rainfall) and leak over its sides. Either way, a landfill can contaminate the local environment. Therefore, a "cap" is placed over the landfill when the landfill is full. The "cap" is supposed to serve as an umbrella to keep rain out, to keep the bathtub from spilling over its sides.

Writing in WASTE AGE, Dr. David I. Johnson and Dr. Glenn R. Dudderar of the Michigan State University Department of Fisheries and Wildlife, have argued,

"There is evidence that the engineered integrity of a cap will not be maintained over the landfill's extended life." (This is somewhat fancy language for "All landfills will eventually leak.")

Johnson and Dudderar go on to say, "Regulations may require bonding for five to 20 years. Yet from a biological and geophysical point of view this time period is a totally inadequate maintenance requirement." (Translation: It may take nature more than 20 years to destroy a landfill cap, but nature has all the time in the world, so you'd better be prepared to maintain a landfill for the long haul--forever.)

Catch 22 #1: A landfill cap is intended to be impermeable--to keep water out. This means water is supposed to run off the surface. But this, in turn, invites soil erosion. "But in the runoff process, cap soil will be carried with the runoff, causing sheet and rill erosion and, ultimately, gullying of the cap." When you get gullies in the cap, it's all over.

Other physical forces working constantly to destroy a landfill cap are freezethaw and wet-dry cycles. Soil shrinkage during dry weather can cause cracks. Rain penetrates the cracks. In winter, rain freezes to ice and expands, widening the cracks. And so on, year in, year out, century after century. The cracks not only let in water, they also provide pathways for plant roots and for burrowing animals.

Catch 22 #2: To minimize soil erosion, and to minimize changes due to wet-dry cycles, you need to establish vegetation on the cap. However, plants maintain their physical stability, and they gather water and nutrients, through roots, which can penetrate a landfill cap, destroying the cap's integrity. Furthermore, plants provide cover (and food) for burrowing animals, which then burrow into the cap, destroying it.

A study of a solid radioactive waste landfill reveals that mice, shrews, and pocket gophers can move 10,688 pounds (5.3 tons) of soil to the surface per acre per year. "Similar activity would have a dramatic impact on landfill cap integrity," Johnson and Dudderar observe. Burrowing animals of concern include woodchucks, badgers, muskrats, moles, ground squirchipmunks, gophers, prairie dogs and badgers. Clay presents little barrier to such animals; "synthetic liners, measured in mils [of thickness], are not likely to impede these same mammals," Johnson and Dudderar observe. Non-mammals are also a problem: crayfish, tortoises, mole salamanders, and "a variety of worms, insects and other invertebrates" can make holes in a landfill cap.

Earthworms alone can have a devastating impact on a landfill cap. Earthworms pass two to 15 tons of soil through their digestive tracts per acre per year. "The holes left as they move through the soil to feed increase water infiltration," Johnson and Dudderar comment. They give evidence that worm channels allowed plant roots to grow to a depth of nine feet in Nebraska clay soils.

In a section called "The fundamental dilemma," Johnson and Dudderar sum up:

"At this point you may well say: 'If we plant, we're encouraging plant and animal penetration of the clay cap. If we don't plant, we get erosion or freeze-thaw destruction of the cap.'

"Unfortunately, that is one of the fundamental dilemmas left us by the normal processes of change in the natural world, be they the progressive conversion of a grassy field to a forest or the utilization of cracks in concrete sidewalks by ants and dandelions.

"This same successional development process, so intensively studied in the ecological literature, will detrimentally affect long-term landfill integrity." So there you have it, right from the pages of Waste Age: the forces of nature, left to themselves, will destroy landfill caps, the key element intended to prevent landfills from leaking.

What hope is there? Perpetual care. A perfectly silly idea. What reasonable hope is there? None whatsoever. All landfills will eventually leak. Happy new year.

For further information, see: David I. Johnson, "Caps: The Long Haul," WASTE AGE March, 1986, pgs. 83-89; David I. Johnson, "Capping Future Costs," WASTE AGE August, 1986, pgs. 77-86; David I. Johnson and Glenn R. Dudderar, "Can Burrowing Animals Cause Groundwater Contamination?" WASTE AGE March, 1988, pgs. 108-111; see also David I. Johnson and Glenn R. Dudderar, "Designing and Maintaining Landfill Caps for the Long Haul," JOURNAL OF RESOURCE MANAGEMENT AND TECHNOLOGY, Vol. 16 (April, 1988), pgs. 34-40. Dr. Johnson [phone 517/353-1997] and Dr. Dudderar [phone 517/353-1990] are with Department of Fisheries and Wildlife, Michigan State University, East Lansing, MI 48824.

Emerging Contaminants at a Closed and an Operating Landfill in Oklahoma

by William J. Andrews, Jason R. Masoner, and Isabelle M. Cozzarelli

Abstract

Landfills are the final depositories for a wide range of solid waste from both residential and commercial sources, and therefore have the potential to produce leachate containing many organic compounds found in consumer products such as pharmaceuticals, plasticizers, disinfectants, cleaning agents, fire retardants, flavorings, and preservatives, known as emerging contaminants (ECs). Landfill leachate was sampled from landfill cells of three different age ranges from two landfills in Central Oklahoma. Samples were collected from an old cell containing solid waste greater than 25 years old, an intermediate age cell with solid waste between 16 and 3 years old, and operating cell with solid waste less than 5 years old to investigate the chemical variability and persistence of selected ECs in landfill leachate of differing age sources. Twenty-eight of 69 analyzed ECs were detected in one or more samples from the three leachate sources. Detected ECs ranged in concentration from 0.11 to 114 μg/L and included 4 fecal and plant sterols, 13 household\industrial, 7 hydrocarbon, and 4 pesticide compounds. Four ECs were solely detected in the oldest leachate sample, two ECs were solely detected in the intermediate leachate sample, and no ECs were solely detected in the youngest leachate sample. Eleven ECs were commonly detected in all three leachate samples and are an indication of the contents of solid waste deposited over several decades and the relative resistance of some ECs to natural attenuation processes in and near landfills.

Introduction

There are 90,000 to 100,000 closed municipal landfills and about 3100 operating landfills (Zero Waste America 2011) in the United States. The closed landfills, many of which are unlined and poorly capped, may be sources of a large number of organic compounds known as emerging contaminants (ECs) to surrounding groundwater and surface water. ECs consist of household and industrial compounds in wastes and consumer products that include fecal and plant sterols, pharmaceuticals, food additives, soaps and detergents, solvents, cleaning agents, fire retardants, plasticizers, perfumes, and pesticides. ECs, although they generally occur in small concentrations in water (<1 mg/L), may singly or in aggregate cause health problems for humans and wildlife ingesting water containing these compounds.

In 2008, approximately 135 million tons of municipal solid waste (MSW) was deposited in landfills in the United States, making landfilling the most common method of MSW disposal (U.S. Environmental Protection Agency 2009). Landfills are the final depositories for a large number of anthropogenic organic compounds, including ECs (Slack et al. 2005). Pharmaceutical compounds may occur in concentrations of approximately 8.1 mg/kg in typical MSW (Musson and Townsend 2009). Having been discarded in landfills, ECs may be degraded/metabolized, adsorbed to solids, or dissolved in leachate (Musson and Townsend 2009). Anaerobic conditions in landfills and nearby groundwater receiving organic-rich leachate from landfills (Cozzarelli et al. 2011) are likely to slow metabolism/breakdown of organic compounds in leachate and groundwater compared to aerobic conditions that are more common in shallow groundwater (Bedient et al. 1997). In groundwater downgradient from an abandoned unlined landfill near Elkhart, Indiana, detergent metabolites, plasticizers, disinfectants, fire retardants, pharmaceuticals, and an antioxidant were detectable at concentrations in the low parts-per-billion range (Buszka et al. 2009). Huset et al. (2011) reported on detection of 24 fluorochemicals in landfill leachates, primarily short-chain (C4-C7) carboxylates or sulfonates associated with paper, textiles, and carpets.

Leaching of organic chemicals from both old and modern landfills to groundwater and surface water is a potentially important environmental problem, with such chemicals potentially being toxic, estrogenic, and carcinogenic to both terrestrial and aquatic organisms (Cozzarelli et al. 2011; Huset et al. 2011; Matejczyk et al. 2011). Some reports have indicated that mixtures of dilute concentrations of ECs in water may deleteriously affect human health, as had been

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**Updated Review of the "Flawed Technology"
of US EPA Subtitle D MSW Landfilling**

G. Fred Lee, PhD, PE, BCEE, F.ASCE and Anne Jones-Lee, PhD

June 7, 2010

The current US EPA Subtitle D landfilling regulations, adopted in 1992, were crafted under the hand of litigation settlement. They were not developed through considered input of and evaluation by the experienced technical community or with scrupulous peer review for the ability of the regulatory specifications to ensure true protection of public health and environmental quality for as long as the landfilled wastes would represent a threat. In fact, during the Subtitle D development process, the US EPA repeatedly indicated that the proposed landfilling regulations would not be protective of groundwater quality over the period that the wastes in the prescribed "dry tomb" (plastic-sheeting and compacted soil-lined) landfill could be a threat. Indeed, the US EPA noted that the "dry tomb" landfills as prescribed and allowed by the regulations could be expected to fail to prevent production of landfill leachate and the migration of that leachate to groundwater. It was clear from the outset that the Subtitle D regulations represented a fundamentally flawed technology. The fundamental flaws of the Subtitle D specifications have not been overcome in the implementation of the regulations over the past 18 years since it adoption.

In the early 1990s Drs. G. Fred Lee and Anne Jones-Lee developed an extensive overview discussion of public health and environmental quality problems that can be caused by landfilling of municipal and industrial solid wastes under the applicable US EPA Subtitle D regulations. The review, which was posted on their website [www.gfredlee.com], was based on their professional experience in reviewing the impacts of proposed and existing landfills, their university research on landfill liner integrity issues, their search and review of the professional literature, and the provisions, requirements, allowances, and implementation of Subtitle D regulations. It included an overview of a number of key deficiencies in Subtitle D with regard to landfill siting, design, construction, operation, closure, and post-closure monitoring and maintenance for the protection of public health and environmental quality for as long as the wastes in the landfill represent a threat to public health, water resources, air quality, and the interests of those in the sphere of influence of a landfill. In addition to highlighting regulatory shortcomings, the review also discussed key elements that need to be incorporated into the landfilling of non-recyclable solid waste components in order to more reliably protect public health, environmental quality, and the interests of those in the sphere of influence of a landfill. It also included substantial references to, and internet links for, professional literature where additional information on the issues discussed could be obtained. Based on their experience and findings, they described the Subtitle D regulations in their review as advancing and enabling a "Flawed Technology" that falls far-short of protecting groundwater and surface water quality from pollution by municipal and industrial solid waste leachate (garbage juice) for as long as the landfilled wastes will be a threat.

Periodically over the past two decades, Lee and Jones-Lee have updated their "Flawed Technology" review with new information on the topics discussed and the addition of discussion of new issues that have come to light since the previous update. In June 2010, Drs. Lee and

Jones-Lee again updated their "Flawed Technology" review, and incorporated an additional nine pages of text and references. The updated, now 94-page, review is available as:

Lee, G. F., and Jones-Lee, A., "Flawed Technology of Subtitle D Landfilling of Municipal Solid Waste," Report of G. Fred Lee & Associates, El Macero, CA, December (2004). Updated June (2010). http://www.gfredlee.com/Landfills/SubtitleDFlawedTechnPap.pdf

In addition to improved clarity of presentation, the June (2010) updated review includes several new or expanded sections on a variety of issues including:

- additional statements by the US EPA acknowledging the inevitability of failure of landfill liner systems,
- monitoring stormwater runoff from landfills and hazardous chemical sites,
- unregulated, potentially hazardous and otherwise deleterious chemicals in municipal solid wastes,
- Subtitle D or equivalent landfills in other countries, including in a new proposed landfill in Alberta, Canada,
- the inappropriate development of a landfill atop a fractured rock, sole-source aquifer system in an area that is subject to intense seismic (earthquake) activity,
- the inadequacy of information published by SWANA on bioreactor landfills,
- the potential for leachate and landfill gas produced in construction and demolition (C&D) waste landfills to pollute groundwater and lead to offsite explosions.

The abstract and table of contents for the June (2010) update of the "Flawed Technology" review is attached.

The authors anticipate continuing to update this review periodically as new information and experience comes to light. Therefore, if you identify topics that are not covered in this review, or if you have comments or questions about this review, please contact G. Fred Lee at gfredlee@aol.com.

Flawed Technology of Subtitle D Landfilling of Municipal Solid Waste

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Updated June 2010

Abstract

This report presents a review of the information available pertinent to public health and environmental quality protection issues for proposed and existing Subtitle D landfills. Based on this review it is concluded that this type of landfill will at most locations cause groundwater pollution by landfill leachate and be adverse to the health, welfare and interests of nearby residents and property owners/users. As discussed, there is normally significant justification for those near a proposed Subtitle D landfill to oppose the development of the landfill and the existence of an operating Subtitle D landfill.

Typically landfilling regulations require that,

(a) the solid waste facility shall not pose a substantial endangerment to public health or safety or the environment;

(b) the solid waste facility shall not cause an environmental nuisance.

Frequently in review of a proposed landfill, the regulatory agency staff do not adequately or reliably evaluate the potential for a proposed landfill to endanger public health, safety and the environment, and cause nuisance on adjacent properties.

Subtitle D landfills have the potential to generate leachate (garbage juice) that will pollute groundwater with hazardous and deleterious chemicals that are a threat to human health and the environment for thousands of years. These landfills have the potential to generate landfill gas that will contain hazardous and obnoxious chemicals for a long period of time well beyond the current minimum 30-year funded postclosure period. Specific deficiencies in the siting, design, operation, closure and postclosure care provisions for Subtitle D landfills include:

- a single composite landfill liner that will eventually fail to prevent leachate pollution of groundwater,
- a landfill cover that will eventually allow rainfall to enter the landfilled wastes which will generate leachate that will pollute groundwater,
- a grossly inadequate groundwater monitoring system that has a low probability of detecting leachate-polluted groundwater before it leaves the landfill owner's property,
- inadequate postclosure funding for landfill monitoring, maintenance and remediation of polluted groundwater for as long as the wastes in the landfill will be a threat,
- inadequate buffer lands between where wastes will be deposited and adjacent properties, which will result in adverse impacts on nearby property owners/users from landfill releases, including odors, dust, vermin, and noise and lights from landfill activities,
- decreased property values for owners of nearby properties.

In addition, at some locations there is an environmental justice issue associated with the development of a landfill that will be adverse to minority communities.

Flawed Technology of Subtitle D Landfilling of Municipal Solid Waste

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Detecting Failure of Subtitle D Landfill Liner Systems

G. Fred Lee, PhD, PE, DEE
G. Fred Lee & Associates, El Macero, California
November 1999

Periodically landfill applicants and some regulators who want to prove that today's Subtitle D landfills are protective will assert that there are no recorded failures of Subtitle D landfills. This is an issue that I have addressed previously in my report, "Detection of the Failure of Landfill Liner Systems," (1996) which is available from my web site, www.gfredlee.com, in the Landfill section.

The statement about "no recorded failures" of Subtitle D landfills is likely correct. I don't know of any recorded failures. However, as discussed in my review, except under extremely sloppy construction and highly lucky groundwater monitoring, the failure of Subtitle D landfills at this time would not be expected to be detected. This is the result of several situations.

First, Subtitle D landfills have only been used for a few years. It should take about 25 years for leachate that passes through holes in the flexible membrane liner to pass through the clay liner.

Second, as discussed in the paper, "Deficiencies in Subtitle D Landfill Liner Failure and Groundwater Pollution Monitoring," (1998) which is also available in the Landfill section of my web site, the typical groundwater monitoring program allowed by regulatory agencies for Subtitle D landfills involving the use of monitoring wells at the point of compliance, which have zones of capture of about one foot, but which are spaced hundreds of feet apart, means that there must be widespread, general failure of the liner system before these monitoring wells can be expected to detect failure.

The initial failure of the liner system will not be through general leakage throughout the bottom of the landfill, but will be through holes, rips, tears, or points of deterioration in the plastic sheeting flexible membrane liner. As discussed by Cherry in 1990, the initial liner failures will produce finger-like plumes of leachate that will have a high probability of passing between the monitoring wells and not being detected by them.

As discussed in my comprehensive review of the deficiencies in the Subtitle D landfilling approach, "Assessing the Potential of Minimum Subtitle D Lined Landfills to Pollute: Alternative Landfilling Approaches," (1998), which is also available from my web site, based on the properties of the wastes allowed in Subtitle D landfills and the characteristics of the liner systems and groundwater monitoring systems, there is no question about the fact that for Subtitle D landfills sited at geologically unsuitable sites where the base of the landfill is connected through a vadose zone to usable groundwaters, it is only a matter of time until those groundwaters are polluted by landfill leachate, rendering them unusable for domestic and many other purposes. This is not a debatable issue.

Many of the components of the wastes in Subtitle D landfills will be a threat to pollute groundwaters forever. The liner systems being allowed at best only postpone when groundwater pollution occurs. The groundwater monitoring systems being allowed are largely cosmetic in detecting off-site groundwater pollution before widespread pollution occurs. Anyone who claims otherwise either doesn't understand the basic issues involved, or is deliberately distorting the readily available information on these issues.

Additional Information on Reliability of Groundwater Monitoring at Subtitle D Landfills

In response to my recently summarizing the fundamentally flawed nature of Subtitle D landfilling of municipal solid wastes in protecting public health and the environment for as long as the waste in a Subtitle D landfill will be threat, a "landfill engineer" suggested that the typical groundwater monitoring well array that is used at Subtitle D landfills will detect leachate-polluted groundwater before off-site adjacent property pollution of groundwater occurs due to dispersion of the leachate-polluted groundwater plume. While dispersion plays a role in determining the ability of a monitoring well array to detect a leak from a small area source, it cannot be relied on to insure with a high degree of reliability that the typical groundwater monitoring well array that is being used today at Subtitle D landfills will detect groundwater pollution when it first reaches the point of compliance for groundwater monitoring. Dispersion can be an important factor for slow-moving groundwater pollution plumes at considerable distances from the source. However, contrary to the "landfill engineer's" suggestion, the situation in monitoring around a leaking tank is not the same as the typical monitoring situation at Subtitle D landfills. It is my experience that rarely are monitoring wells near a leaking tank somewhat randomly spaced hundreds to a thousand or so feet apart along the down groundwater gradient edge of the tank, as they are with Subtitle D landfills.

Detection of Leaks from Underground Tanks Versus Detecting Landfill Liner Leaks

When investigating leaking underground storage tanks, the potential source of the leak, i.e., the tank and its associated plumbing, are confined to a small area. To determine whether a tank has leaked sufficiently to pollute groundwaters, it is necessary to define, through the use of three monitoring wells, the direction of groundwater flow. Once this direction has been defined, then the placement of monitoring wells to detect leaks is usually straightforward for relatively homogeneous aquifer systems. However, for landfills, which can occupy hundreds to a thousand or more acres, the initial leakage point is unknown. Therefore, it is not possible to strategically locate monitoring wells downgradient which would reliably detect the leak when it first reaches the point of compliance for groundwater monitoring.

In accord with Subtitle D regulations, the point of compliance can be no more than 150 meters from the down groundwater gradient edge of the landfill, and must be on the landfill owner's property. Since there are no restrictions on landfilling to the edge of the property, I have repeatedly seen landfills with waste deposition areas within a few feet of the adjacent property line. Further, in some states, such as California, the point of compliance for Subtitle D landfill groundwater monitoring is the down groundwater gradient edge of the waste deposition area. This means that there can be little distance between where leaks can occur along the down groundwater gradient edge of the landfill, and the point of compliance for groundwater monitoring. While dispersion might be important for helping to detect leaks from the up groundwater gradient side of the landfill for slow-moving groundwater pollution plumes, it is of limited value in detecting leaks on the down groundwater gradient side of the landfill.

Dr. Cherry and his associates at the University of Waterloo examined the lateral dispersion that occurs in a relatively homogeneous aquifer system from a two-foot-long line source of a tracer. This group found that the two-foot-wide source had spread to about ten feet within 150 meters of the source. This means that monitoring wells would have to be spaced no more than 10 to 20 feet apart in order to reliably detect down groundwater gradient side of the landfill leaks. With monitoring wells spaced at least hundreds of feet apart at distances less than 150 meters from the down groundwater gradient edge of the landfill, there is appreciable distance between the monitoring wells, where substantial leachate plumes could pass without being detected.

It is inappropriate to suggest that detecting leaks from underground storage tanks is similar to detecting liner leaks from municipal landfills. The two situations are obviously significantly different.

Detecting Leaks from Landfills Sited above Fractured Rock Aquifer Systems

There are many Subtitle D landfills sited above fractured rock aquifer systems where it is impossible to reliably monitor landfill liner leakage, even if the monitoring wells are spaced only a few feet apart. Under most of these types of situations dispersion will not overcome the fundamental problems of monitoring the eventual failure of the landfill liner system.

Support of Dr. Cherry's Conclusions on the Unreliability of Groundwater Monitoring at FML-Lined Landfills

The work of Dr. John Cherry and his associates at the University of Waterloo has been supported by a number of competent hydrogeologists with whom I have worked, in review of the potential of proposed Subtitle D landfills to pollute groundwaters, as well as the ability of a proposed groundwater monitoring well array to detect this pollution in accord with Subtitle D requirements, when the pollution first reaches the point of compliance for groundwater monitoring.

Detecting Leaks in Fast and Slow-Moving Plumes

For fast-moving plumes in homogenous aquifer systems, dispersion will not necessarily be adequate to significantly improve the reliability of the typical Subtitle D monitoring well array. There are many places within a landfill footprint where leaks could occur and not be detected at the point of compliance for groundwater monitoring. For slow-moving plumes, there are important questions about whether the monitoring system will be maintained and operated when these plumes reach the point of compliance for groundwater monitoring. With no assured post-closure funding after 30 years, there is no assurance that groundwater monitoring systems will still be maintained and operated when they are needed, when the slow-moving plume with its dispersion reaches the point of compliance for ground water monitoring.

Recommended Approach for Permitting of Landfills

It has been my recommendation at landfill permitting hearings, that rather than assuming that arbitrarily spaced groundwater monitoring wells will reliably detect landfill liner leaks in accord with Subtitle D requirements, i.e., when the leachate-polluted groundwater first reaches the point of compliance for groundwater monitoring, the landfill applicant should be required to provide reliable information on the monitoring well spacing, considering the site-specific characteristics of the geology-hydrology of the aquifer system that will be polluted when the Subtitle D liner system fails to prevent significant leakage of leachate through the liner. The burden of proof for the reliability of the groundwater monitoring system should be on the landfill applicant and not the public whose groundwater could be polluted if the arbitrarily developed groundwater monitoring system fails to detect the leachate-polluted groundwater at the point of compliance. It should be the responsibility of the landfill applicant to define, based on the site-specific characteristics of the aquifer, the monitoring well array needed to have a 95% probability of detecting one to two-foot-long rips, tears, or points of deterioration in the landfill FML liner at the point of compliance for groundwater monitoring, when the leachate-polluted groundwater first reaches this point.

Adopting this approach would quickly show what is well understood, that today's groundwater monitoring systems at many Subtitle D landfills are cosmetic and provide little in the way of reliable monitoring of leachate-polluted groundwaters before widespread liner deterioration occurs. At many Subtitle D landfills, the leaks through the liners will likely first be detected in off-site production wells, rather than by the groundwater monitoring system.

Assessing the Potential of Minimum Subtitle D Lined Landfills to Pollute: Alternative Landfilling Approaches

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Abstract

The US EPA Subtitle D regulations specify as a minimum, MSW landfills be lined with a single composite liner which is part of a leachate collection and removal system. Upon reaching the landfill capacity, a low-permeability cover is installed. A groundwater monitoring system is used to detect liner failure during the 30-year mandated post-closure care period. The waste in a minimum Subtitle D Adry tomb@ landfill will be a threat to pollute groundwaters by leachate, effectively forever. The landfill liner and cover have a finite period of time when they can be expected to function effectively to keep moisture out of the landfill that generates leachate and to collect leachate formed within the landfill. The groundwater monitoring systems typically used with monitoring wells having zones of capture of about one foot on each side, spaced hundreds of feet apart, have low probabilities of detecting landfill liner failure that leads to groundwater pollution before off-site pollution occurs. The 30 years of mandated post-closure care is an infinitesimally small part of the time that the waste in a minimum Subtitle D Adry tomb@ landfill will be a threat to generate leachate that can pollute groundwater. Fundamentally, the minimum Subtitle D MSW landfill is a technologically flawed approach that, at best, only postpones when groundwater pollution occurs for those landfills sited at geologically unsuitable sites, i.e. those without natural groundwater quality protection. The US EPA Subtitle D regulations also fail to address the justifiable NIMBY associated with active life releases (odors, dust, blowing paper, etc.) from the landfill to the surrounding area. This paper discusses the deficiencies in minimum Subtitle D landfilling of MSW and provides guidance on alternative landfilling approaches that can protect public health, groundwater resources, environment and the interests of those within the sphere of influence of the landfill.

Impact of Municipal and Industrial Non-Hazardous Waste Landfills on Public Health and the Environment: An Overview

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Prepared for California Environmental Protection Agency's Comparative Risk Project, May (1994).

Executive Summary

Classical unlined sanitary landfills are well-known to release large amounts of hazardous and otherwise deleterious chemicals to nearby groundwater and to the air, via leachate ("garbage juice") and landfill gas. It is known that such releases contain a wide variety of potential carcinogens and potentially toxic chemicals that represent a threat to public health. However, little quantitative information exists on the total hazard that landfills represent to those who live or otherwise use properties near the landfill. Epidemiological studies of the "exposed" populations near landfills and Superfund sites have not detected a clearly discernable increase in the incidence of cancer in those populations. This is to be expected because of the insensitivity of epidemiological methods for detecting small increases in cancer incidence in limited populations over the normal lifetime cancer risk for the US population of one cancer in three people. It would be rare that a sufficient number of individuals near Superfund site landfills would experience an average increased cancer risk of 1 in 1,000.

The leachate from MSW landfills is a highly concentrated "chemical soup," so concentrated that small amounts of leachate can pollute large amounts of groundwater rendering it unsuitable for use for domestic water supply. In addition to potential carcinogens and highly toxic chemicals, MSW leachate contains a variety of conventional pollutants that render a leachate-contaminated groundwater unusable or highly undesirable due to tastes and odors, reduced service life of appliances (e.g., dishwashers, hot water heaters, plumbing), fabric (clothes), etc. Furthermore, both gas and leachate from MSW landfills contain many organic chemicals that have not been characterized with respect to specific chemical content or their associated public health or other hazards. These "non-conventional pollutants" include more than 95% of the organics in MSW leachate.

There are more than 65,000 chemicals in US commerce today; about 1,000 new chemicals are being developed each year. Of those chemicals, only about 200 are regulated and measured in studies of MSW landfill leachate-contamination. Given the highly concentrated nature of MSW landfill leachate, that a large portion of the organics in MSW leachate are of unknown character and hazard, and that a comparatively few chemicals are regulated, it should not be assumed that the fact that a leachate-contaminated groundwater meets all drinking water MCL's (maximum contaminant lev-

els) means that the water should be considered safe to consume. Furthermore, once a groundwater is contaminated by MSW landfill leachate of the type produced in today's Subtitle D landfills, it and the associated aquifer cannot be cleansed so as to render a water that can be considered reliable for consumption and certain other uses. The contaminated portion of the aquifer must be abandoned for future use as a domestic water supply source and for conjunctive use storage of surplus surface waters for use during drought periods. Therefore, it is prudent public health and water resource management policy to assume that any contamination of groundwater by MSW landfill leachate represents a significant threat to public health and the environment and should cause termination of the use of the water for domestic water supply purposes.

Landfill gas emissions also contain large amounts of obnoxious and otherwise deleterious chemicals that are highly detrimental to nearby property owners and users. The methane in landfill gas releases, while odorless, poses a threat of explosions in enclosed structures and contributes to the greenhouse gases that promote global warming. Both methane and C02 in landfill gas can also be highly detrimental to vegetation on the landfill cover and near the landfill. The obnoxious odors that are emitted from MSW landfills can persist for a mile or more from the landfill. Such odors provide a tracer for non-odorous as well as odorous hazardous chemicals in gaseous emissions. Because of the large amounts of non-conventional pollutants in landfill gas, the detection of landfill odors on offsite properties should warn of a significant public health threat. Odors and other adverse conditions created by landfill operations cause property values to decrease within a mile or so of the landfill.

New Subtitle D regulations prescribe a "dry tomb" landfilling approach in which untreated MSW is placed in plastic-sheeting- and compacted-soil-lined landfills in an attempt to isolate the wastes from water for as long as the wastes will be a threat. Evaluation of the character of the systems incorporated relative to physical, chemical, and biological processes as they occur in such systems, and the nature of the materials placed in them shows the "dry tomb" landfilling approach to be a flawed technology that will not protect the public health, or groundwater and air resources under and above the landfill and adjacent properties. At best, it will only postpone the leakage of leachate and gas to adversely affect public health and environmental quality.

MSW in a "dry tomb" landfill will be a threat to public health, groundwater resources, and the environment forever. The effectiveness of Subtitle D landfill liner systems in preventing leachate migration is compromised after installation, and will deteriorate over time allowing increasing amounts of leachate to pass through the liner into the groundwater system hydraulically connected to the bottom of the landfill.

The US EPA and states' Subtitle D groundwater monitoring approach of using vertical monitoring wells spaced hundreds to a thousand or more feet apart at the groundwater monitoring point of compliance is grossly inadequate for detecting incipient groundwater pollution from lined landfills. Unlike leakage from unlined landfills in homogeneous hydrological settings, the initial leakage from plastic sheeting-lined Subtitle D landfills will be through holes, tears, or imperfections in the sheeting. Such point-source leakage results in the emanation of "fingers" of leachate-contaminated groundwater which are a few feet wide at the point of compliance for groundwater monitoring. Vertical monitoring wells have effective zones of capture of leachate-contaminated groundwater of only about one foot around the wells. With the spacing of such wells allowed, the US EPA Subtitle D groundwater monitoring approach will not detect groundwater pollution, much less incipient landfill leakage, before widespread groundwater pollution has occurred.

The municipal solid waste stream of today and of the future potentially contains less industry-derived hazardous chemicals than the classical sanitary landfill. However, it does, and will continue to, contain large amounts of highly hazardous and otherwise deleterious chemicals that will render groundwaters contaminated by such leachate unusable for domestic water supply purposes.

RCRA set forth a minimum post-closure care period of 30 years; that period was also used by the US EPA in implementing Subtitle D regulations. However, 30 years is an imperceptibly small, and insignificant part of the total time that MSW in Subtitle D "dry tomb" landfills will be a threat to public health, groundwater resources, and the environment. Insufficient funds are being collected from waste generators and set aside to meet the inevitable and unending needs for post-closure care monitoring and maintenance, and groundwater and landfill remediation for Subtitle D landfills. The Subtitle D landfilling approach and requirements adopted by the US EPA are superficial and only serve as a stop-gap measure for managing MSW. They enable today's society to continue to enjoy solid waste "disposal" without the responsibility and expense of preventing them from causing future problems. This is being enjoyed at the expense of future generations' public health, groundwater resources, and welfare.

Contrary to claims made by the US EPA in implementing Subtitle D landfill regulations in October 1991, Subtitle D landfill requirements do not address the justifiable "NIMBY" concerns and problems associated with the active life of landfills or the post-closure care impacts on those who own or use properties within several miles of the landfills. In not recognizing the potential significance of non-conventional pollutants, the nature of processes within the landfills, the nature and limitations of the liner systems and monitoring approaches, and the perpetual threat of contaminants in landfills, the US EPA Subtitle D and state regulations do not protect public health or groundwater resources for as long as the wastes represent a threat. Since Subtitle D landfills only postpone groundwater pollution, and for many landfills, gas emission problems, Subtitle D landfills do not significantly alleviate the threat of landfill gas and leachate to those who own or use properties within the sphere of influence of the landfill. The "dry tomb" landfilling approach should be recognized as "temporary" storage for MSW that will ultimately require exhumation and treatment of the wastes unless groundwaters hydraulically connected to them are to be abandoned as water resources.

More protective alternatives to US EPA Subtitle D "dry tomb" landfills are available to address both the near-term and long-term threats that such landfills represent to public health, groundwater resources and the environment, as well as to the welfare of those within the sphere of influence of the landfill. The additional costs for such approaches are insignificant compared to the long-term costs that will have to be paid by future generations for today's waste management mistakes. One such alternative is a fermentation/leaching "wet-cell" approach. In brief, that approach includes the recycling of landfill leachate in a double-composite-lined landfill that contains shredded MSW followed by a decade or so of clean-water washing (leaching) of the solid waste to produce non-polluting residues. The lower composite "liner" serves not for last-resort containment, but rather as a lysimeter leak detection system for the upper-composite liner. Associated with that waste treatment/management concept is required the setting aside of sufficient funding in a dedicated trust fund derived from increased disposal fees to exhume the wastes when leakage through the upper-composite liner cannot be stopped. To address justifiable active-life NIMBY concerns and problems, it is necessary that the landfill be sited with an adequate landfill owner-owned land buffer of at least one mile about the outer reaches of the landfill. The landfill buffer would be used to dilute the adverse impacts of the landfill, such as odors, seagulls, etc. that occur with today's landfilling operations. The estimated initial cost of this approach is about 10 to 15 cents/person/day more than that paid for solid waste management in Subtitle D landfills. Expenditures of this amount will not only address justifiable NIMBY issues of today's landfills, but also significantly improve the protection of future generations from adverse impacts of gaseous and leachate emissions. Further information on each of these issues is provided in this report and in references contained therein.

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THE WALL STREET JOURNAL.

Plastic dump liners have been slow in coming

Bailey, Jeff. **Wall Street Journal**. (Eastern edition). New York, N.Y.: Nov 14, 1996. pg. A4, 5 pgs

Abstract (Summary)

Five years after federal rules were rolled out aimed at requiring environmental protecting plastic liners under garbage dumps, the liners are installed at only about one third of the nation's dumps, a consultant's study found. What's more, the EPA is gearing up to allow increasing varieties and amounts of industrial wastes, some of them formerly channeled to hazardous-waste-only disposal sites, to go to regular trash dumps.

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Five years after federal rules were rolled out aimed at requiring environment-protecting plastic liners under garbage dumps, the liners are installed at only about one third of the nation's dumps, a consultant's study found.

What's more, the Environmental Protection Agency is gearing up to allow increasing varieties and amounts of industrial wastes, some of them formerly channeled to hazardous-waste-only disposal sites, to go to regular trash dumps.

In addition to raising environmental concerns, these two developments are angering waste-handling companies that compete against dumps, particularly trash and hazardous-waste incinerators that already have much higher operating costs.

The Integrated Waste Services Association, which represents operators of more than 100 big trash-to-energy plants, objects to what it considers unequal treatment. The waste-burning plants are just beginning a $400 million retrofit to comply with Clean Air Act regulations, and some have been suffering because a glut of disposal capacity has driven disposal prices downward in some big markets.

"It's not fair," said Maria Zannes, president of the Washington-based association. "These guys get all the breaks."

The study was conducted by Environmental Information Ltd., a Minneapolis consulting and publishing concern. The firm has accepted funding from hazardous-waste handlers to perform other studies, but funded this study entirely on its own, said Jeff Smith, a senior associate.

According to the study, only 960 of the nation's 2,931 active dumps have synthetic liner systems.

The liner-installation shortfall arose as the EPA delegated to states the implementation of dump rules, and allowed the states to exempt many disposal facilities from any synthetic-liner requirement. Most commonly exempted were dumps in some remote areas, those that take smaller volumes of waste, and, those in arid climates where low rainfall reduces the likelihood that water contaminated by waste would seep into groundwater.

But some large and active dumps, particularly those owned by municipalities, continue to accept waste into unlined areas because the rules allowed "vertical expansion" to continue on top of older, unlined dump areas.

This shows how even a simple environmental safeguard -- itself far from an absolute protection against fouling groundwater -- ends up being watered down as the EPA, states, local government and the waste industry all get involved in the implementation of federal rules.

To be sure, the biggest and busiest dumps in the U.S. tend to have synthetic liner systems, which include piping to extract and treat garbage juice known as leachate.

Browning-Ferris Industries Inc., the nation's No. 2 dump operator, said 80 of its 82 active U.S. trash dumps have such liner systems. WMX Technologies Inc., No. 1 among dump operators, said it has synthetic liners in all of its dumps horizontally expanded since 1993 -- about 80% of its more than 100 U.S. sites. Some of the remaining 20%, though not all, also have such liners.

It's not only the big dumps that are of concern. Many of the nastiest Superfund cleanup sites, born during the dump-it-anywhere days before regulations, were in fact small facilities.

Adding a synthetic liner costs $25,000 or more an acre at dumps, according to the EPA, while cleaning up even small contaminated dump sites can costs millions of dollars. "The EPA and states seem to prefer a pound of cure to an ounce of prevention," Environmental Information's Mr. Smith said.

The EPA itself doesn't keep track of how many dumps have synthetic liners, leaving that to states. "I'm not shocked," said Bob Dellinger, acting director of the agency's municipal and industrial solid-waste section, of the study's finding about the lack of synthetic liner systems. Mr. Dellinger said the EPA expected about 800 dumps to qualify under the "small, dry and remote" exemptions, and that many of the other dumps without liners are probably still piling trash on top of older, unlined areas.

Proximity to groundwater and the mix of wastes that go into a dump are considered by many waste experts to be as important -- or more so -- than whether a site has a synthetic liner. Mr. Dellinger said the rules and various exemptions were designed to require liners at dumps that pose greater threats.

Credit: Staff Reporter of The Wall Street Journal

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Unexpected leakage through landfill liners.Janet Raloff. ***Science News*** 135.n11 (March 18, 1989): pp164(1). (757 words)

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Unexpected Leakage Through Landfill Liners

For years, the standard way to dispose of hazardous chemicals was to bury them in landfills. Intended as permanent resting places, most of these graves incorporated a bathtub-shaped liner of compacted clay to keep water -- and buried toxic wastes -- from escaping. While clay does limit water leaks fairly well, new field research shows it fails to block the major route by which many toxic chemicals, such as organic solvents, escape.

The researchers say this finding carries grave implications not only for the safety of hazardous-waste landfills begun prior to 1985, but also for the adequacy of current techniques of containing landfill leaks and toxic chemicals spilled on land.

Water provides the two primary means by which pollutants move from landfills. Through a "vehicular" pathway, water can carry dissolved wastes as it flows from areas of high pressure, such as pools collected on the inside of a landfill, to regions of low pressure, such as drier soils underneath. A second pathway uses water quite differently -- as a potentially fixed "conduit" through which dissolved contaminants "diffuse" from regions where their concentrations are higher to areas where they are lower.

Today, notes Richard Johnson, an environmental scientist at the Oregon Graduate Center in Beaverton, engineers work at controlling the vehicular pathway only. Until recently, the standard approach was to line landfills with "impermeable" clay barriers -- ones designed to leak no more than 89 gallons of water per acre daily, according to Environmental Protection Agency (EPA) engineer Kenneth Skahn of Washington, D.C. Diffusion control was all but ignored, Skahn says, because of a prevailing attitude that "diffusion really will never be much of a factor" in landfill leaks. Unfortunately, Johnson says, this attitude fostered a false sense of security.

Johnson's research, reported in the March ENVIRONMENTAL SCIENCE AND TECHNOLOGY, shows significant toxic-chemical diffusion into the barrier of a five-year-old, clay-lined hazardous-waste landfill in Sarnia, Ontario. As expected, there was wide variability in contaminant mobility, with the most water-soluble pollutants moving fastest. Chloride ions, for example, had penetrated about 28 inches into the clay floor. Less water-soluble organic chemicals spent more of their time preferentially clinging to carbon in the clay. Acetone and ketones, among the more water soluble of these organics, traveled only about 5 inches -- three to 20 times farther than would be expected for far less soluble solvents, like benzene and toluene.

Owing to the unusual depth of this landfill's natural clay floor -- about 130 feet -- no contaminant broke through this barrier. However, Johnson says, if the clay's thickness had been more typical of hazardous-waste landfills -- perhaps 3 feet -- his data suggest the more mobile contaminants might have broken through in just five years, and slower ones, like benzene, in 70 years.

So closely do these field data mirror theory, Johnson says, "that if I know what a contaminant's solubility is, and the [barrier's] organic carbon content, I can now predict how fast a chemical will [diffuse through]."

Comments Donald H. Gray, a civil engineer at the University of Michigan in Ann Arbor, "There are important implications here for the design and construction of containment envelopes around hazardous-waste landfills." The new findings show that once water permeability is well controlled, diffusion becomes the dominant exit route for interred wastes.

Since 1985, EPA has banned landfilling of solvents -- like benzene -- and required that new hazardous-waste landfills use multiple barriers of clay and synthetic materials. Less water-permeable than clay, plastics also provide a major barrier to diffusion. Thus, Johnson says, the real concern is with landfills built before 1985. EPA's Robert Landreth says agency officials don't know how many U.S. hazardous-waste landfills rely on clay barriers, but a good guess might be "more than 10 and less than 50." Johnson says a more likely estimate is "at least hundreds."

The new findings are relevant also to current containment efforts, says Walter Weber, a colleague of Gray's at the University of Michigan. Today, engineers commonly cordon off chemical spills in soil and leaking landfills by digging a thick trench around them, preferably down to a natural clay deposit, and filling the trench with a slurry of clay and soil. Once it hardens, the slurry wall becomes relatively impermeable to water. However, this barrier -- often the only one surrounding the toxic chemicals -- offers little protection from diffusion, Weber notes. So he and Gray are studying ways to increase its carbon content -- currently by incorporating fly ash -- to slow the diffusion of trapped organics.

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HAWAII NEWS NOW

Document shows landfill operator fined for design failures

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By Ben Gutierrez - bio | email

KAPOLEI (HawaiiNewsNow) - A document has come to light, showing that the operator of the Waimanalo Gulch landfill and the city were fined $424,000 last year for design failures at the landfill.

The fine was in a notice of violation issued in May 2010, which contended that Waste Management and the city failed to follow design specifications for a liner that was supposed to cover waste, and built the west berm of the landfill too high. According to the notice, the liner was of a lower quality than specified.

Carroll Cox

Carroll Cox, of the environmental group EnviroWatch, noted that the company had paid an even bigger fine. "That comes on the heels of a $2.8 million dollar fine that they paid earlier, for earlier violations. So this is just a constant dripping, so to speak, of one big problem after the other," Cox said.

The huge fine was assessed in 2006; according to the notice of violation, the design process involved in the latest fine began the same year.

Cox contends that the failure to follow the design contributed to the problems that arose when floodwaters went through the landfill and spread refuse and medical waste along the Leeward Oahu coast. "I think I would probably not be here doing this interview, and we wouldn't see the people of Ko Olina, who are rightfully outraged," said Cox. "We wouldn't have the general public querying this one big question: How did medical waste get into the environment, get into the ocean?"

Ko Olina residents were present at a Kapolei Neighborhood Board meeting Wednesday night to discuss the problems at the landfill. Meantime, the city announced Wednesday that the landfill would reopen Friday to allow city crews to dispose of backlogged waste. It will reopen to the general public next week Wednesday.

Cox says the document also points to continuing problems at Waste Management, which have been only made worse by the heavy rain.

"What they are really facing now is having to work in the mud now, in that area. Not just from that storm, but also from water that had gotten behind the liner, and gotten into the cell and presenting a bigger problem," Cox said.

The city's Environmental Services Department said the fine had been settled with the state Health Department. But Cox said it's no longer just an environmental cost, but a cost to taxpayers, because of the fines.

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REVIEW

Health effects associated with the disposal of solid waste in landfills and incinerators in populations living in surrounding areas: a systematic review

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Abstract
Objectives Potential health hazards for the environment and people living nearby landfills and incinerators are claimed to be related to several methods of waste management. Independent systematic review of the scientific literature is a key procedure to support the lay public and policy makers to achieve informed decisions.
Methods The study design and potential biases of papers retrieved in this comprehensive literature search were analyzed.
Results The most consistent result is that the risks of congenital anomalies and hospitalization due to respiratory disease are likely to be real nearby special waste landfills. From the very little information on exclusively urbanwaste depots it is reasonable to say that correct management of landfill does not increase the risk of these health effects. It is confirmed that historically incinerators are an important source of pollution and harm for the health of populations living nearby; however, changes in technology are producing more reassuring results.
Conclusions A moderate level of confidence is possible in limited areas of knowledge, implying the need to overcome the limitations of current studies about exposure assessment and to control confounders at the individual level.

Keywords Incinerator · Landfill · Environmental exposure · Environmental diseases · Population health

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Electronic supplementary material The online version of this article (doi:10.1007/s00038-013-0496-8) contains supplementary material, which is available to authorized users.

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Introduction

Management of solid waste disposal is a priority issue in the organization of modern societies. In spite of the increasing recycling activities, landfills and incinerators are widely used to manage the final phase of waste disposal. Potential health hazards for the environment and people living nearby are claimed to be related to waste management, which is known to release potentially harmful substances although in small quantities and at very low levels. Many uncertainties surround the assessment of health effects, and the need for independent systematic reviews of the current scientific information is urgent in order to provide the lay public and policy makers with reliable lines of scientific knowledge. A number of reviews are already available (Vrijheid 2000; Hu and Shy 2001; Rushton 2003; Dolk and Vrijheid 2003; Department for

Environment, Food and Rural Affairs (DEFRA) 2004; Franchini et al. 2004; Michaels and Monforton 2005; Minichilli et al. 2005; Linzalone and Bianchi 2007; World Health Organization (WHO) 2007; Russi et al. 2008; Signorelli et al. 2008; Giusti 2009; Porta et al. 2009). The reviews underline the difficulties in interpreting data from primary studies because of the lack of accurate exposure information and control of potential confounders. This problematic interpretation further complicates a scenario where risk communication is poorly manageable, risk perception is greatly biased, and conflicting interests become the dominant issues for discussion, implying huge difficulties in managing public health issues affecting the safety of communities. This review updates the evaluation of evidence (19 more papers on landfills and 13 on incinerators included in the tables in the "Electronic supplementary material") derived from the literature on the health effects of landfills and incinerators in people living in their proximity and discusses the degree of uncertainty associated with the risk estimates, thereby providing researchers, citizens, and institutions with an updated independent piece of evidence. This process has been promoted by the Italian authorities after the dramatic garbage management failures in Campania, an Italian area where the safety of communities has been put in danger by very bad organization and the presence of several illegal landfills; the resultant potential health hazards in some areas of Campania are associated with higher mortality rates for various diseases in comparison with those in other regional areas (Altavista et al. 2004; Comba et al. 2006; Martuzzi et al. 2009; Fazzo et al. 2008, 2011).

Methods

The scientific literature was scrutinized through computerized literature searches using PubMed, Embase, Web of Science, and the Cochrane Library from 1 January 1983 to 1 June 2012. The search strategy consisted in the use of various combinations, in line with the specific database language, of the terms "incinerat* OR "refuse disposal" OR "refuse disposals" OR landfill*", "population* OR habitant*", "environmental exposure", "environmental disease"; the search was subsequently improved using more restrictive terms related to both exposure to disposal sites and disease outcomes. Primary publications on the health effects of landfills and/or incinerators on the population living in the proximity were the subject of this systematic review. Other types of papers (systematic reviews, biomonitoring of toxic agents in the proximity of waste disposal sites, environmental impact estimation) were consulted in order to integrate all the available scientific information for the interpretation of the results. The search was completed using the references identified in the retrieved papers and any highlighted by the working group. A total of 201 relevant papers were identified, 101 on landfills and 100 on incinerators. The papers were screened for eligibility by two independent reviewers; disagreements were resolved by discussion. Out of 100 papers on landfills, 71 were excluded (1 systematic review, 1 duplicate paper, 1 focused on occupational exposure, 34 biological studies, 34 other non-relevant types of papers); therefore 29 papers were evaluated (4 cohort studies, 8 case–control studies, 17 ecological studies). Out of 100 papers on incinerators, 69 were excluded (2 systematic reviews, 1 duplicate paper, 1 focused on occupational exposure, 29 biological studies, 36 other non-relevant types of papers); therefore 31 papers were evaluated (2 cohort studies, 9 case–control studies, 17 ecological studies, 3 cross-sectional studies). The list of excluded papers is reported in Appendix A (Electronic supplementary material).

Information on study subjects (number, age, gender, country), exposure assessment, outcome assessment, estimated effects, and potential bias were independently abstracted by three observers using a predefined format, and disagreements were resolved by discussion. Characteristics of the studies are reported in Appendices B and C (Electronic supplementary material) for landfills and incinerators, respectively. The tables therein are arranged by outcome.

To assess the size and direction of potential biases an evaluation scale is proposed that envisages exposure assessment, outcome assessment, and confounding control (Table 1). For each item the null value (0) indicates that no influence on the estimation is likely, a positive sign that the effect estimates could be less (+) or more (++) overestimated, and a negative sign that the effect estimates could be less (−) or more (− −) underestimated. As for exposure assessment, underestimation is considered according to the study designs; conversely for outcome and confounding assessment, overestimation is considered (Porta et al. 2009; WHO 2007; Franchini et al. 2004; Giusti 2009). The results of this evaluation were discussed among three authors (SP, EB, and PC) and the grade was assigned according to the majority rule in case of inconsistencies.

An attempt to define the relationship between the process (landfill/incinerator) and the various diseases in terms of potential cause–effect evaluation was performed according to Porta et al. (2009), using the International Agency for Research on Cancer (IARC) criteria for carcinogenesis (IARC–WHO, 2013). The results of this evaluation were discussed among three authors (SP, EB, and PC) and the relationship was assigned according to the majority rule in case of inconsistencies.

Table 1 Qualitative assessment of internal validity of the reviewed studies

Item	Risk of bias	Evaluation criteria
Exposure	−	If defined by both the distance from the site and some measurement of polluting substances
	− −	If defined only by the distance from the site or by an exposure area
	0	Use of individual data
Outcome	0	If reported from cancer registries or direct measure of incidence
	+	If reported by death registries
	++	If reported by hospital discharge forms or detected through questionnaires
Confounding	0	Use of individual data
	+	Control at a population level (including deprivation index)
	++	No control

Results

Studies on communities living near landfills

Twenty-nine papers on the health effects in communities living in the proximity of landfills were evaluated. One of the major issues in the evaluation was the difficulty in distinguishing between solid urban waste and other types of wastes. There is not yet a standardized definition of the various types of wastes. The terms dangerous, special, toxic, industrial, and commercial are not uniformly used in different countries and over time periods. Moreover, the types of wastes disposed in a landfill may have changed over time. The outcomes considered in the papers were all cancers, birth defects, respiratory diseases, and total mortality. In some papers multiple outcomes were evaluated.

Cancer

The relationship between landfills and cancer has been evaluated in seven studies (5 ecological, 1 cohort, and 1 case–control)

Colorectal A cohort study carried out in Finland compared the incidence of colorectal cancer in a community in the proximity of a landfill containing industrial and urban wastes to that in a control cohort (Pukkala and Pönkä 2001). No difference was found, but the low number of cases and the lack of adjustment for confounders, beside age and sex, make the results less reliable. An ecological study in Australia evaluated mortality and incidence in populations living nearby a landfill containing urban special and dangerous wastes, both liquid and solid, did not find any risk excess, but again involved a low number of cases (Williams and Jalaludin 1998).

Liver In an ecological study that analyzed mortality in a community living in an Italian area containing a landfill, an incinerator, and a refinery, liver cancer mortality was not different in populations living at various distances from the sites, after adjustment for age and deprivation index and separately by sex (Michelozzi et al. 1998). In another Italian study a potential risk was found in males, but no adjustment was made and information on outcomes cannot be related to the distance from the landfills (Minichilli et al. 2005). A Canadian case–control study found no significant trend in populations living at various distances from an urban waste landfill, adjusting for some confounders (Goldberg et al. 1999). Multiple comparisons on 30 cancer sites and the low number of cases suggest that caution be adopted in interpreting these results. A Brazilian ecological study of urban landfills in Sao Paolo found no difference comparing people living at less and more than 2 km from several sites (Gouveia and Ruscitto do Prado 2010a).

Bladder A large national ecological study, carried out in the UK, analyzed the incidence of bladder cancer in populations living at various distances from a landfill site (Jarup et al. 2002) and did not detect any association, nor when only special wastes were considered. Two other studies were unable to detect any association (Williams and Jalaludin 1998; Gouveia and Ruscitto do Prado 2010a).

Larynx A significant decrease of mortality rates as the distance from the sites increased was reported in Italy, but with low numbers (Michelozzi et al. 1998). Another study in Canada did not detect any association (Williams and Jalaludin 1998).

Lung None of the three evaluated studies was able to detect any association (Williams and Jalaludin 1998; Michelozzi et al. 1998; Pukkala and Pönkä 2001).

Kidney Two studies found a modest non-significant increase in risk (Michelozzi et al. 1998; Goldberg et al. 1999).

Lymphomas Only one study (Goldberg et al. 1999) found a significant association, whereas those by Williams and Jalaludin (1998) and Michelozzi et al. (1998) did not.

Leukemia Two studies in children (Jarup et al. 2002; Gouveia and Ruscitto do Prado 2010a) and four in adults (Williams and Jalaludin 1998; Michelozzi et al. 1998; Jarup et al. 2002; Gouveia and Ruscitto do Prado 2010a) were unable to detect any association.

Brain No association was found in a UK study (Jarup et al. 2002). An increased risk only in males living in the proximity of the landfill was detected in a US study (Williams and Jalaludin 1998), limited by low numbers of cases.

Other cancers In a previously described study no association was found for breast, uterus, prostate, stomach, and skin cancers (Williams and Jalaludin 1998). Goldberg found an increased risk for pancreatic cancer but not for prostate (Goldberg et al. 1999). Another study found an increased risk for skin and pancreatic cancers only in males (Pukkala and Pönkä 2001).

Birth defects and reproductive disorders

Out of the 22 studies analyzing the relationship between these disorders and the presence of landfills, 13 are ecological, 2 cohort, and 7 case–control.

Birth defects in general

Six studies found statistically significant associations (Fielder et al. 2000, 2001; Elliott et al. 2001, 2009; Palmer et al. 2005; Vrijheid et al. 2002), but five other studies (Morris 2003; Dummer et al. 2003b; Boyle et al. 2004; Kloppenborg et al. 2005; Gouveia and Ruscitto do Prado 2010a) did not. In the UK an ecological study of residential distance from a site, the risk of congenital malformations was higher; however, that risk was also detected by analyzing data before the opening of the landfill (Fielder et al. 2000). A national UK study analyzed congenital anomalies and low birth weight in populations living at different distances from a large number of waste sites (19,196) (Elliott et al. 2001). A statistically significant association was found (RR 1.05), but it disappeared for urban solid waste (RR 0.99) when analyzed separately from toxic waste (RR 1.08) (Elliott et al. 2009). A Danish national ecological investigation found no association in comparing people living at different distances from the sites (Kloppenborg et al. 2005). Evaluating the rates before and after the opening of 24 landfills in Wales, Palmer et al. (2005) found a significant increase over time. Among residents of areas close to 15 landfills in Brazil no association was detected comparing rates of people living at less than 2 km and the whole city, after adjustment for sex and age (Gouveia and Ruscitto do Prado 2010a). Another UK study reported on a landfill where all kinds of wastes (urban solid, industrial, and special) were transferred, and compared three areas close to site and 26 distant areas (Fielder et al. 2001). After the opening of the site a significant risk increase in the closest areas was found, but the authors cautiously interpreted the findings owing to poor accuracy and incompleteness of data. A Scottish investigation found no association in residents at less than 2 km from the site compared with those at more after adjustment for age and deprivation index (Morris 2003). A multicenter case–control study (EUROHAZCON), carried out in five countries (Belgium, Denmark, France, Italy, and the UK), found a significant increase in congenital malformations in people living nearby sites containing dangerous substances (Vrijheid et al. 2002). Caution is suggested in interpreting the results owing to the difficulty in correctly classifying the sites according to their dangerousness. A previous investigation on dangerous waste landfills had found conflicting results (Geschwind et al. 1992). In a UK retrospective cohort study stratifying by three time periods and four types of landfills, Dummer et al. (2003b) found no association. A similar lack of association was found in a study on urban solid wastes in Northern Ireland (Boyle et al. 2004).

Non-chromosomal birth defects

The EUROHAZCON case–control study detected an increase in risk of non-chromosomal birth defects in people living at less than 3 km from landfills containing both urban solid and industrial or toxic wastes (Dolk et al. 1998). In this study a statistically significant increased risk was found in the subgroups of neural-tube defects (OR 1.86), malformations of the cardiac septa (OR 1.49), and anomalies of great arteries and veins (OR 1.81).

Nervous system birth defects

In a UK retrospective cohort study in which data were stratified by three time-periods and four types of landfills, congenital anomalies were significantly higher close to urban solid waste landfills (Dummer et al. 2003b), whereas a previous study had not found this relationship (Croen et al. 1997). Another study confirmed the association for a landfill containing toxic substances (Marshall et al. 1997).

Cardiovascular defects, hypo- and epispadias, oral defects

Statistically significant higher risk of hypo- and epispadias was detected in children living close to industrial toxic wastes (Geschwind et al. 1992). For cardiovascular and oral anomalies no such risk was found in another investigation (Croen et al. 1997).

Down syndrome

No association was found for Down syndrome in the analysis of 6,829 sites (Jarup et al. 2007).

Sirenomelia and cyclopia

The two studies on this malformations analyzed four cases of sirenomelia and four of cyclopia (Castilla and Mastroiacovo 2008; Orioli et al. 2009). The identification of a possible cluster of sirenomelia has to be interpreted cautiously in the light of this very low number of observations.

Low birth weight

A retrospective cohort study in Alaska took into account several confounders and classified sites according to dangerousness, finding a risk nearby the sites with intermediate and high dangerous levels (Gilbreath and Kaas 2006). An ecological study in the UK, part of the EUROHAZCON on mixed sites, found a small significant risk increase in residents at less than 3 km, evaluating seven areas close to ten sites (Morgan et al. 2004). A case control study in Quebec found a small increase in risk which persisted after adjustment for several confounders; however, it did not find any association with preterm births (Goldberg et al. 1995). As reported in a previous section a nationwide UK study reported an increase, with no distinction between the types of waste disposed (Elliott et al. 2001). Only an ecological UK study, described above, found no association (Fielder et al. 2000).

Respiratory diseases

A retrospective Finnish study on a site containing urban and industrial wastes reported an increase of asthma incidence (Pukkala and Pönkä 2001), and an ecological investigation in the UK found an increase in hospitalization for respiratory diseases, again dealing with a waste site also containing industrial wastes (Fielder et al. 2001). In another retrospective US cohort study the results suggested an increased rate of hospitalization for asthma and respiratory diseases (Ma et al. 2007).

Total mortality

Three ecological studies reported on this association: no association was reported in one (Williams and Jalaludin 1998), whereas in two there was some indication of a positive association (Fielder et al. 2001; Minichilli et al. 2005). However, in the study by Williams and Jalaludin (1998) the detected risk was consistent with that reported before the opening of the site; in the other studies there is no indication of the distance from the site. No association was found in a US cohort study (Gensburg et al. 2009).

Studies of communities living near incinerators

Thirty-one papers on the health effects in the communities living in the proximity of incinerators were evaluated. The following outcomes were considered: cancers (15), birth defects (10), respiratory diseases (5), cardiovascular diseases (1), total mortality (1), and skin disease (1). In some papers multiple outcomes were evaluated.

Cancer

Fifteen studies analyzed the relationship between incinerators' activity and cancer. Most studies are ecological or case–control and only one is based on a retrospective cohort.

All cancers Three ecological (Elliott et al. 1996; Goria et al. 2009; Federico et al. 2010) and one retrospective cohort study (Ranzi et al. 2011) evaluated the association between incinerators and all cancers in adults. In a UK ecological study the incidence increased; however, no adjustment for relevant confounders was performed and the authors claimed to be cautious in their interpretation (Elliott et al. 1996). In an Italian study no association was reported in the four geographical areas analyzed (Federico et al. 2010), whereas another Italian cohort study reported an increase in all-cancer mortality (RR 1.47) in women exposed to elevated levels of heavy metals (>2 ng/m^3) (Ranzi et al. 2011). In a modeling risk estimation study a linear relationship was found, but limitations in study design and patient selection imply problems of interpretation (Goria et al. 2009). In an ecological study no excess risk of cancer mortality was found in children aged less than 5 years (Gouveia and Ruscitto do Prado 2010b), but according to analyses coming from a companion study to that of Elliott et al. (1996) the influence of population migration might influence the results owing to poor accuracy of the case findings (Knox 2000). Overall, the evidence appears weak and conflicting.

Non-Hodgkin lymphomas Three ecological studies and one cohort study found no association (Elliott et al. 1996, Federico et al. 2010; Gouveia and Ruscitto do Prado 2010b; Ranzi et al. 2011), whereas two case–control studies and one ecological study found a positive association with dioxin levels (Viel et al. 2000; Floret et al. 2003; Viel et al. 2008a), especially in women (Viel et al. 2008a); however, some exposure measurement errors may misestimate the effects. An ecological Italian study reported higher Standardized Mortality Ratio (SMR) between 1986 and 1992 for non-Hodgkin lymphomas (not for Hodgkin lymphomas) in a municipality where an incinerator had operated until 1985 (Biggeri and Catelan 2005).

Sarcoma and soft tissues Six ecological (Elliott et al. 1996; Viel et al. 2000; Floret et al. 2004; Biggeri and Catelan 2005; Viel et al. 2008a; Federico et al. 2010), two case–control (Comba et al. 2003; Zambon et al. 2007), and one cohort studies (Ranzi et al. 2011) provide data. No association was shown in five (Elliott et al. 1996; Floret et al. 2004; Biggeri and Catelan 2005; Federico et al. 2010; Ranzi et al. 2011). The other studies reported: (a) significant risk increase associated with living less than 2 km from the site, but based on five cases and with a very wide confidence interval (Comba et al. 2003); (b) significant risk increase by level and duration of exposure, especially in women (Zambon et al. 2007); (c) risk increase but at exposure levels higher than those detectable in more modern incineration technologies (Viel et al. 2000, 2008a). The evidence of risk due to an old-generation plant is convincing.

Breast No association was found in a case–control and a cohort study (Viel et al. 2008b; Ranzi et al. 2011). A small association was found in a study designed to compare different ways of modeling exposure and confounding, and the results are strongly limited by this study objective (Goria et al. 2009).

Lung Two ecological studies and one case–control study reported a risk excess in people living close to the emission site (Elliott et al. 1996; Biggeri et al. 1996; Parodi et al. 2004). In the studies carried out in Italy, there might be an exposure misclassification because other pollution sources were present but not identified (Biggeri et al. 1996; Parodi et al. 2004). More recent investigations, with better exposure measurement, found no association (Federico et al. 2010; Gouveia et al. 2010b; Ranzi et al. 2011).

Colorectal An increased risk with distance from the site was reported in the UK, but the authors cautiously suggest possible overestimation due to poor control of confounding factors (Elliott et al. 1996). No risk was found in an ecological study in Italy, with a good outcome measurement (Federico et al. 2010). In the same region another cohort study found higher mortality in men and higher incidence in women, but the increased risk was found at heavy metal exposure levels of 1–2 ng/m^3 and not at higher levels (Ranzi et al. 2011).

Liver Recent studies found no association (Federico et al. 2010; Gouveia et al. 2010b; Ranzi et al. 2011). A less recent investigation in the UK had found a significant risk increase associated with smaller distances from the sites (Elliott et al. 1996). A subsequent analysis of this data and including a histological evaluation of cancer cases confirmed the findings. (Elliott et al. 2000). A Brazilian study carried out in rural deprived areas found an association, but its validity is diminished by flaws in the study design (Goria et al. 2009).

Larynx Three ecological studies and one cohort study found convincing associations (Elliott et al. 1996; Federico et al. 2010; Gouveia et al. 2010b; Ranzi et al. 2011)

Leukemia An Italian ecological study found a modest risk increase in residents between 2 and 3.5 km from the site, but not at shorter distances; the authors suggest that this risk is hardly linkable with the distance from the site (Federico et al. 2010). No association was found in a cohort study in adults in Italy (Ranzi et al. 2011) and in an ecological study in children in Brazil (Gouveia et al. 2010b). A UK ecological study in children under 16 years found a risk increase but with a mixed exposure (incinerator and industrial combustion) (Knox 2000).

Stomach An ecological study found a significant risk increase associated with the distance from the site, but control of confounding factors was poor (Elliott et al. 1996). An Italian cohort study reported a risk increase for women exposed to heavy metal levels of 1–2 ng/m^3, but not for those exposed to higher levels (Ranzi et al. 2011).

Bladder No association was found either in a UK ecological study (Elliott et al. 1996) and in an Italian cohort study (Ranzi et al. 2011).

Cerebral, myeloma, lymphatic system, prostate Only one study reported on these cancers (Ranzi et al. 2011); no association was found between incidence and mortality for these diseases and exposure to heavy metals in populations living nearby two incinerators.

Birth defects and reproductive disorders

Ten studies were evaluated (Lloyd et al. 1988; Jansson and Voog 1989; Williams et al. 1992; ten Tusscher et al. 2000; Cresswell et al. 2003; Dummer et al. 2003a; Tango et al. 2004; Cordier et al. 2004; Vinceti et al. 2008; Cordier et al.

2010): eight ecological, one case–control, and one retrospective cohort study. The results are often inconsistent; however, the paper by Cordier is relevant for interpretation because confounders were controlled for on an individual basis, through a questionnaire (Cordier et al. 2010).

Orofacial defects No risk increase was found for cleft palate by a Swedish study (Jansson and Voog 1989), whereas both in France and the Netherlands a risk increase was detected (ten Tusscher et al. 2000; Cordier et al. 2004). However, the site analyzed in the Dutch study was open to many chemical substances (ten Tusscher et al. 2000).

Urinary tract defects The French study by Cordier showed a risk increase (around double after adjustment) for congenital urinary tract defects when women, resident within 10 km from 21 active incinerators, were exposed to atmospheric dioxin and dioxin deposits in the ground during the first months of pregnancy (Cordier et al. 2010). The authors also suggest a possible role of the dioxin in contaminating locally produced food. These data together with those for renal dysplasia require special attention.

Other congenital anomalies Two studies reported a modest risk increase of spina bifida, cardiac defects, and renal dysplasia in the areas proximal to the incinerator (Dummer et al. 2003a; Cordier et al. 2004). No significant association was found for low birth weight and reproductive defects (Tango et al. 2004), chromosomal and non-chromosomal anomalies (Cresswell et al. 2003), spontaneous abortion and other studied reproductive outcomes (Vinceti et al. 2008). Occurrence of twin and female births were increased (Williams et al. 1992; Lloyd et al. 1988).

Respiratory diseases

Two studies reported a decrease in respiratory function and an increase in respiratory wheezing in children living in the proximity of an incinerator (Hsiue et al. 1991; Miyake et al. 2005). Increased prevalence of chronic respiratory symptoms was detected in other studies comparing populations resident at various distances from the site (Lee and Shy 1999; Shy et al. 1995). In an Italian retrospective cohort a higher respiratory disease mortality was found in men exposed to heavy metals levels of 0.5–1 ng/m^3; however, no risk was detected in individuals exposed to higher levels (Ranzi et al. 2011). In the same investigation no difference was found for total mortality and hospitalization for respiratory diseases.

All-cause mortality and cardiovascular diseases

Ranzi found that total mortality in women was associated with the presence of an incinerator at any level of exposure to heavy metals, and an increase in cardiovascular disease mortality in women, in hospitalization for chronic cardiac insufficiency and acute myocardial infarction in men in the mid-category exposure (0.5–1 ng/m^3) to heavy metals, but not for the highest (higher than 2 ng/m^3) (Ranzi et al. 2011).

Skin diseases

A Japanese study found no association with atopic dermatitis (Lee and Shy 1999), but a reporting bias and poor control of confounding factors indicate a unsatisfactory quality of the paper.

Discussion

The evaluation of the possible health effects has to be done taking into account two relevant issues: (a) in the majority of the papers on landfills it is virtually impossible to distinguish the role of urban solid from other types of waste coming from different sources; (b) the evolving technology of modern incinerators, with improved control of dioxin and heavy metals emission, may enhance the inconsistencies of the results. Because of these constraints any conclusion has to be viewed in the light of variability and some uncertainty in the results. Nevertheless, this review appears to have new important information if compared with the latest published systematic review (Porta et al. 2009).

Landfills

For total mortality evidence is insufficient to indicate a role of urban solid waste; moreover, the lack of control of important confounding factors in most papers is a real issue. For cancers the inadequate level of evidence already reported in previous reviews (Porta et al. 2009) is supported by more recent data (Gouveia et al. 2010a). More intriguing are the results on birth defects and reproductive disorders. An effect is detectable for toxic wastes, as pointed out by old and more recent papers, but this is much less clear when only urban solid wastes are considered. The evaluation of 9,565 landfills in the UK in which Elliott et al. (2009) distinguished between deposits of non-special from special or unknown waste confirmed an effect of the latter and no evidence of harm from the former. The environmental impact evaluation performed by the INTARESE group in three European countries (Italy, Slovakia, and the UK) on residents living at less than 2 km from a landfill with mixed waste estimated an excess risk of 1.96 newborns with defects in the period 2001–2030 (Forastiere et al. 2011). It is reasonable to conclude that the risk of congenital anomalies is likely to be real. Within the framework of a correct management of landfill of strictly urban waste, the risk of these defects is less likely, indicating that solid waste should be very accurately selected before being thrown in a landfill.

Incinerators

Papers dealing with the health effects of incinerators active in the years 1969–1996 consistently report a detectable risk of some cancers in the populations living nearby. The good quality studies confirm these data, as pointed out in other reviews (Franchini et al. 2004; Linzalone and Bianchi 2007; Porta et al. 2009). The large UK study by Elliott et al. (1996) on 72 incinerators found a risk excess for all cancers, stomach, colorectal, liver, lung, and non-Hodgkin lymphomas; other studies carried out in Italy, France, and the UK indicate some suggestive but not consistent results for non-Hodgkin lymphomas and soft tissue sarcomas (Elliott et al. 1996; Viel et al. 2000; Comba et al. 2003; Floret et al. 2004; Zambon et al. 2007; Viel et al. 2008a; Federico et al. 2010; Ranzi et al. 2011). One study that did not detect any association is quite interesting for a number of reasons (Ranzi et al. 2011): the investigation was carried out on a technologically advanced plant which had undergone a number of improvements; the observations were based on a complex model of dispersion as an estimate of exposure; morbidity and mortality were quite accurately evaluated. The paper also provides an interesting analysis comparing emissions at different time periods relative to a different technology: the ratios of concentrations of released substances in 2008 compared with the period 1994–1996 are 0.214 for total suspended particulate, 0.20 for mercury and cadmium, and 0.0001 for dioxins [polychlorinated dibenzo-*p*-dioxins (PCDD) and polychlorinated dibenzofurans (PCDF)]. These data suggest a dramatic change in the amount of dangerous emissions and the need for accurate monitoring of pollution. In the comparison between older and newer observations, the results for cancer incidence and mortality are largely not consistent.

Attention should be paid to the risk excess for urinary tract defects as reported in a well-designed study by Cordier et al. (2010), even if other studies are inconsistent. Orofacial defects are reported to be associated with exposure to special waste incinerators, whereas no risk is found for reproductive disorders such as spontaneous abortion (Vinceti et al. 2008).

A first general comment is that, historically, incinerators have been consistently indicated as an important source of pollution and harm for the health of populations living nearby the sites. Studies on biomarkers support this: populations exposed to emissions more than others have higher biological levels of released substances (Gonzalez et al. 2000; Reis et al. 2007). Where an incinerator had been the only source of pollution in a defined area for many years in the past, the harmful effects on the health have been consistently detected in a later period (Viel et al. 2000). Second, where a health impact of the change of technology has been reported (as for the Italian study by Ranzi et al. 2011) the results appear reassuring; however, this implies new challenges for the evaluation of environmental impact on health in other societal environments. New objectives of evaluation are needed: (a) the size of incinerators, accurate measurement of nanoparticles; (b) markers of "minor", but not less important health outcomes (respiratory symptoms, annoyance of the residents, stress-induced risk conditions). The evaluation of the aforementioned conditions in public health should include both incinerators and landfills owing to their association with the quality of life of residents during the time of exposure (de Wet et al. 2011).

Main methodological issues

Environmental epidemiology of waste disposal suffers from limitations conducive to inadequate or contrasting results: because most disease are "rare" in populations, a large number of individuals have to be observed for a long time period to identify a potential determinant, and studies carried out in small communities for a limited number of years lack statistical power; specific attention is often given to communities where exposure is "visibly" higher compared with others, thereby emphasizing the effect; exposure is mostly not based on individual measurements or accurate modeling of differences in population groups; potential concomitant causes of harm to health should be measured and controlled for in the analyses as confounders such as the socioeconomic conditions; the lack of information on individual risk factors competitive for many diseases such as smoking, dietary habits, alcohol use, and occupation, is mostly common. This large variety of conditions impaired the calculation of summary estimates of risks through meta-analyses.

Cause–effect relationship

A summary table (Table 2), using the IARC criteria for cause–effect evaluation, as described in the methods (IARC–WHO) is proposed. Although this classification is applied to evaluate the causal role of potential carcinogens, it allows us to compare the conclusions proposed by us with those by Porta et al. (2009), the latest comprehensive systematic review performed before ours. Only two categories (*limited* and *inadequate*) have been used because of the insufficient design of the evaluated studies that suffer from poor exposure measurement, outcome definition, and

Table 2 Evaluation of the evidence according to IARC criteria for evaluated diseases

Health effect	Level of evidence	
	Landfills	Incinerators
All cancers	Inadequate	Limited
Stomach	Inadequate	Inadequate
Colorectal	Inadequate	Inadequate
Liver	Inadequate	Inadequate
Larynx	Inadequate	Inadequate
Lung	Inadequate	Inadequate
Soft tissues sarcoma	Inadequate	Limited
Kidney	Inadequate	Inadequate
Bladder	Inadequate	Inadequate
Lymphomas	Inadequate	Inadequate
Leukemia	Inadequate	Inadequate
Brain	Inadequate	Inadequate
Children's cancers	Inadequate	Inadequate
Other cancers	Inadequate	Inadequate
All birth defects and reproductive disorders	Limited	Limited
Neural tube defects	Limited	Inadequate
Orofacial defects	Inadequate	Limited
Genitourinary tract defects	Limited	Limited
Abdominal wall defects	Inadequate	Inadequate
Gastrointestinal defects	Inadequate	Inadequate
Cardiac defects	Inadequate	Inadequate
Low birth weight	Limited	Inadequate
Respiratory diseases or symptoms	Limited[a]	Inadequate
Cardiovascular diseases	Inadequate	Inadequate
Skin diseases	Inadequate	Inadequate

[a] Data confined to industrial waste

adjustment for confounding factors. Nevertheless, we have important hints. The category *limited* is used for some disease, indicating points-of-attention for etiology, the estimation of risks, and their management in public health. One reassuring point is that we should appreciate the continuous improvement in research design and analysis of the relevant investigations. The choices on the mode of waste disposal management are not "neutral"; powerful political and economic interests play a great role "like the choices on energy production, mode of transportation or greenhouse gas emission" and often stand "predominant over the epidemiological evidence" (Forastiere et al. 2008). Within this framework—similarly to other public health decisions taken on a scientific basis—in order to overcome issues of conflicts of interest in scientific production and to avoid the construction of false reassurances or deplorable uncertainties (Michaels and Monforton 2005), it is advantageous to rely on independent systematic reviews where transparency of methods and rigorous evaluation criteria can be checked by the readers.

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Effect of aging on the leachate characteristics from municipal solid waste landfill

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ABSTRACT

Leachate emanating from solid waste deposited in landfill possess dissolved or an entrained environmentally harmful substances. They consist of soluble organic and inorganic compounds as well as suspended particles. These leachates also have a distinguishing characteristic in that they are highly variable and contain significantly elevated concentrations of undesirable material derived from the waste. Depending on whether leachate flow increases (during rainy season) and decreases (during dry/summer season) can change the composition. The concentration of waste change dramatically changes over the life of the landfill due to chemical degradation and biological decay of organic matter present. Consequently, the physical characteristics also vary considerably depending on the age of the waste. This paper brings out the effect of aging on the leachate characteristics from a municipal solid waste located at the Terra Firma Biotechnologies Ltd situated at Gundlahalli village in Doddaballapur taluk, near Bangalore. For the sake of comparison the leachates from two different parts of the site one from the location where old waste was dumped and another from the location where the waste was dumped relatively recently during the same period. Thus the two leachate samples from the same site representing different stages degradation of waste were collected to represent leachate from old waste and another from relatively fresh waste. The samples were analyzed for various physicochemical parameters to estimate its pollution potential. The results showed that most of the parameters examined in the leachate samples such as colour, conductivity, hardness, BOD, COD, TOC were found higher in the fresh leachate than aged leachate. In addition, low BOD/COD ratio of <0.1 in aged leachate and BOD/COD ratio of 0.33 in fresh leachate are observed. This shows that the major portion is organic matter which is not quickly biodegradable in the leachate from Terra Firma Biotechnology. The compost site is non-engineered solid waste landfill, which has neither bottom liner system nor any leachate collection and treatment system. Hence, leachate may percolate through subsoil causing pollution to ground water and surface water resources. Further the properties of soil below can change due to changing composition of the pore fluid.

Keywords: Aging, BOD, COD, Leachate, Municipal Solid Waste.

1. INTRODUCTION

Leachate is a contaminated liquid that drains through the bottom of the solid waste disposal facilities such as landfills. Its composition varies widely depending on the composition of waste as well as the age of waste. It contains number of dissolved and suspended materials. After municipal solid waste landfill site is closed, landfill will continue to produce contaminated leachate and this process can last for 30-50 years which can have significant environmental impact when released untreated into the environment(Peter et al., 2002). Quality of leachate is site-specific and even at a single landfill site the quality of leachate is strongly variable. Variability caused by many factors such as rainfall regime, geology, landfill age, composition of solid waste, physico-chemical conditions at the landfill (Zgajnar et al., 2009).

Within the land fill waste mass, biodegradable waste includes food waste, green waste and certain wastes arising from commercial and industrial sources. This kind of waste will easily decompose within the first few months of disposal. Non biodegradable waste like paper, wood and plastics also yield organic compounds to leachate, but only in small percentage over long periods of time. The majority of inorganic compounds are readily soluble and the ions released usually appear within a short time. Heavy metals contained in the solid waste are usually released slowly into the leachate and the process may take up to several years. Moreover, there is a complex interplay between leaching of ionic species and the maturity of the solid waste landfill site. This affects the compositional characteristics of the leachate (Renou et al., 2005).

As landfill passes through different phases of its life cycle, the leachate composition also varies widely through the successive aerobic, acetogenic, methanogenic and stabilization stages. The degradation process of the waste in a landfill passes through different phases. The first phase which is normally short is characterized by the aerobic degradation of organic matter, CO2 is produced and the temperature of waste can increase up to 80^0C, this can affect the later stage of leachate production. In this phase, leachate contributes moisture during compaction as well as from precipitation through the buried waste (Kjeldsen et al., 2002). The amount of leachate leaving the landfill is limited due to the water holding by the waste, until the leachates reaches the collection system and is drained to the collection basin(Armstrong and Rowe,1999). This stage usually lasts only a few weeks and consequential phase appears when the oxygen is depleted, the degradation continues anaerobically. The anaerobic degradation process consists of two major fermentation phases, the acidogenic phase generating young, biodegradable leachate and the methanogenic phase, generating old, stabilised leachate (Bhala et al., 2012).

Young leachate from the early acidogenic phase contains large amounts of readily biodegradable organic matter. The complex organic compounds are fermented anaerobically, yielding mainly soluble organic acids such as free volatile fatty acids (VFAs), amino acids, other low molecular weight compounds and gases like H_2 and CO_2 (Harmsen, 1983). The concentration of VFAs can be quite significant, representing 95% of the TOC, leading to low pH (less than 5). BOD5/COD will have high ratio values of 0.5-0.7 indicate large amounts of biodegradable organic matter (Granet et al., 1986). COD values are 3,000-60,000 mg/l (Aisien et al., 2010). During this phase the metals are more soluble because of lower pH and the bonding with the VFAs, leading to relative high concentrations of Fe, Mn, Ni and Zn (Harmsen, 1983).

Old leachate will be in the methanogenic phase with lower concentration of VFAs (Chain and Dewalle, 1976). This is due to their conversion into methane and carbon dioxide (CO2) as gaseous end products during this second fermentation period. VFAs and other readily biodegradable organic compounds in the leachate decreases, the organic matter in the leachate becomes dominated by refractory compounds, such as humic like compounds and fulvic acid like substances (Chian and Dewalle,1976). Thus BOD5/COD will have low ratio values, most often close to 0.1, is a characteristic value for stabilised leachates. The dark colour in leachate is mainly due to humic substance. The decrease of VFAs results in an increase in pH. A characteristic pH value for stabilised leachate is close to 8 (Granet et al., 1986). The concentration of metal ions is in general low due to the decreasing solubility of many metal ions with increasing pH. In case of lead, it forms very stable complexes with the humic acids (Harmsen, 1983). Due to the effect of the shifting pH on metal-ions, reduction of sulphate to sulphide during methanogenic phase, this increases the precipitation of metals ions.

Generally, leachate strength get reduces with time due to biological breakdown of organic compounds and precipitation of soluble elements like heavy metals. With increasing age of leachate production, the organic compounds decrease more rapidly than the inorganic compounds. Hence, the ratio of total volatile solids to total fixed solids decreases with the age of the landfill (Robinson and Gronow, 1993)

The aim of our study is to bring out the effect of aging on the leachate characteristics from a municipal solid waste of Terra Firma Biotechnologies Ltd situated at Gundlahalli village in Doddaballapur taluk, near Bangalore. Two leachate samples were collected at different locations from the same site representing different stages of degradation of waste. Further the leachate contamination potential has been assessed based on the concept of leachate pollution index (LPI).

2 SITE DESCRIPTION

Terra Firma Biotechnologies Ltd(TFBL) is situated at Gundlahalli village, 18 km from Doddaballapur taluk of Karnataka state,India. TFBL receives about 1,000 tons of MSW daily from BBMP while remaining 400 tons of MSW is collected from hotels, IT parks..etc. The MSW collected is treated through composting, biomethanation and landfill facility. The first leachate (sample-1) originated from the old part of the landfill as show in fig 1.

Fig. 1 Leachate location from the Old part of the Landfill

The second leachate (sample-2) was sampled at the same landfill but it is active part of the landfill as show in fig 2.

Fig. 2. Leachate location from the fresh dump site

3. SAMPLING AND ANALYSES

A municipal solid waste leachate sample was collected in the month of April from the Terra Firma Biotechnologies Ltd in Bangalore. Glass bottles were used to collect leachate samples for chemical analyses, whereas, samples preserved for BOD and COD tests were collected in polyethylene bottles covered with aluminium foils. A few drops of concentrated nitric acid were added to the leachate sample collected for heavy metals analysis to preserve the samples. The samples were then transported in cooler boxes at temperature below 5°C, and transported immediately to the laboratory. Sample of leachate were stored in refrigerator at 4°C before proceeding for the analysis. The analysis is carried out according to standard methods for examination of water and wastewater unless otherwise stated (APHA, 1998).

3.1 Determination of Physico-chemical parameters

Table 1. Method of determination of Physico-chemica parameters

Parameters	Method of determiantion
pH	pH meter
Conductivity, µS/cm	Conductivity meter
TDS, mg/l	TDS meter
COD, mg/l	Open reflux method
BOD_3 , mg/l	Winkler's method
Sulphate, mg/l	Titration
Chloride, mg/l	Titration
Calcium, mg/l	EDT titration
Alkalinity, mg/l	EDT titration
Sodium, mg/l	flame photometer method
Potassium , mg/l	flame photometer method
Nitrate,mg/l	Spectrophotometer method
Heavy metal	Absorption Spectrophotometer

4 RESULTS AND DISCUSSION

The physico-chemical properties of both leachates are presented in Table 2.

Table 2. Leachate characteristic of TFBL

Details	Sample-1	Sample-2
pH	7.38	5.7
Colour	Brownish	Dark Black
Odour	Very High	Medium
Temperature,ºC	29	29
Conductivity, µS/cm	2750	1050
Turbidity (NTU)	470	80
TDS, mg/l	1375	310
COD, mg/l	498	4960
BOD_5, mg/l	40	1680
Sulphate, mg/l	42	30
Chloride, mg/l	960	2300
Calcium, mg/l	159	680
Hardness, mg/l	26000	30000
Alkalinity, mg/l	-Nil-	2500
Iron, mg/l	5.28	6.61
Copper, mg/l	0.001	0.223
Silver, mg/l	0.785	0.192
Chromium, mg/l	BDL	BDL
Cadmium, mg/l	0.026	0.015
Lead, mg/l	0.252	0.145
Zinc, mg/l	48	0.2
Nickel, mg/l	0.074	BDL
Sodium, mg/l	260	508
Potassium , mg/l	200	508
Nitrate,mg/l	82.73	8.91

The Sample-1 leachate originating from the old landfill had typical properties of leachate from landfill in the methonogenic phase (Kjeldsen et al., 2002). High pH, low concentration of organic matter and typically very low BOD_5/ COD ratio (<0.1), indicating low biodegrability potential.

On the other hand, leachate from the active part of the landfill (sample-2) was significantly more polluted, it contained high concentrations of chlorides, sulphate, calcium and its pH was lower (5.7) indicate that the landfill is at the end of the acidic anaerobic phase (waste buried in the landfill is about 4 years) and it will proceed to another phase i.e. methanoenic.

The sample -2 leachate is a strongly odoured black coloured liquid when it comes from a landfill site. The smell is acidic and offensive because of sulfur, hydrogen and nitrogen rich organic species such as an organosulfur compound As it becomes oxygenated it tends to turn brown because of the presence of Iron salts in solution and in suspension. It also quickly develops a bacterial flora often comprising substantial growths of Sphaerotilus.

Concentrations of metals were low in both leachates samples except for Fe and Zn. Generally heavy metals appear in the municipal solid waste from Batteries, consumer electronics, ceramics, light bulbs, house dust and paint chips, lead foils such as wine bottle closures, used motor oils, plastics, and some inks and glass. Concentration of heavy metals in a landfill is generally higher at earlier stages because of higher metal solubility as a result of low pH caused by production of organic acids. It is now recognized that most trace elements are readily fixed and accumulate in soils, and because this process is largely irreversible, repeated applications of amounts in excess of plant needs eventually contaminate a soil and may either render it non-productive or the product unusable. Although plants do take up the trace elements, the uptake is normally so small that this alone cannot be expected to reduce appreciably the trace element. It is interesting to note that the zinc levels are very high in leachate from old waste compared to leachate from fresh waste. However the concentrations of iron is about the same in the both the leachate samples.

4.1 Indications from BOD and COD values

The BOD/COD ratio can used to indicate the age of the waste fill. Relatively BOD levels decrease with age faster than COD due to rapid disintegration of bio degradable waste. Thus generally the ratio of BOD/COD will decrease with age and can be used to indicate the age of the waste.. Any waste water, having its BOD_5/COD ratio more than 0.63 can be considered to be quite controlled to biological treatment.

Table 3. Age of waste based on BOD & COD values of leachate (Hui, 2005).

BOD5/COD	Age of fill	COD
≥ 0.5	Young (< 5yr.)	>10,000
0.1-0.5	Medium(5yr -10yr)	500-10,000
<0.1	Old(>10 yr)	<500

From table 3, it shows that BOD_5 was 1290 mg/l and the value of COD was 13400 mg/l. The ratio of BOD_5/COD is 0.09 for sample-1 leachate. The value of BOD_5/COD can characterize the age of the landfill according to the leachate constituents (Table 3). The value of COD and BOD_5/COD from Table 3 shows that the leachate (sample-1) in this study was collected from the landfill with a age of more than 10 years and (sample-2) leachate found to be in medium age between 5 and 10 years.

5. LEACHATE POLLUTION INDEX CONCEPT

LPI provides an efficient method for evaluating the leachate contamination potential. The leachate pollution index (LPI) and it is formulated based on the Delphi technique. The LPI is a quantitative tool by which the leachate pollution data of the landfill sites can be reported uniformly. LPI formulation process involves selecting variables, deriving weights for the selected pollutant variables, formulating their sub indices curves, and finally aggregating the pollutant variables to arrive at the LPI (Kumar and Alappat, 2003).

LPI process involves: Selection of pollutant variables, Pollutant weights are assigned, formulating their sub indices curves and aggregating the pollutant variables to arrive at the LPI.

The LPI is calculated using the following equations:

$$LPI = \sum_{i=1}^{n} WiPi \qquad (1)$$

Where LPI= the weighted additive LPI, Wi= the weight for the ith pollutant variable, Pi = the sub index score of the ith leachate pollutant variable, n= number of leachate pollutant variables used in calculating LPI.

However, when the data for all the leachate pollutant variables included in LPI are not available, the LPI can be calculated using the concentration of the available leachate pollutants. In that case, the LPI can be calculated by the equation:

$$LPI = \frac{\sum_{i=1}^{m} WiPi}{\sum_{i=1}^{m} Wi} \qquad (2)$$

Where m is the number of leachate pollutant parameters for which data are available, but in that case, m<18 and ΣW<1 contamination from the pollutant to the overall leachate pollution.

LPI values were calculated for leachate sample of Terra Firma site. Tables 4 show the calculations for LPI values of leachate samples in Terra Firma site.

Table 4. LPI for the landfill leachate (sample-1)

Pollutant, mg/l	Sample 1	W_i	P_i	(P_iW_i)
pH	7.38	0.055	5	0.275
TDS	1375	0.050	8	0.40
BOD_5	40	0.061	55	3.36
COD	498	0.062	80	4.96
TKN	831	0.053	95	5.035
AN	1	0.051	100	5.10
Iron	5.28	0.044	5	0.22
Copper	0.001	0.050	5	0.25
Nickel	0.074	0.052	5	0.26
Zinc	48	0.056	5	0.28
Lead	0.252	0.063	5	0.31
Chromium	0.011	0.064	10	0.64
Chlorides	960	0.048	5.3	0.2544
Final LPI value = 13.22				

Table 5. LPI for the landfill leachate (sample-2)

Pollutant, mg/l	Sample 2	W_i	P_i	(P_iW_i)
pH	5.7	0.055	5	0.275
TDS	310	0.050	8	0.40
BOD_5	1680	0.061	55	3.36
COD	4960	0.062	80	4.96
TKN	485	0.053	95	5.035
AN	350	0.051	100	5.10
Iron	6.61	0.044	5	0.22
Copper	0.223	0.050	5	0.25
Nickel	0.001	0.052	5	0.26
Zinc	0.2	0.056	5	0.28
Lead	0.145	0.063	5	0.31
Chromium	0.001	0.064	10	0.64
Chlorides	2300	0.048	5.3	0.2544
Final LPI value = 16.11				

The results indicate that the leachate sample has high LPI value and therefore, has relatively more contamination potential. Terra Firma leachate sample can therefore pose threat to the environment and human health and hence, measures and continuous monitoring must be ensured. This threat potential does not seem to be reducing even with increase of the leachate.

It is interesting to note that the LPI of both the leachates is not much different. While pollution threat from Leachate 1 (from old waste) is less from BOD and COD, its threat is mainly due to high concentrations of Zinc, TDS and Total Kjeldahl Nitrogen (TKN). On the contrary the pollution threat from fresh leachate arises mainly form high BOD, COD and chloride levels. However the threat exists from leachates from both fresh waste and aged leachate.

6. CONCLUSIONS

1. Based on the physico-chemcial analysis the leachate from the active part (fresh waste) of the landfill, it has been inferred that anaerobic acidic phase is established.
2. The leachate from the closed part showed typical characteristics of leachates generated during the methanogenic phase of the landfill life phase.
3. Based on BOD_5/COD ratio suggested that the leachate (sample-1) (closed part of landfill) from the landfill with the age more than 10 years and (sample-2) leachate (fresh waste) found to be in medium age.
4. The LPI is a quantitative tool by which the leachate pollution data of the landfill sites can be reported uniformly. High LPI values indicate that the leachates generated from landfill site are not yet stabilized even after 10 years, resulting in high pollution threat. While pollution threat from Leachate 1 (from old waste) is less from BOD and COD, its threat is mainly due to high concentrations of Zinc, TDS and TKN. On the contrary the pollution threat from fresh leachate arises mainly form high BOD, COD and chloride levels.

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USGS science for a changing world

Environmental Health - Toxic Substances Hydrology Program

Landfill Leachate Released to Wastewater Treatment Plants and other Environmental Pathways Contains a Mixture of Contaminants including Pharmaceuticals

Signup

New scientific research from the U.S. Geological Survey (USGS) details how landfill leachate, disposed from landfills to environmental pathways, is host to numerous contaminants of emerging concern (CECs).

Landfills are the final repository for a heterogeneous mixture of liquid and solid waste from residential, industrial, and commercial sources, and thus, have the potential to produce leachate—a liquid waste product that consists of a diverse mixture of chemicals as precipitation or applied water moves through the waste. Landfills are often not the final repository for leachate which can be discharged to surface waters following onsite or offsite wastewater treatment.

Sample bottels like these filled with leachate were analyzed for contaminants of emerging concern (CECs) including pharmaceuticals, industrial chemicals, household chemicals, steroid hormones, and plant/animal sterols. Photo Credit: Dana W. Kolpin, USGS

In this national-scale study, scientists provide an assessment of CECs in landfill leachate disposed offsite that has undergone treatment or storage processes (final leachate) at landfills across the United States to gain a greater understanding of this potential contaminant source to the environment. This study follows and advances previous USGS research of leachate prior to onsite treatment, storage processes, and offsite disposal (fresh leachate).

In this study, final leachate samples from 22 landfills were collected and analyzed for 190 CECs including pharmaceuticals, industrial chemicals, household chemicals, steroid hormones, and plant/animal sterols. The sampling network included municipal and private landfills with varying landfill waste compositions; geographic and climatic settings; ages of waste, waste loads, and leachate production; and leachate management strategies.

Scientists determined that final leachate samples contained 101 of the 190 chemicals analyzed for the study, with chemicals present in every final leachate sample collected at levels ranging from as low as 2 nanograms per liter (ng/L) to as high as 17,200,000 ng/L. The most frequently detected CECs were lidocaine (local anesthetic, found in 91 percent of samples), cotinine (nicotine breakdown product, 86 percent), carisoprodol (muscle relaxant, 82 percent), bisphenol A (component for plastics and thermal paper, 77 percent), carbamazepine (anticonvulsant, 77 percent), and N,N-diethyltoluamide (DEET, insect repellent, 68 percent).

A detailed comparison of CEC concentrations between final leachate in landfills included in this study and the previous study of fresh leachate indicated that levels of CECs were significantly less in final leachate compared to those observed in fresh leachate samples. Nevertheless, final leachate still contained a complex mixture of CECs at concentrations that may be potential cause for concern if released to the environment.

This research is part of continuing USGS efforts to quantify the contribution of contaminants in leachate released from landfills to various pathways that ultimately lead to the environment. Use of landfills as a means of waste disposal will likely increase as the global population continues to increase. Despite advancements in recycling, source reduction, and composting, the amount of municipal solid waste discarded in U.S. landfills increased from 150 million tons in 1985 to 165 million tons in 2010. The study is intended to inform landfill managers, stakeholders, and regulators about chemicals present in landfill leachate disposed offsite to environmental pathways.

The study was supported by the USGS Toxic Substances Hydrology Program.

In some cases USGS scientists collected leachate samples from manhole access points like this one. Photo Credit: Dana W. Kolpin, USGS

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More Information

- For more information contact Dana W. Kolpin, USGS Iowa Water Science Center, or Jason R. Masoner, USGS Oklahoma Water Science Center
- Frequently Asked Questions about this Science Feature Article
- USGS Technical Announcement: Storage and Treatment of Liquid Waste from Landfills Doesn't Remove All Contaminants, Including Pharmaceuticals
- USGS Emerging Contaminants in Landfill Leachate
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CHAPTER 3 Landfill Gas Safety and Health Issues

This chapter provides information about health and safety issues associated with landfill gas—specifically, possible explosion and asphyxiation hazards and issues related to odors emanating from the landfill and low-level chemical emissions. It also contains information about health and safety issues associated with landfill fires (which may or may not be the direct result of landfill gas). This chapter also describes the tools that can be used to help environmental professionals respond to community health concerns. It provides information about what is known and unknown about the short-term and long-term health effects associated with landfill gas emissions, which can be mixtures of hundreds of different gases.

When reading this chapter, keep in mind that if people are not being exposed to landfill gases, no adverse health effects are expected. Exposures occur only if the landfill is producing harmful levels of gases *and* if the gases are migrating from the landfills *and* reaching people. Responding to community concerns about the possible health impacts of known or potential landfill gas emissions can often be difficult. Data (at the point of exposure) are needed to fully evaluate exposures, and these data are often limited or not available (see Chapter Four).

How are people exposed to landfill gas?

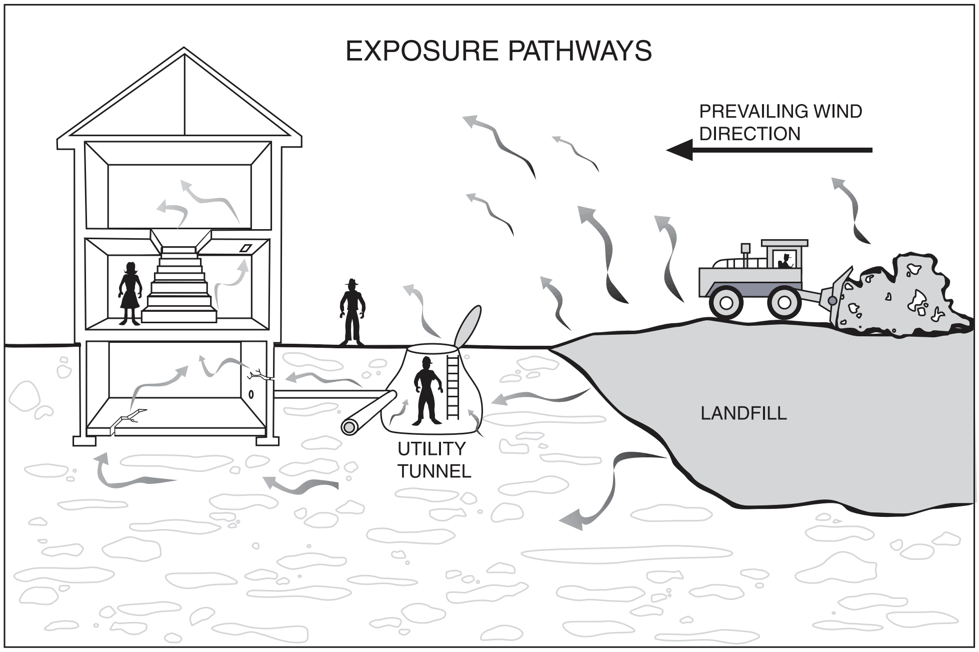
People may be exposed to landfill gases either at the landfill or in their communities. As discussed in Chapter Two, landfill gases may migrate from the landfill either above or below ground. Gases can move through the landfill surface to the ambient air. Once in the air, the landfill gases can be carried to the community with the wind. Odors from day-to-day landfill activities are indicative of gases moving above ground. Gases may also move through the soil underground and enter homes or utility corridors on or adjacent to the landfill. Figure 3-1 illustrates the movement of landfill gases and potential exposure pathways. The levels of gases that migrate from a landfill and to which people are exposed are dependent on many factors, as described in Chapter Two. Landfill gas collection and control systems have the greatest impact on gas migration and exposures. If a collection or control system is in place and operating properly, migration and exposures should be minimal.

Explosion Hazards

Landfill gas may form an explosive mixture when it combines with air in certain proportions. This section provides information about:

- The conditions that must be met for landfill gas to pose an explosion hazard.
- The types of gases that may potentially pose explosion hazards.
- What can be done to assess whether a landfill is posing an explosion hazard.

Figure 3-1: Potential Exposure Pathways to Landfill Gas



When does landfill gas pose an explosion hazard?

The following conditions must be met for landfill gas to pose an explosion hazard:

- ***Gas production.*** A landfill must be producing gas, and this gas must contain chemicals that are present at explosive levels.
- ***Gas migration.*** The gas must be able to migrate from the landfill. Underground pipes or natural subsurface geology may provide migration pathways for landfill gas (see Chapter Two, "What factors affect landfill gas migration?"). Gas collection and treatment systems, if operating properly, reduce the amount of gas that is able to escape from the landfill. (See Chapter Five.)
- ***Gas collection in a confined space.*** The gas must collect in a confined space to a concentration at which it could potentially explode. A confined space might be a manhole, a subsurface space, a utility room in a home, or a basement. The concentration at which a gas has the potential to explode is defined in terms of its lower and upper explosive limits (LEL and UEL), as defined at right.

Lower and Upper Explosive Limits (LEL and UEL)

The concentration level at which gas has the potential to explode is called the explosive limit. The potential for a gas to explode is determined by its lower explosive limit (LEL) and upper explosive limit (UEL). The LEL and UEL are measures of the percent of a gas in the air by volume. At concentrations below its LEL and above its UEL, a gas is *not* explosive. However, an explosion hazard may exist if a gas is present in the air between the LEL and UEL and an ignition source is present.

Landfill Gas Explosions

Although landfill gas explosions are by no means common occurrences, a number of incidents known or suspected to have been caused by landfill gas explosions have been documented.

1999	An 8-year-old girl was burned on her arms and legs when playing in an Atlanta playground. The area was reportedly used as an illegal dumping ground many years ago. (Atlanta Journal-Constitution 1999)
1994	While playing soccer in a park built over an old landfill in Charlotte, North Carolina, a woman was seriously burned by a methane explosion. (Charlotte Observer 1994)
1987	Off-site gas migration is suspected to have caused a house to explode in Pittsburgh, Pennsylvania. (EPA 1991)
1984	Landfill gas migrated to and destroyed one house near a landfill in Akron, Ohio. Ten houses were temporarily evacuated. (EPA 1991)
1983	An explosion destroyed a residence across the street from a landfill in Cincinnati, Ohio. Minor injuries were reported. (EPA 1991)
1975	In Sheridan, Colorado, landfill gas accumulated in a storm drain pipe that ran through a landfill. An explosion occurred when several children playing in the pipe lit a candle, resulting in serious injury to all the children. (USACE 1984)
1969	Methane gas migrated from an adjacent landfill into the basement of an armory in Winston-Salem, North Carolina. A lit cigarette caused the gas to explode, killing three men and seriously injuring five others. (USACE 1984)

See the box above for a few of many documented situations where all the conditions for explosions were met and explosions actually occurred.

What types of gases can pose an explosion hazard?

- ***Methane.*** Methane is the constituent of landfill gas that is likely to pose the greatest explosion hazard. Methane is explosive between its LEL of 5% by volume and its UEL of 15% by volume. Because methane concentrations within the landfill are typically 50% (much higher than its UEL), methane is unlikely to explode within the landfill boundaries. As methane migrates and is diluted, however, the methane gas mixture may be at explosive levels. Also, oxygen is a key component for creating an explosion, but the biological processes that produce methane require an anaerobic, or oxygen-depleted, environment. At the surface of the landfill, enough oxygen is present to support an explosion, but the methane gas usually diffuses into the ambient air to concentrations below the 5% LEL. In order to pose an explosion hazard, methane must migrate from the landfill and be present between its LEL and UEL.
- ***Other landfill gases.*** Other landfill gas constituents (e.g., ammonia, hydrogen sulfide, and NMOCs) are flammable. However, because they are unlikely to be present at concentrations above their LELs, they rarely pose explosion hazards as individual gases. For example, benzene (an NMOC that may be found in landfill gas) is explosive between its

LANDFILL GAS SAFETY AND HEALTH ISSUES

LEL of 1.2% and its UEL of 7.8%. However, benzene concentrations in landfill gas are very unlikely to reach these levels. If benzene were detected in landfill gas at a concentration of 2 ppb (or 0.0000002% of the air by volume), then benzene would have to collect in a closed space at a concentration 6 million times greater than the concentration found in the landfill gas to cause an explosion hazard.

Table 3-1 summarizes the potential explosion hazards posed by the important constituents of landfill gas. Keep in mind that methane is the most likely landfill gas constituent to pose an explosion hazard. Other flammable landfill gas constituents are unlikely to be present at concentrations high enough to pose an explosion hazard. However, the flammable NMOCs do contribute to total explosive hazard when combined with methane in a confined space.

Table 3-1: Potential Explosion Hazards from Common Landfill Gas Components

Component	Potential to Pose an Explosion Hazard
Methane	Methane is highly explosive when mixed with air at a volume between its LEL of 5% and its UEL of 15%. At concentrations below 5% and above 15%, methane is not explosive. At some landfills, methane can be produced at sufficient quantities to collect in the landfill or nearby structures at explosive levels.
Carbon dioxide	Carbon dioxide is not flammable or explosive.
Nitrogen dioxide	Nitrogen dioxide is not flammable or explosive.
Oxygen	Oxygen is not flammable, but is necessary to support explosions.
Ammonia	Ammonia is flammable. Its LEL is 15% and its UEL is 28%. However, ammonia is unlikely to collect at a concentration high enough to pose an explosion hazard.
NMOCs	Potential explosion hazards vary by chemical. For example, the LEL of benzene is 1.2% and its UEL is 7.8%. However, benzene and other NMOCs alone are unlikely to collect at concentrations high enough to pose explosion hazards.
Hydrogen sulfide	Hydrogen sulfide is flammable. Its LEL is 4% and its UEL is 44%. However, in most landfills, hydrogen sulfide is unlikely to collect at a concentration high enough to pose an explosion hazard.

How can I assess whether a landfill in my community poses an explosion hazard?

The checklist on the following page can help determine if a landfill may pose an explosion hazard. If your evaluation identifies the potential for an explosion, several actions can be taken to prevent harm to the community. Measures and controls to prevent explosion hazards are discussed in Chapter Five. Possible public health actions are described in Appendix B.

Landfill Gas Explosion Hazard Checklist

- ❑ **Is the landfill producing gas and, if so, how much?**
  Because methane and carbon dioxide are the main components of landfill gas and these chemicals are both odorless and colorless, monitoring data are necessary to answer this question. (See Chapter Four for information about how landfill gas is monitored.)

- ❑ **Is a landfill gas collection system in place?**
  Landfill gas collection systems reduce levels of gas migrating from the landfill to surrounding areas. (See Chapter Five for information about collection systems.)

- ❑ **Is gas migrating from the landfill?**
  Off-site monitoring data may be necessary to answer this question. (See Chapter Four.)

- ❑ **If gas is migrating from the landfill and reaching structures, are there places for gas to collect?**
  Uncontrolled gases escaping from a landfill may migrate to structures on the landfill itself or in the surrounding area. However, the further a structure is from the landfill, the less likely it is that gases are migrating to it at concentrations great enough to pose an explosion threat. The most common places for gases to collect are basements, crawl spaces, or buried utility entry ports. Homes with basements, especially those with pipes or cracks in the basement that would allow gas to enter, are more likely to collect gases.

- ❑ **Is gas collecting at concentrations that are high enough to pose an explosion hazard?**
  Monitoring data are needed to answer this question. Caution should be used in selecting sampling equipment to ensure that an ignition source is not introduced into the area. (See Chapter Four for information about monitoring.)

- ❑ **Is there an ignition source?**
  Gases can be ignited by many different sources, such as a furnace in the basement or a pilot light on a gas stove. Other sources may include candles, matches, cigarettes, or a spark. Because there are so many ignition sources, it is safest to assume that the potential for an ignition source is always present.

Asphyxiation Hazards

Landfill gas poses an asphyxiation hazard only if it collects in an enclosed space (e.g., a basement or utility corridor) at concentrations high enough to displace existing air and create an oxygen-deficient environment. The Occupational Safety and Health Administration (OSHA) defines an oxygen-deficient environment as one that has less than 19.5% oxygen by volume (OSHA n.d.a). Ambient air contains approximately 21% oxygen by volume. Health effects associated with oxygen-deficient environments are described in Table 3-2.

Any of the gases that comprise landfill gas can, either individually or in combination, create an asphyxiation hazard if they are present at levels sufficient to create an oxygen-deficient environment.

Carbon dioxide, which comprises 40% to 60% of landfill gas, may pose specific asphyxiation hazard concerns. Because it is denser than air, carbon dioxide that has escaped from a landfill and collected in a confined space, such as a basement or an underground utility corridor, may remain in the area for hours or days after the area has been opened to the air (e.g., after a man-

Science News Online

Landfills Make Mercury More Toxic- by Janet Raloff

Mercury, a nerve poison, is a major ingredient in many products—from thermometers and fluorescent bulbs to batteries and old latex paint. A new study finds that landfill disposal of such products can chemically alter the mercury in them, not only rendering it more toxic but also fostering its release into the air.

While open landfills (above) may expose wildlife directly to poisonous mercury, closed landfills can vent tainted gases through pipes (below).

Although even mercury in its elemental form is toxic, its most poisonous embodiment is methyl mercury, the result of a chemical modification by bacteria (SN: 3/9/91, p. 152). The finding of such a process in landfills underscores the importance of ensuring that mercury doesn't enter the municipal-waste stream, says study leader Steve E. Lindberg of Oak Ridge (Tenn.) National Laboratory.

The decomposition of interred landfill wastes creates methane. Some landfill managers burn the gas in flares as it exits pipes atop the waste field. Most managers, however, merely vent the gas—and any contaminants it may carry—into the air.

Two years ago, Lindberg's team found methyl mercury in the water vapor that condensed out of the gas emanating from a Florida landfill. Concentrations were at least 100 times those typically seen in water. The finding made sense, Lindberg recalls: In wetlands, researchers had previously identified certain bacteria that methylate natural, inorganic mercury derived from minerals. This same family of microbes resides in landfills.

However, methyl mercury comes in two forms—mono- and dimethyl-mercury—with the latter being the more toxic. To probe which form is made in landfills, Lindberg and his coworkers collected gases destined for flaring. In the August Atmospheric Environment, they report finding some 50 nanograms of dimethyl mercury per cubic meter of landfill gas.

That "is higher, by a factor of 30 or 40, than concentrations of total mercury in ambient air," Lindberg notes, and it's at least 1,000 times that of any dimethyl-mercury concentration ever recorded in open air. His team also detected lower concentrations of the less volatile mono-methyl mercury in the landfill gas.

Although chemists had detected methyl mercury in air and rain, "nobody had been able to demonstrate where it comes from," notes John W.M. Rudd of the Winnipeg (Manitoba) Freshwater Institute, part of Canada's Department of Fisheries and Oceans. The new study offers "the first real evidence that landfills might be a major source," he says.

Some 60,000 U.S. children are born each year with developmental impairments triggered by fetal exposure to methyl mercury, usually as a result of their moms having eaten tainted fish (SN: 7/29/00, p. 77). "If it doesn't get methylated, mercury doesn't get into fish," observes Edward Swain of the Minnesota Pollution Control Agency in St. Paul.

To limit the rain of mercury from human activities, regulators have focused on curbing emissions of inorganic mercury from coal burning. However, Lindberg notes, although chemists assumed that mercury could become methylated in the air, they couldn't show it.

Now, Swain posits, a "shift in paradigms" may be in order. He says that sending mercury-containing wastes to landfills may essentially be spoon-feeding copious amounts of the toxicant to methylating bacteria, which then cough the injurious forms into air.

The new findings point to the need to inventory emissions by landfills—especially the older ones, which hold the richest stores of mercury-tainted wastes—says Frank D'Itri of Michigan State University's Institute of Water Research in East Lansing.

Lindberg plans to embark on such an inventory. He says that the new data also suggest a need for technologies to capture methyl mercury from landfills before it can enter the atmosphere.

Vinyl In Landfills Most Likely to Blame For Toxic Gases

- *To*: press-releases@xs2.greenpeace.org
- *Subject*: Vinyl In Landfills Most Likely to Blame For Toxic Gases
- *Date*: Fri, 27 Nov 1998 13:26:19 -0800

VINYL IN LANDFILLS MOST LIKELY TO BLAME FOR TOXIC GASES
Municipalities across Canada urged to investigate

TORONTO - November 27, 1998 - Toxic substances found in the air downwind from Toronto area landfill sites are most likely caused by the dumping of PVC plastic (vinyl), according to Greenpeace, the Toronto Environmental Alliance, and City Councillor Jack Layton, Chair of Toronto's Environmental Task Force. The environmental organizations and Mr.. Layton are urging municipalities across Canada to investigate and take action after worrying levels of cancer-causing vinyl chloride were reported in a Ministry of Environment report obtained by the Globe and Mail.

Studies have shown that PVC provides between one-half and two-thirds of the chlorine present in municipal waste, making it the most probable source of a wide range of chlorine-containing gases emitted by landfills. Vinyl chloride is especially likely to originate from PVC because it is the basic chemical building block of the plastic. According to the U.S. Agency for Toxic Substances and Disease Registry, vinyl chloride is a known human carcinogen which causes liver cancer in people. In animals, it causes numerous kinds of cancer.

A recent study by the New York State Department of Health reported that women living near municipal landfills where gas is escaping have a four-fold increased chance of bladder cancer or leukemia. A 1995 study of families living near Montreal's Miron Quarry landfill also found an elevated incidence of several cancers and a 20% increased likelihood of low birth weight among those most heavily exposed to gases from the landfill.

"These findings are of great concern and I will be urging the Canadian Federation of Municipalities to investigate and consider restrictions on PVC," said Mr. Layton. The Federation's Environment Committee is meeting next week in Laval, Quebec.

"This news from Toronto is a wake-up call for Canada's mayors to get chlorine - and chlorine-based materials - out of our dumps, " said Lois Corbett, executive director of the Toronto Environmental Alliance.

PVC waste is notorious for its environmental problems. In incinerators, which Environment Canada lists as the largest emitters of deadly dioxin to the atmosphere, PVC is the dominant source of chlorine without which the dioxin cannot be produced, and each kilo of PVC incinerated generates between one and two kilos of secondary hazardous waste. In 1997 when PVC plastic waste burned at the Plastimet recycling plant in Hamilton, the site became contaminated with extraordinarily high concentrations of dioxin. A U.S. study has shown that nearly 200 times more virgin PVC was produced between 1990 and 1996 than was recycled, the worst recycling ratio of any common plastic.

The production of PVC plastic also involves highly toxic precursors and generates hazardous emissions and wastes. And because it often requires hazardous additives such as phthalate esters, lead and cadmium, to make it functional, use of PVC products can also pose risks to human health. This was the case in Health Canada's recent advisory to parents to discard soft PVC teethers and rattles for infants.

"These toxic landfill emissions show there is no acceptable way to deal with PVC waste - neither incineration, recycling or landfilling," said Greenpeace toxics specialist Dr. Matthew Bramley. "We've had mini-blinds, Plastimet, hazardous PVC children's products, and now landfill emissions. How many scandals does it take to get national action to restrict PVC?"

Greenpeace on the Internet at http://www.greenpeace.org

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the Galt Global Review
Career, IT and Business Issues for the 21st Century

Business News

Old PCs toxic in landfill sites

Your computer equipment could contain highly toxic materials.
The European Union is developing a solution.
Composition of a Desktop Personal Computer
Risks related to some e-toxins found in computers

By: Lindsay Wood

Landfill and incinerator facilities are often the final resting-place for electronic waste. Computers, cell phones, electronic games, television sets - are piling up with increasing rapidity, ready to be burned or buried. But are you aware that these leftover gadgets are loaded with toxins that can leak into the groundwater or produce carcinogens and toxins?

Your computer equipment could contain highly toxic materials.

Computer equipment is a complicated assembly of more than 1,000 materials, many of which are highly toxic, such as chlorinated and brominated substances, toxic gases, toxic metals, biologically active materials, acids, plastics and plastic additives.

The average computer has a lifespan of less than two years, and hardware and software companies are constantly generating new programs that fuel the demand for more speed, memory and power. Y2K concerns generated an increase in the number of new systems bought. According to the National Safety Council, as recently as 1994, buyers held on to their computers from four to six years.

The San Francisco Toxic Coalition website states that three quarters of all computers ever bought in the US are sitting in people's attics and basements because they don't know what to do with them.

At the end of last year another 24 million computers in the United States had become "obsolete". Only about 14 percent (or 3.3 million) of these will be recycled or donated. The rest - more than 20 million computers in the U.S. -- will be dumped, incinerated, shipped as waste exports or put into temporary storage in attics, basements, etc.

In contrast, for major appliances such as washing machines, air conditioners, refrigerators, dryers, dishwashers and freezers, the proportion recycled in 1998 was about 70 percent of the number put on the market that year.

The "Electronic Product Recovery and Recycling Baseline Report" --published by the National Safety Council's Environmental Health Center states that by the year 2004, experts estimate that there will be over 315 million obsolete computers in the US.

SVTC say that recycling of hazardous products has little environmental benefit - it simply moves the hazards into secondary products that eventually have to be disposed of. Unless the goal is to redesign the product to use non-hazardous materials, such recycling is a false solution. Carnegie Mellon University estimate that, in four years, there will be 70 million computers in landfills.

To add to the list of injuries, a recent Swedish study found that when computers, fax machines or other electronic equipment are recycled, dust containing toxic flame-retardants is spread in the air.

SVTC also add that the stream of decay involved in electronic scrap significantly contributes to the heavy metals and halogenated substances contained in the municipal waste stream. Because of the variety of different substances found together in "electroscrap", incineration is particularly dangerous. For instance, copper is a catalyst for dioxin formation when flame-retardants are incinerated.

The introduction of waste computers into incinerators results in high concentrations of metals, including heavy metals, in the slag, in the fly ash, the flue gas and in the filter cake. In this context, more than 90 percent of the cadmium put to an incinerator is found in the fly ash and more than 70 percent of the mercury in the filter cake.

Municipal incineration is the largest point source of dioxins into the US and Canadian environments and among the largest point source of heavy metal contamination of the atmosphere.

The European Union is developing a solution.

The European Union is developing a solution that will make producers responsible for taking back their old products. This legislation - which includes "take-back" requirements and toxic materials phase-outs -- also encourages cleaner product design and less waste generation. Under current environmental regulations, a manufacturing facility is responsible for the environmental impacts of its activities; this responsibility does not cover environmental impacts from the products it manufactures.

Extended Producer Responsibility (EPR) encourages producers to prevent pollution and reduce resource and energy use in each stage of the product life cycle through changes in product design and process technology. The term was coined by Thomas Lindhqvist a Swedish professor of environmental economics and was first mandated in Germany on 1991.

Using the principle of EPR, product manufacturers are responsible for the total life-cycle environmental impact of their products, from raw materials extraction and manufacturing to use and disposal (i.e., the product system). The aim of EPR is to encourage producers to prevent pollution and reduce resource and energy consumption at each stage of the product's life cycle.

Examples are partnership agreements with suppliers, consumers, or others; mandatory or voluntary product labeling and disclosure of environmental information; government procurement policies; deposit-refund systems; product take-back programs; product stewardship programs; leasing systems; and life-cycle management programs.

The EC's proposals could cost as much as $18 billion US to $27 billion to implement, estimates the European industry group Orgaville. The electronics industry is lobbying for an extension of the phaseout timetable on the grounds that there are no alternative materials available at the moment.

Many companies have already taken the initiative and are producing cleaner products. Compaq Computer Corp takes back 200,000 computers a year in North America. Hewlett-Packard Company has developed a safe cleaning method for chips using carbon dioxide cleaning as a substitute for hazardous solvents. In 1998 IBM introduced the first computer that uses 100 percent recycled resin (PC/ABS) in all major plastic parts for a total of 3.5 pounds of resin per product.

Researchers at Delft University in Holland are investigating the design of a wind up laptop similar to the wind-up radio that plays one hour for every 20 seconds of hand winding.

Everyone, all those involved along the product chain share responsibility for life-cycle environment impacts of a product, whether buying in parts or complete products or recycling and reusing.

For information on what to do with your old computer see svtc.org for their clean computer campaign and recycling directory.

Composition of a Desktop Personal Computer

Source: Microelectronics and Computer Technology Corporation (MCC).

Plastics Lead Aluminum Germanium Gallium Iron Tin Copper Barium Nickel Zinc Tantalum Indium Vanadium Terbium Beryllium Gold Europium Titanium Ruthenium Cobalt Palladium Manganese Silver Antinomy Bismuth Chromium Cadmium Selenium Niobium Yttrium Rhodium Platinum Mercury Arsenic Silica

Risks related to some e-toxins found in computers

Source: Clean Water Action Alliance, SVTC, Clean Water Fund.

Lead - Found in cathode-ray tubes, solders. Each cathode-ray tube can contain five pounds of lead or more. Can cause damage to the central and peripheral nervous systems, blood system and kidneys in humans. Damage to a child's brain development has also been noted.

Cadmium - Printed circuit boards, semiconductors. By 2005, a total of more than 2 million pounds will exist in discarded computers. Cadmium and cadmium compounds accumulate in the human body, in particular in kidneys it is adsorbed through respiration but is also taken up with food. Cadmium can easily be accumulated in amounts that cause symptoms of poisoning.

Mercury - Batteries, switches. By 2005, 400,000 pounds across the US. Methylated mercury causes chronic damage to the brain.

Chromium - Used as corrosion protection in steel. By 2005, estimated 1.2 million pounds. Chromium VI can easily pass through membranes of cells and is easily absorbed producing various toxic effects within the cells. It causes strong allergic reactions even in small concentrations. Asthmatic bronchitis is another allergic reaction linked to chromium VI. Chromium VI may also cause DNA damage.

PVC Plastics - Cables and housings. Potential waste of 250 million pounds per year. An MCC study estimated that the largest volume of plastics used in electronics manufacturing (at 26%) was polyvinyl chloride (PVC), which creates more environmental and health hazards than most other type of plastic

Brominated Flame Retardants - Used in electronic products as a means for reducing flammability. In computers, they are used mainly in four applications: in printed circuit boards, in components such as connectors, in plastic covers and in cables. Scientific observations indicate that Polybrominated Diphenylethers (PBDE) might act as endocrine disrupters. Research has revealed that levels of PBDEs in human breast milk are doubling every five years and this has prompted concern because of the effect of these chemicals in young animals

These chemicals make computer recycling particularly hazardous to workers

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In Our Backyard: Environmental Racism in Dickson

colorlines.com/archives/2009/09/in_our_backyard_environmental_1.html

by Michelle Chen | Print |

You may not have heard of Dickson, Tennessee, but this weekend, the town is center stage in the movement for environmental justice. Civil rights leaders gathered there for a national summit on environmental racism to highlight environmental health issues facing communities of color.

The location was a pointed choice. For about a decade, the town of about 12,000 has been at the center of an environmental lawsuit involving a local family and a contaminated landfill, which is just a stone's throw from dozens of homes in a mostly Black community. The Holts claim that family members have been plagued by health problems due to a toxin from the landfill, trichloroethylene (TCE). Sheila Holt-Orsted and Beatrice Holt, together with the Natural Resources Defense Council, are suing the County alleging that the chemical has poisoned their water system and should be held accountable for the family's struggles with cancer and other ailments.

The federal Environmental Protection Agency has a mandate to support "fair treatment for people of all races, cultures, and incomes, regarding the development of environmental laws, regulations, and policies." But the challenge runs much deeper than regulatory statutes or a contaminated well.

> *The Town of Dickson purchased the land for a "city dump" in 1946. Sometime between 1946 and 1956, the newly acquired land, which was bounded by the old "Negro Coaling School," a one-room county school with grades 1 through 9 that dates back to 1895, became the Dickson "city dump," an open unlined dump….*

According to government records, in 1968, the same year Dr. Martin Luther King was assassinated in Memphis, Scovill-Shrader and several other local industries, buried drums of industrial waste solvents at an "open dump" landfill site…

For years, drums of toxic industrial waste solvents were dumped at the landfill, which later contaminated the groundwater.

Contaminated waste material was cleaned up from other areas in this mostly white county and was trucked to the landfill in the mostly black Eno Road community.

The report also compared the government's testing and monitoring of environmental hazards in Black and white areas and found that "the care and precaution that the government officials initiated to protect the health of the white families was not extended to the black Holt family."

The Holt family's plight is emblematic not just of the depth of environmental racism but of a warped paradigm of upward mobility that mires communities of color in a state of continual disenfranchisement. The report concludes:

> *After slavery, dozens of black families acquired hundreds of acres of land—not part of the empty "40 acres and a mule" government promise—and lived a quiet and peaceful existence in Dickson's historically black Eno Road community. That is, until their wells were poisoned by a county landfill….*
>
> *The Holt family's American Dream of land ownership has become a "toxic nightmare." For more than a decade, this black family has experienced the terror of not knowing what health problems may lay ahead for their children and their children's children.*

Perversely, the modest roots the Holts have struggled to put down now act as another kind of ball and chain.

The Dickson case has garnered national attention because it symbolizes the extremes of environmental racism's reach. But other neighborhoods and homesteads across the country bear the toxic burden more subtly—the kid in West Oakland whose bedroom overlooks a smog-laden highway, or the immigrant farmworker who comes home each night spattered in pesticide. In all these places, and in our backyard, the burden of pollution is heavy with the weight of history.

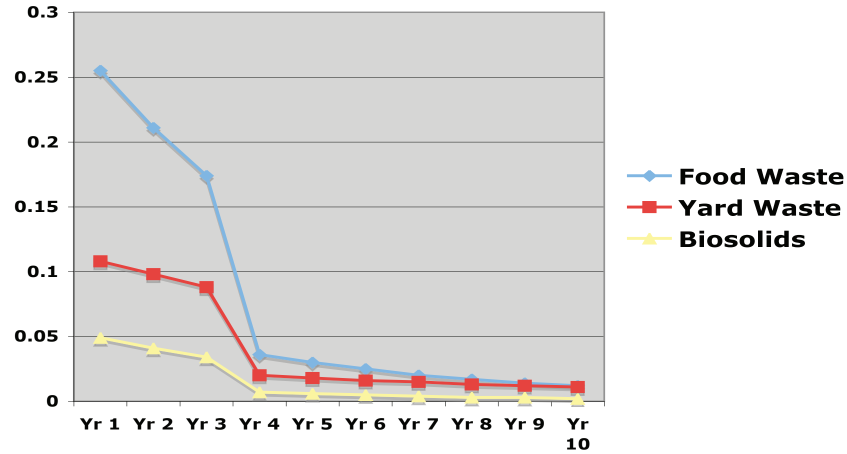
4. **Segregate remaining organics in landfills for the most effective and cost-efficient gas collection** (always maintaining high suction)**.**
5. **Keep out all liquids** from landfills (including not recirculating leachate) to reduce fugitive emissions.
6. **Cap landfills with temporary covers** over the working face to keep out rain and **then install permanent synthetic covers and gas collection systems as soon as possible** (within months is important). (The current 5-year NSPS requirement harms our environment and health.)
7. **All captured methane should be burned in a flare, boiler or a high efficiency turbine**, or used to replace natural gas for heating or fuel cells (after proper filtration to remove harmful gasses); internal combustion (IC) engines should not be used because of unburned methane releases.
8. **Stop new landfill gas to energy projects and don't give "renewable energy" credits to landfill gas** (unless capture rates over the entire landfill and destruction efficiencies are constantly monitored and demonstrated[30] to be equal to those of a flare.) (The argument that credits should be given if gas collection projects are installed earlier than local or NSPS requirements should not apply, since fugitive emissions have been found to be so large. The only way to eliminate these fugitive emissions is to eliminate organics from landfills, which would make landfill gas to energy projects uneconomic. Giving renewable energy credits to landfill gas allows it to undercut clean sources like wind and solar and, most importantly, puts source reduction, reuse, recycling, diversion, composting, and anaerobic digestion at a competitive disadvantage.)

[30] Peter Anderson mentions monitoring costs in "Critique of SCS Engineers' Report Prepared for California's Landfill Companies on Gas Collection Performance," Sept. 5, 2008, p. 12 (anderson@recycleworlds.net). However, a spectroscopy method developed by Picarro proposes efficient monitoring, Rella, Chris, et al., 2009, (http://www.picarro.com/assets/docs/Quantfying_Methane_Fluxes_Simply_and_Accurately_-_Trace_Dilution_Method.pdf).

32% in the first year alone) (see Figure 2.), usually before the gas cap and capture systems are put in place. The normal reason for the delay putting on the cover is the operator is still adding waste to that section of the landfill.

Figure 2. Over 80% of the Methane from Food Waste Escapes in the First 3 Years, Usually Before Capping

[Emissions in tons of methane (CO_{2e}) per wet ton of waste]

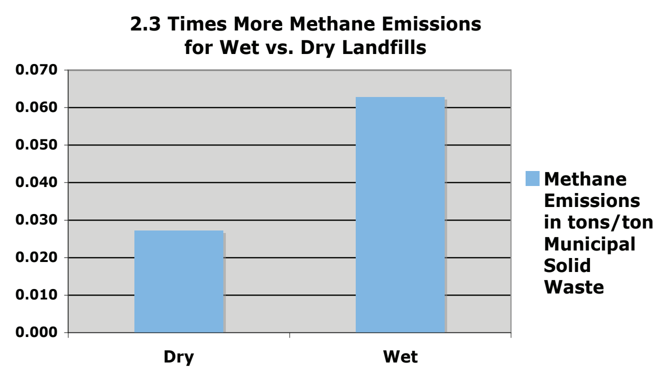


To get the above data, the Chicago Climate Exchange uses a decay model to calculate GHG emissions from a landfill, which is described in detail in their paper.[8] The bottom line is, if there are <u>any</u> organics in the landfill, we need to deal with the ongoing methane emissions from the remaining waste. For many years people installed impermeable caps and gas collection systems to capture the methane and put it into a flare to burn it. Every ton of methane captured and burned avoids the equivalent of adding 104 tons of CO2 to the atmosphere (calculated over a 20-year period).[9]

Wet vs. Dry Landfills

But then people thought, why waste that biomethane burning it in a flare? Why not use it to replace fossil fuels? It sounded like a good idea, except, if you take the methane from a dry landfill and try to burn it in an engine or turbine, it is inefficient. The normal methane flow from a "dry tomb" landfill is so slow and impure, that the operator doesn't make enough money to pay for the additional capital and operating expenses of an engine or turbine. So they need more moisture in the landfill. As the chart below from research done for the U.S. EPA shows, **wet** landfills generate 2.3 times more methane than **dry** ones (based only on measuring the <u>collected</u> gas, not the total emitted, which was not looked at in these studies).[10] If the collection efficiency were the same in both cases, the result is up to **2.3 times more GHG emissions** for energy recovery sites.[11]

Figure 3. Moisture Greatly Increases Methane Emissions



[8] Chicago Climate Exchange, Avoided Emissions from Organic Waste Disposal, Offset Project Protocol, 2009, p. 22. (https://www.theice.com/publicdocs/ccx/protocols/CCX_Protocol_Organic_Waste.pdf)
[9] Calculated from methane global warming factor 105 minus the 1 part CO_2 from the flare burning the methane.
[10] Reinhart, D.R. et al. First-Order Kinetic Gas Generation Model Parameters for Wet Landfills, report prepared for US EPA, 2005, p. 4-5. (nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P100ADRJ.txt). See also Sally Brown, "Putting the Landfill Energy Myth to Rest," *BioCycle*, May 2010, p. 5.
[11] We note that these data are from experimental sites; some energy recovery sites may not be this wet.

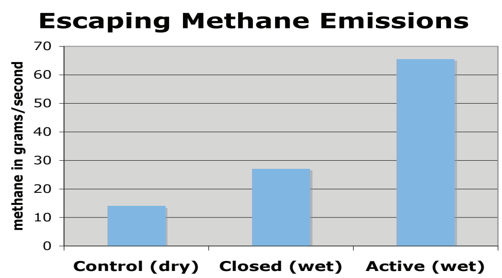
Since it is supposed to be illegal to deliberately add water to a landfill, waste engineers came up with a variety of ideas to increase the gas production in the short term and decrease costs so they could make more money, including such methods as[12]:

- Leaving the cap off as long as possible so more water from rain and snow can enter.
- Regrading the slopes to drain rain into the landfill.
- Recirculating the liquid leachate flowing from the bottom of the landfill back into the top.[13]
- Turning off gas collection wells on a rotating basis in order to give each field time to recharge moisture removed by the gas extraction process itself.
- Reducing the vacuum pump pull on gas collection wells when imperfections in the landfill cover allow air to be drawn into the waste mass. Pulling lower amounts into the collection system allows more methane to escape. (Note: While landfills that just flare gas can accept 3%-5% oxygen infiltration before risking igniting fires, those recovering energy are restricted to as low as 0.1% because a high rate of methane production depends upon having an oxygen-starved environment.)
- Installing more gas collection wells at the center of the landfill, where methane ratios are greatest, and less at the periphery, which could allow more gas to escape with no wells to capture it.

Result of Increasing Moisture is More Uncollected, Fugitive Emissions

The problem is that these aids to more profitable "energy recovery" result in much more uncaptured methane. A report for the US EPA analyzed fugitive emissions for three types of approaches: (1) normal dry tomb landfill, (2) closed landfill, but circulating leachate to provide moisture for energy recovery, and (3) active landfill circulating leachate to provide moisture for energy recovery. The results are shown in Figure 4. The closed, but wet landfill had 1.9 times more escaping emissions, while the active wet landfill designed for maximum energy production had 4.7 times more emissions.[14]

Figure 4. Moisture Increases Fugitive Methane Emissions from a Landfill, by up to 4.7 times



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[12] List compiled in March 2010 by Peter Anderson, RecycleWorlds Consulting, based on these publications:

- Augenstein, Don, Landfill Operation for Carbon Sequestration and Maximum Methane, (http://www.osti.gov/bridge/purl.cover.jsp?purl=/795745-EMfXDz/native).
- Institute for Environmental Management (IEM), Emission Control: Controlled Landfilling Demonstration Cell Performance for Carbon Sequestration, Greenhouse Gas Emission Abatement and Landfill Methane Energy, Final Report, February 26, 2000.
- Augenstein, Don, et. al., Improving Landfill Methane Recovery - Recent Evaluations and Large Scale Tests (2007) (http://www.globalmethane.org/expo_china07/docs/postexpo/landfill_augustein_paper.pdf)
- Oonk, Hans, Expert Review of First Order Draft of Waste Chapter to IPCC's 4th Assessment Rpt, 2008 (available from Peter Anderson, anderson@recycleworlds.net)
- SCS Engineers, Technologies and Management Options for Reducing Greenhouse Gas Emissions From Landfills, 2008 (http://www.calrecycle.ca.gov/Climate/CATSubgroups/2008Feb26/Report.pdf).
- U.S. Environmental Protection Agency, 40 CFR Part 60 WWW (proposed and final rule).
- Sierra Club LFGTE Task Force, Sierra Club Report on Landfill-Gas-to-Energy, January 2010 (http://sierraclub.org/policy/conservation/landfill-gas-report.pdf)

[13] "[Director of Butte County's solid waste program] Mannel explained that in this process, liquid is introduced into the sealed "waste cells" in the landfill. The addition of the liquid improves the production of methane up to five times more than the unaugmented process." Chico Enterprise-Record, 6/14/2010 (chicoer.com/news/ci_15292646)

[14] Mark Modrak, et al., Measurement of Fugitive Emissions at a Bioreactor Landfill (2005) (available at http://clubhouse.sierraclub.org/people/committees/lfgte/docs/measurements_fugitivieemissions.pdf)

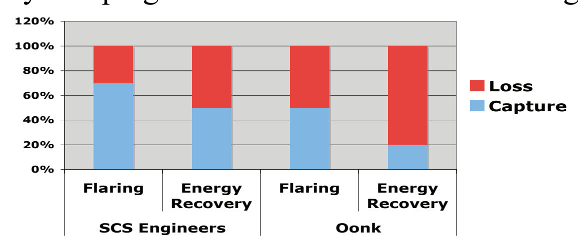
The IPCC estimated that, over the long term, including the extensive times (before and after installation of the gas capture systems) when there is little or no gas collection, the average total fraction captured may be as low as 20%.[15] U.S. EPA's *Compilation of Air Pollutant Emission Factors* (AP-42) assumes a range from 60 to 85 percent, with 75 percent as "typical" for sites having a well-designed active collection control system in place.[16] However, EPA gives no estimates of the amounts lost before the installation of the gas capture system and after landfill maintenance ends, which often are very large.[17]

A report by consultants for the solid waste industry[18] provides their view of the ranges of gas collection values: 50-70% for an active landfill, 54-95% for a inactive landfill or portions of a landfill that contain an intermediate soil cover, or 90-99% for closed landfills that contain a final soil and/or geomembrane cover systems. Their view is stated as, "The **high ends** of the range of these values are proposed for sites with NSPS or similar **quality LFG collection** systems which are designed for and achieve compliance with air quality regulations and surface emissions standards." "The **low end** of the range would be for full LFG systems that are installed and operated for other purposes, such as **energy recovery**, migration control, or odor management; . . ." (emphasis added). Our interpretation of these statements is the high ends of the ranges apply to sites using flaring, while the low ends apply to those doing energy recovery.

However, we note that the Palos Verdes landfill study in the 1990s, which was cited by SCS Engineers for its "capture efficiencies above 95%,"[19] was for a landfill that had been closed for nearly 20 years and had a 5-foot thick clay cap installed. That study was recently reevaluated by the California Air Resources Board, which found a collection rate of only 85%.[20] Thus for closed landfills with a final cover, 85% capture is a more substantiated upper limit, meaning that more than 15% is escaping.

In any event, the SCS report indicates the waste industry recognizes the potential losses in the collection efficiency of energy recovery compared to state of the art flaring. This means that an active landfill (shown in the left two columns in Figure 5 on the next page) using an energy recovery system could have a collection efficiency as low as 50%, compared to about 70% for one using flaring, which implies 1.6 times more methane is likely escaping when a landfill is used for energy recovery. A study of Dutch landfills[21] shown in the two right columns found that, averaged over the life of the landfill, flaring gas extraction systems designed for minimizing emissions could realize collection efficiencies only up to 50%, while energy recovery systems averaged only 20% efficiency. However, the numerical factor is the same, 1.6 times more methane is likely escaping when a landfill is used for energy recovery.

Figure 5. Methane Capture Efficiency at Flaring sites is 1.6 Times greater than at Energy Recovery sites.



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[15] Intergovernmental Panel on Climate Change, *Fourth Assessment Report*, Waste Chapter 10, p. 600 (2008). (Note that 54% of all waste x 75% collection efficiency x 50% when collecting = 20%.)
[16] Office of Air Quality Planning and Standards and Office of Air and Radiation, *Emission Factor Documentation for AP-42, Section 2.4, Municipal Solid Waste Landfills* (Revised 1997) (http://www.epa.gov/ttnchie1/ap42/ch02)
[17] "Critique of SCS Engineers' Report Prepared for California's Landfill Companies on Gas Collection Performance," by Peter Anderson, Center for a Competitive Waste Industry, 2008 ().
[18] SCS Engineers, *Current MSW Industry Position and State-of-the-Practice on LFG Collection Efficiency, Methane Oxidation, and Carbon Sequestration in Landfills*, for the Solid Waste Industry for Climate Solutions (June 2008), p. 16-17 (http://www.scsengineers.com/Papers/FINAL_SWICS_GHG_White_Paper_07-11-08.pdf).
[19] California Integrated Waste Management Board, Overview of Climate Change and Analysis of Potential Measures to Implement Greenhouse Gas Emission Reduction Strategies, May 8, 2007.
[20] "Initial Statement of Reasons for the Proposed Regulation to Reduce Methane Emissions from Municipal Solid Waste Landfills," (May 2009) p. IV-5 and Appendix D (http://www.arb.ca.gov/regact/2009/landfills09/isor.pdf).
[21] Oonk and Boom, 1995, *Landfill gas formation, recovery and emissions*, Chapter 7, TNO-report 95-130.

We note that a recent report[22] by Patrick Sullivan, senior vice president of SCS Engineers, consultants for the solid waste industry, states, "Opponents of landfills claim development of LFGTE projects will increase methane emissions at landfills [in comparison with flaring]. . . This is simply not true." Some of the points he makes are quoted in italics below:

1. *"The landfill is required by federal regulations to achieve the same surface emission limits and LFG system operational requirements in either case."* Our response is the landfill operator must demonstrate there is no increase in fugitive emissions from practices that aid LFGTE, such as the six strategies mentioned on page 3 above.
2. *"Landfill opponents suggest that LFG engines, which represent the largest majority of LFGTE devices, do not destroy methane as well as flares. Indeed, the capacity of flares to destroy methane is greater than most LFGTE equipment, but the true difference between the two devices is very small with flares and other control devices achieving more than 99% control and lean-burn LFG engines achieving more than 98% control of methane (Solid Waste Industry for Climate Solutions [SWICS], 2007)."* He is referencing his own company report, but the report cited actually states that methane destruction efficiency of flares is 99.96% compared to internal combustion engines 98.34%. As we will show later, this **1.6% difference is very significant**, even using the outdated GHG multiplier of 21 (and much worse using the 20-year multiplier 105).[23] This means that it is impossible to use engines and have less net impact than flaring, but turbines with high destruction efficiency are acceptable, as are systems that inject the methane directly into natural gas pipelines for normal uses.
3. *"There are some landfills, which are not required by regulation to collect and control LFG, that are developed for LFGTE."* Our response is this is a valid point. Voluntary LFGTE projects undertaken before the NSPS standards require temporary capping and collection could significantly reduce GHG emissions compared to cases where operators wait as long as possible (up to 5 years is allowed for active cells) to cap and install collection systems. A consultant report found the very large collection of methane before the five year limit produced substantial carbon reduction credits.[24] However we feel the EPA needs to drastically tighten the NSPS standards, especially in light of the analyses reported above that the largest emissions from wet organics occur within the first three years.

Combining the Two Effects Produces Much More Net GHG Emissions for Energy Recovery

In addition to the 1.6 times increase in fugitive emissions at energy recovery sites, there is the effect reported above that **wet** landfills produce 2.3 – 4.7 times more methane than dry ones. If we combine these two observed effects, the net result would be **3.8 - 7.8 times more net GHG emissions for energy recovery compared to flaring** (this value is irrespective of the value of the GHG multiplier for methane, but the GHG impact is five times greater when using the 105 multiplier for methane).

The charts in Figure 6 indicate the actual global warming savings using the captured methane from energy recovery to replace the burning of fossil methane are very small (0.0007 tons of carbon dioxide equivalent per typical ton of municipal solid waste (MSW)), much less than the overall impacts of the escaping methane. The left chart shows a net increase of GHG emissions of 0.034 CO_2 equivalent tons/ MSW ton using the old (1995) multiplier of 21 (which is still used by the US EPA for "consistency").

The right chart shows a net increase of GHG emissions of 0.172 CO_2 equivalent tons/MSW ton using the latest (2009) multiplier of 105 over the next critical 20 years. Below the large right red bars for energy recovery in both figures, there is a very tiny blue line (that looks almost like a shadow) that

[22] Patrick Sullivan, SCS Engineers, The Importance of Landfill Gas Capture and Utilization in the U.S., April 2010, p. 28-30. (http://www.scsengineers.com/Papers/Sullivan_Importance_of_LFG_Capture_and_Utilization_in_the_US.pdf)

[23] It is very unfortunate that EPA 40 CFR Part 98 allows the use of a default 99% destruction efficiency for methane for all types of LFG combustion devices, including engines, ignoring this large GHG impact.

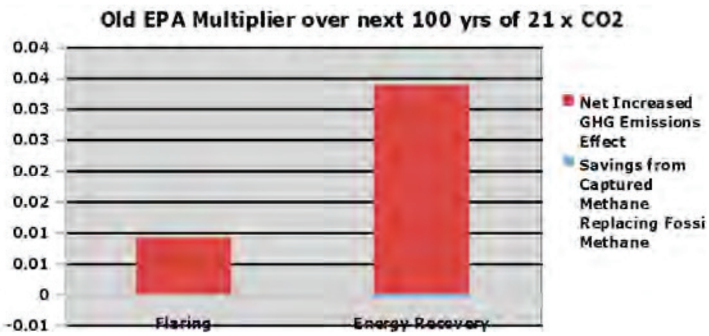
[24] McCommas Bluff LFGTE Project, Voluntary Carbon Standard Assessment, Jan. 2010, by Blue Source LLC, available from the author, Annika Colson, (212) 253-5348, acolston@bluesource.com

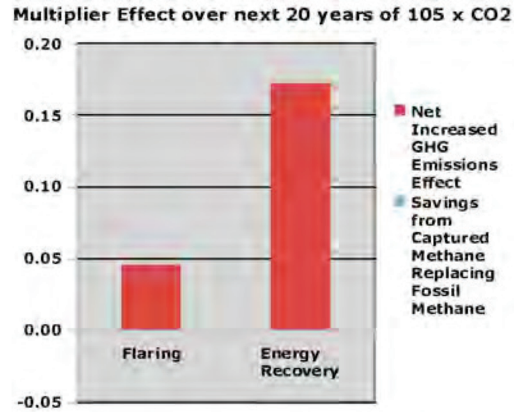
represents the amount of benefit from offsetting the use of fossil fuels, which in each case is only 0.0007 tons of carbon dioxide equivalent per typical ton of MSW.

Note that the charts essentially apply to landfills with active gas collection systems, and do not include the methane lost before the landfill is capped, or after the permanent landfill cap is no longer maintained and starts to leak, adding moisture from precipitation, which will increase methane emissions.

Figure 6. Energy recovery procedures increase global warming impact by at least 3.8 times using either multiplier of 21 or 105, even considering the savings from "energy recovery."

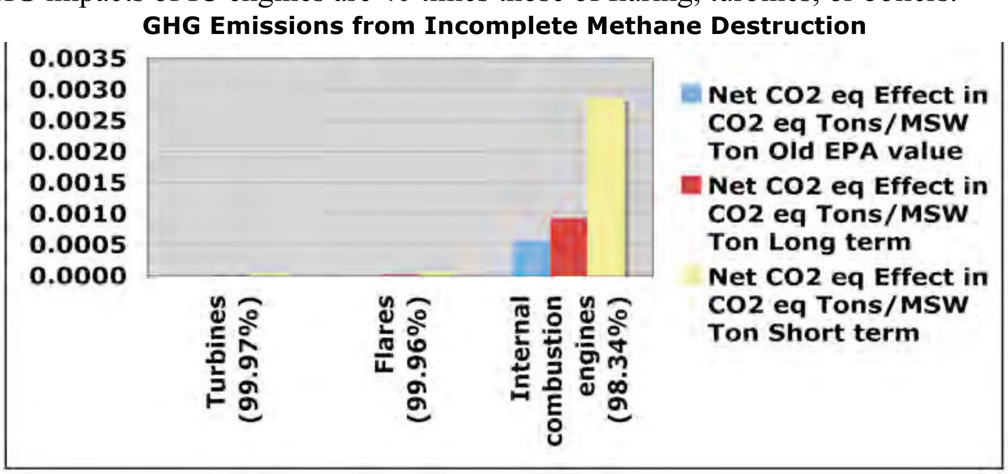
The GHG emissions from escaping methane are expressed in $CO_{2\ equivalent}$ Tons per MSW Ton





Methane Destruction Inefficiency of Internal Combustion Engines Increases GHG Impact

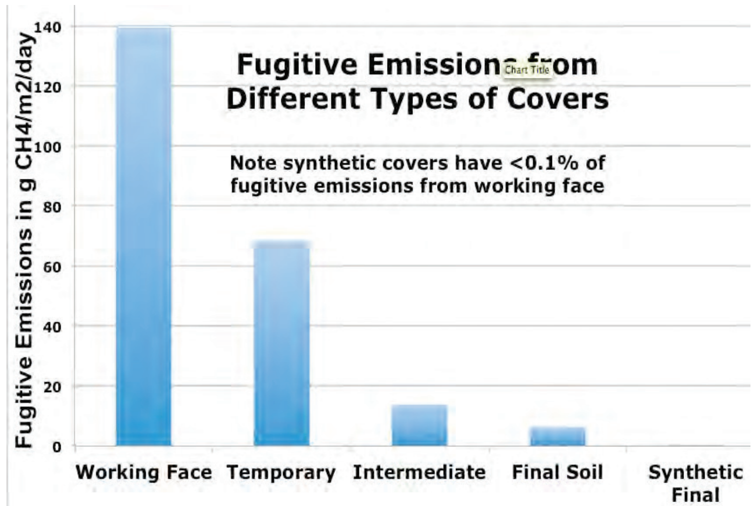
It is important to include recent data from the waste industry of average methane destruction efficiency of flares (99.96%) compared to internal combustion (IC) engines (98.34%) and turbines (99.97%).[25] Their analysis indicates turbine destruction efficiency is essentially equivalent to a flare, but an internal combustion engine adds significant GHG impact from its 1.6% lower destruction efficiency. An EPA report found that a boiler was similar to a flare.[26] But using an engine increases the GHG impact from energy recovery by 0.0006 CO_2 equivalent tons per MSW ton, using the old multiplier of 21, or 0.0028 CO_2 equivalent tons per MSW ton, using the latest 20-year multiplier of 105. The methane destruction **in**efficiency of an internal combustion **engine** (0.0006) essentially **negates its global warming savings** from replacing fossil methane at the old multiplier (0.0007). Using the short-term multiplier of 105 shows the GHG impacts of IC engines are 40 times those of flaring, turbines, or boilers.



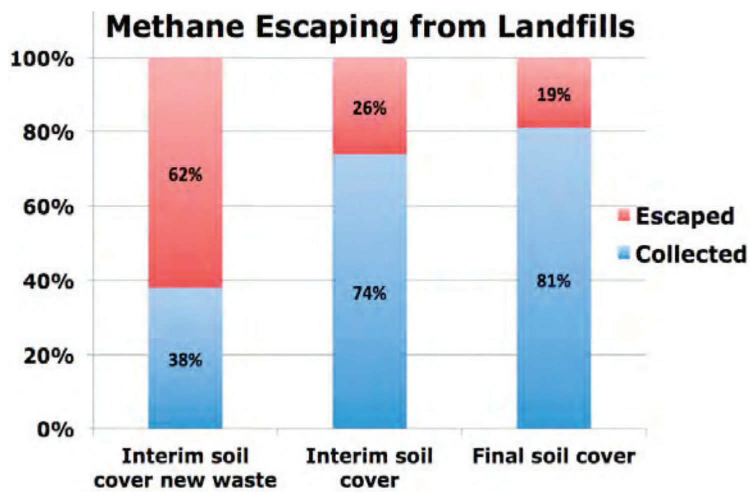
[25] SCS Engineers, *Current MSW Industry Position and State-of-the-Practice on Methane Destruction Efficiency in Flares, Turbines and Engines*, prepared for the Solid Waste Industry for Climate Solutions (July 2007), p. 2.

[26] Roe, S.M., Fields, P.G., and Coad, R. Methodologies for Quantifying Pollution Prevention Benefits from Landfill Gas Control and Utilization. EPA/600/SR-95/089, July 1995. (http://www.p2pays.org/ref/07/06277.pdf)

Effects of Different Types of Covers



A recent paper by Goldsmith et al.[27] compares the efficacies of different types of flat landfill covers in reducing fugitive emissions. Goldsmith et al. discuss the impact of different climates on the fugitive emissions, but since they found such a wide range of emissions for a given cover type within each climate zone, this chart compares the averages of all the results they obtained for the five cover types. Even a temporary cover reduces emissions by over 50%, an intermediate cover by 90%, final soil by 95%, and a synthetic final cover by 99.9%.



A recent EPA report[28] using tracer gas data and optical remote sensing measurements to analyze fugitive emissions from both the tops and side slopes found collected gas for intermediate covers ranged from 70% to 77% for a site with interim soil cover and 73-88% for a site with a final soil cover. Both sites had not accepted waste for years. The one that had just stopped receiving new waste had only 38% capture rate. The gas was being flared with no energy recovery. Note that this EPA report contradicts the report mentioned in footnote 17, by SCS Engineers, consultants for the solid waste industry, which claims collection efficiencies of 90-99% for closed landfills that contain a final soil cover. The results of the Goldsmith and EPA reports make it even more urgent that all landfills install a waterproof, airproof synthetic final cover and efficient gas collection system as soon as each small cell is filled, preferably within a few weeks.

Policy Recommendations

In summary, to reduce global warming requires the following steps to be implemented immediately:

1. Use current GHG impact value of 33 (over 100 years) or 105 (over 20 years) for methane to calculate the **impacts of methane** emissions from landfills.
2. **Divert all organics** (except sewage sludge) from landfills to reduce uncollected emissions.[29]
3. **Either compost all organics or digest them in sealed processors** that capture all methane.

[27] Goldsmith, Jr., C.D., Chanton, J., Abichou, T., Swan, N., Green, R., and Hater, G., *Journal of the Air & Waste Management Association*, 62(2):183–197, 2012.

[28] Quantifying Methane Abatement Efficiency at Three Municipal Solid Waste Landfills. EPA/600/R-11/033, report prepared in 2012 by ARCADIS U.S. for Susan A. Thorneloe.

[29] We note that clean organics can be processed by aerobic composting or by anaerobic digesters that can capture all the methane for energy purposes and produce high quality compost, with only small amounts of inert waste remaining for a landfill. However, toxic contaminated organics such as sewage sludge/"biosolids" digestate should be monofilled in separate cells in existing landfills because of the high contamination.

4. **Segregate remaining organics in landfills for the most effective and cost-efficient gas collection** (always maintaining high suction)**.**
5. **Keep out all liquids** from landfills (including not recirculating leachate) to reduce fugitive emissions.
6. **Cap landfills with temporary covers** over the working face to keep out rain and **then install permanent synthetic covers and gas collection systems as soon as possible** (within months is important). (The current 5-year NSPS requirement harms our environment and health.)
7. **All captured methane should be burned in a flare, boiler or a high efficiency turbine**, or used to replace natural gas for heating or fuel cells (after proper filtration to remove harmful gasses); internal combustion (IC) engines should not be used because of unburned methane releases.
8. **Stop new landfill gas to energy projects and don't give "renewable energy" credits to landfill gas** (unless capture rates over the entire landfill and destruction efficiencies are constantly monitored and demonstrated[30] to be equal to those of a flare.) (The argument that credits should be given if gas collection projects are installed earlier than local or NSPS requirements should not apply, since fugitive emissions have been found to be so large. The only way to eliminate these fugitive emissions is to eliminate organics from landfills, which would make landfill gas to energy projects uneconomic. Giving renewable energy credits to landfill gas allows it to undercut clean sources like wind and solar and, most importantly, puts source reduction, reuse, recycling, diversion, composting, and anaerobic digestion at a competitive disadvantage.)

[30] Peter Anderson mentions monitoring costs in "Critique of SCS Engineers' Report Prepared for California's Landfill Companies on Gas Collection Performance," Sept. 5, 2008, p. 12 (anderson@recycleworlds.net). However, a spectroscopy method developed by Picarro proposes efficient monitoring, Rella, Chris, et al., 2009, (http://www.picarro.com/assets/docs/Quantfying_Methane_Fluxes_Simply_and_Accurately_-_Trace_Dilution_Method.pdf).

POLICY. SCIENCE. BUSINESS.

EPA

Court orders agency to address landfill emissions

Ellen M. Gilmer, E&E News reporter

Published: Tuesday, May 7, 2019

Solid waste landfills, like this one in Arizona, are a source of methane emissions. Alan Levine/Flickr

The Trump administration violated the Clean Air Act by not taking action on harmful emissions from landfills, a federal court ruled yesterday.

The U.S. District Court for the Northern District of California **found** EPA failed to meet its statutory obligation to restrict climate-warming methane and various conventional pollutants that spew from municipal solid waste landfills across the country.

The waste sites are the third-largest emitters of human-caused methane in the United States. They also release benzene and other pollutants that can harm human health.

The Obama administration crafted landfill emissions guidelines in 2016 after years of consideration, but Trump officials have not taken the requisite next steps to review state implementation plans or craft a federal program.

"There is no denying EPA's clear failure to meet its nondiscretionary duties," Judge Haywood Gilliam Jr. wrote.

Proponents of tight restrictions on landfill pollutants cheered the ruling as another rebuke to Trump officials' efforts to delay or roll back various environmental standards.

"Courts are showing no patience for EPA's blatant violations of law," David Hayes, executive director of the State Energy & Environmental Impact Center, said in a statement.

"Thankfully, California Attorney General Xavier Becerra and other state attorneys general are holding the Trump Administration accountable for outrageously flouting the rule of law," he added later.

Government lawyers did not dispute allegations that EPA shirked its mandatory duties; instead, they argued that the coalition of states challenging the agency lacked legal standing to bring the case because they failed to show a clear connection between EPA's inaction and specific harm the states would face.

Gilliam, an Obama appointee, rejected the argument, citing the "special solicitude" afforded to sovereign states in litigation, as laid out in the landmark *Massachusetts v. EPA* ruling in which the Supreme Court ruled Massachusetts could challenge EPA's refusal to regulate greenhouse gases.

The state coalition in the landfill case included California, Illinois, Maryland, New Mexico, Oregon, Pennsylvania, Rhode Island and Vermont.

"Noxious landfill emissions affect everyone, but disproportionately hurt our most vulnerable communities, impacting their health, environment, and standard of living," Becerra (D) said in a statement. "Once again, we've held the EPA accountable for its failure to perform its mandatory duties under the Clean Air Act, and for its unwillingness to protect public health."

The Environmental Defense Fund intervened in the case on the states' side.

"I definitely see this as part of the streak of Trump administration rollbacks that are not holding muster in court," EDF attorney Rachel Fullmer told E&E News.

Under the court's order, EPA must make final decisions approving or disapproving existing state plans by Sept. 6 and finalize a federal plan by Nov. 6 — keeping the court apprised of its progress through status reports every 90 days.

EPA said it is reviewing the decision.

The agency is separately working on a proposal to formally delay implementation deadlines for landfills. The new deadlines would more closely align with those in the Trump administration's proposed replacement for the Obama-era Clean Power Plan, which targeted greenhouse gas emissions from the power sector.

Reporter Jennifer Hijazi contributed.

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We've made some changes to EPA.gov. If the information you are looking for is not here, you may be able to find it on the EPA Web Archive or the January 19, 2017 Web Snapshot.

News Releases from Region 09

EPA resolves Clean Water Act violations with Honolulu and Waste Management at Waimanalo Gulch Landfill

04/29/2019

Contact Information:
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For Immediate Release: April 29, 2019

HONOLULU – The U.S. Department of Justice, U.S. Environmental Protection Agency, and Hawaii Department of Health (DOH) have settled with the City and County of Honolulu (CCH) and Waste Management of Hawaii, Inc. (WMH), over Clean Water Act violations at the Waimanalo Gulch Sanitary Landfill in Kapolei, Oahu.

CCH and WMH will pay a combined penalty of $425,000, which will be split evenly between the U.S. and the State of Hawaii. The state will use the funds for coral reef and habitat restoration, monitoring and conservation on the leeward coast of Oahu.

The agreement also calls for a series of facility upgrades to maintain compliance with stormwater regulations. CCH and WMH will retrofit the landfill's existing stormwater drainage pipeline, install a trash screen, revise their stormwater pollution control plan, comply with specific operational and monitoring limits for the stormwater basin, and apply for an individual stormwater permit for the facility. The consent decree is subject to a 30-day public comment period.

"Today's action requires the City and County of Honolulu and Waste Management to improve their stormwater drainage, controls, and monitoring program at Waimanalo Gulch Sanitary Landfill," said EPA Pacific Southwest Regional Administrator Mike Stoker. **"Managing stormwater runoff is critical to protecting residents' health and Oahu's coastal waters."**

"Actions detailed in this consent decree will help prevent future harmful discharges from the landfill and provide resources to restore corals that were impacted by the violations," said Hawaii DOH Deputy Director of Environmental Health Keith Kawaoka. **"The consent decree concludes years of dispute over the horrific discharges of medical waste and sediment that occurred during the winter of 2010."**

Today's settlement marks the end of a long-term effort by EPA and the state of Hawaii to bring the landfill – the largest on Oahu – into compliance with laws designed to protect public health, natural ecosystems, and wildlife.

Waste Management operates the Waimanalo Gulch landfill, which is owned by the City and County of Honolulu. In 2009, WMH and CCH began work on a landfill expansion and new stormwater diversion structure. During construction, Waste Management used temporary stormwater pipes to divert stormwater around the landfill.

Before completion of the permanent stormwater diversion structure, WMH began placing waste in the landfill expansion area. In December 2010 and January 2011, several large storms overwhelmed the temporary pipes and flooded the expanded area of the landfill. The flooding discharged stormwater contaminated with leachate, trash, and medical waste into the Pacific Ocean. Medical waste washed up on area beaches for several weeks, prompting leeward Oahu area beach closures.

EPA issued an order in January 2011 requiring cleanup of leachate, trash, and medical waste discharged during the storms. EPA issued an additional Clean Water Act order in 2012 requiring WMH and CCH to: complete construction of the facility's stormwater diversion system; finish a study of the landfill's detention basin to evaluate its capacity to store and treat stormwater; and develop an interim stormwater monitoring plan. WMH and CCH have completed the requirements in those orders.

In July 2015, WMH pleaded guilty to criminal violations for negligent discharge of pollutants on seven days in violation of the Clean Water Act. The company paid $400,000 in criminal fines, and $200,000 in restitution.

The consent decree for this settlement will be lodged in the federal district court by the U.S. Department of Justice and is subject to a 30-day public comment period and final court approval. A copy of the decree will be available on the Department of Justice website at: https://www.justice.gov/enrd/consent-decrees

For more information on EPA's Stormwater Program please see: https://www.epa.gov/npdes/stormwater-discharges-industrial-activities

For Hawaii's Stormwater program, please see: http://health.hawaii.gov/cwb/permitting/industrial-storm-water/

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WASTEDIVE

BRIEF

Report identifies factors in Advanced Disposal landfill slope failure that left one dead

By Igor Geyn

Published Feb. 7, 2019

Dive Brief:

- The Pennsylvania Department of Environmental Protection (DEP) has approved a third-party root cause analysis (RCA) report identifying the source of a fatal Feb. 2017 slope failure at the Advanced Disposal Services Greentree Landfill in Kersey, PA.
- According to the report, the "placement of non-conventional waste streams … including low shear strength sludges" interacted with an inability to install necessary gas well infrastructure to displace 15.5 acres of waste, resulting in the death of William Pierce.
- The report identified three categories of "factors" as the "primary focus" of the incident investigation team: operational factors, leachate and landfill gas factors (which subsequently contributed to "excessive pore pressure"), and geometric factors “associated with cell configuration and management of waste within [the] configuration.”

Dive Insight:

The 2017 incident led to the DEP requiring Advanced Disposal to pay $695,000 in civil penalties, as well as remediate the slope failure area and consent to restrictions on sludge acceptance. The company was also responsible for $12,000 in OSHA fines. The company's most recent quarterly filing indicates it had incurred $6.4 million in expenses, net of insurance recoveries, as of June 2018 due to the incident.

Advanced Disposal did not respond to a request for comment on this new report.

In its RCA report, Geosyntec Consultants identified a series of operational conditions that factored into the failure, but said that none "led to (or would have led to)" the collapse in isolation. In combination with pore fluid pressures and geometric factors, Advanced Disposal’s use of oil and gas drill cuttings for interim cover, implementation of a "100-ft plus" setback in the affected landfill cell and installation of a segregation layer "led to an unstable waste mass that resulted in the Slope Failure."

Although Greentree staff acted "aggressively" to implement landfill gas well infrastructure, and met both permit conditions and industry standards in individual decisions, the combination of these operational decisions created a section of concentrated, hydrologically nonconductive low shear strength waste (LSSW) that produced bulging, eruption and the eventual collapse.

In a separate lecture on the geotechnical stability of waste fills, Geosyntec Chairman and Senior Principal Dr. Rudolph Bonaparte explained how the lack of timely gas well installation and concentration of more than 40% LSSW in the Greentree Landfill cell exploited the slope’s weak zones. Bonaparte also connected the observations from the Greentree failure to a need for greater understanding of “unintended consequences” of waste fill operations, including the management of special waste.

The Advanced Disposal site, which has been in operation since 1986, is permitted for an average of 5,500 daily tons of waste and currently accepts an average of 3,000 tons. It's included in the solid waste plans of several Pennsylvania counties and has contracts with multiple generators in the region.

According to the Bureau of Labor Statistics (BLS), three of the 63 fatalities in the "waste management and remediation services" category occurred at landfills in 2017. While this is a small number relative to the 30 fatalities among collection workers — which often receive more regular attention in safety discussions — it indicates that risks are still present at closed sites. While official 2018 BLS data won't be available until later this year, anecdotal reports indicate that there have already been at least two fatalities at landfills so far in 2019.

WASTEDIVE

BRIEF

Waste Management reaches $4.1M settlement over Ohio landfill

By Rina Li

Published Dec. 5, 2018

Dive Brief:

- Waste Management will pay $4.1 million in a class-action lawsuit over the Stony Hollow Landfill in Dayton, Ohio, reports Dayton Daily News. The settlement was finalized in federal district court on Nov. 26.
- The suit, which was filed in 2016 following numerous odor complaints from neighboring communities, claims Waste Management "failed to sufficiently collect, capture, and destroy landfill gas generated at its landfill to prevent fugitive emissions and to otherwise prevent odors from the landfill from invading the homes and property."
- An estimated 2,000 individuals will share $1.875 million provided by the settlement, according to court documents. In addition to doling out funds to class-action members, Waste Management will also be required to implement $1.45 million worth of improvements to the landfill by the end of 2022 in order to reduce odor emissions.

Dive Insight:

The 169-acre landfill, which takes in an average of 1,100 tons of waste per day, has been an ongoing source of grief for adjacent communities; odor emissions have prompted hundreds of complaints from area residents since April 2016. While Waste Management has acknowledged the odors — and, according to the landfill's website, taken "significant action" to address underlying structural issues — community members and city officials remain frustrated with the lack of progress.

The suit marks the culmination of a series of odor-related headaches centered around Stony Hollow Landfill. The Ohio EPA issued the site a $16,000 fine for emissions last year, while odor issues have prompted Montgomery County to explore alternative options for solid waste disposal. In addition, Dayton barred the landfill from discharging waste into the city's sanitary sewers after the presence of prohibited chemicals forced cleanup crews to seek medical attention.

Strained relations between landfills and neighboring communities have become increasingly common in recent months: odor emissions from a Waste Connections-owned landfill in Louisiana have prompted multiple pending class-action suits, while another Waste Management landfill in New York was hit with its own class-action suit over odors this past summer.

NEW YORK STATE OF OPPORTUNITY | Department of Environmental Conservation

For Release: Monday, February 5, 2018

DEC Cites High Acres Landfill for Failure to Reduce Odors

Notice of Violation Issued to Waste Management of New York, LLC, for Ongoing Violations of State's Air Pollution Control Requirements and Solid Waste Management Regulations

New York State Department of Environmental Conservation (DEC) Commissioner Basil Seggos today announced that on Friday, Feb. 2, 2018, DEC issued a Notice of Violation (NOV) to Waste Management of New York, LLC, operator of the High Acres Western Expansion Landfill located in the towns of Perinton in Monroe County and Macedon in Wayne County, for ongoing violations of the state's solid waste management regulations, as well as the state's air pollution control requirements related to ongoing odor issues.

DEC Commissioner Basil Seggos said, "The odor condition at High Acres Landfill is unacceptable. New York's stringent rules and regulations governing waste exist to ensure facilities in our state are adhering to the safest practices and highest standards possible to protect public health and the environment. DEC takes any violation of these policies seriously and is taking necessary action to hold these violators accountable. The communities next door to the High Acres Landfill deserve no less."

DEC has received numerous complaints from the neighboring community of persistent unpleasant odors emanating from the landfill that are adversely impacting properties and quality of life. In response to these concerns, DEC immediately bolstered its monitoring of the landfill to determine the nature and extent of the odors, including increased on-site inspections. In addition, DEC has been working in cooperation with the town of Perinton and its Conservation Board to resolve the issue.

Under the terms of the NOV, Waste Management, LLC, must implement operational modifications to ensure best management practices are being applied at High Acres Landfill and undertake several structural improvements to strengthen the integrity of the facility's gas collection and odor mitigation systems to achieve significant odor reductions as expeditiously as possible.

DEC will continue to closely monitor operations and air quality conditions at the landfill and in surrounding communities and will provide strict oversight as the required corrective actions and modifications are implemented by March 16, 2018. Some of the corrective actions are already underway. In addition, DEC is continuing its increased presence at the site to ensure implementation of these measures until the odor issue is resolved.

Waste Management, LLC, may be liable for penalties for past or future violations.

The complete NOV is available (PDF, 212 KB).

BREAKING NEWS

AG Koster releases new expert reports concluding radiation and other pollutants have migrated off-site at Bridgeton Landfill

Sep 3, 2015, 10:06 AM

-- Data also indicates that underground fire has moved beyond the interceptor wells separating the North and South quarries --

Jefferson City, Mo. – Attorney General Chris Koster released today new reports from expert witnesses in the case he is prosecuting against Republic Services, Inc. relating to the subsurface fire at the Bridgeton Landfill. Collectively, the reports paint a troubling picture of the environment surrounding the landfill site. Contamination in groundwater outside the landfill perimeter has been identified, including radiological contamination detected in trees surrounding the site. Further, data indicate that the fire has moved past the two rows of interceptor wells positioned at the neck of the landfill, closer to the North Quarry.

Koster's office gathered the reports to better understand the facts relevant to the lawsuit Koster filed in 2013 against Republic Services for alleged violations of law associated with the still-burning fire. The Attorney General's Office is publicly releasing the reports because they contain information important to the health and safety of the people who live and work near the landfill.

The reports may be viewed below. Their conclusions are briefly summarized as follows:

- Drs. Joel Burken and Shoaib Usman, Environmental Engineering Professor and Nuclear Engineering Associate Professors, respectively, at Missouri University of Science and Technology (S&T), detected radiological and organic contamination in trees on the property of neighboring landowners. According to the report, these findings "indicate the off-site migration of RIM [radiologically impacted material], either in groundwater or aerial transport of particulate matter[,]" and similar off-site migration of organic pollutants, likely through movement of leachate-impacted groundwater.
- Peter Price, a scientist with the Missouri Geological Survey, and Dr. David Wronkiewicz, a Geology Associate Professor at Missouri S&T, discovered volatile organic compounds, including benzene, acetone, and 2-butanone, in high concentrations in the groundwater in wells outside the perimeter of the landfill. They are able to trac the contamination to the landfill by comparing its characteristics to leachate taken from the landfill.
- Drs. Tony Sperling, a landfill-fire expert and professional engineer, and Ali Abedini, a landfill-gas specialist, concluded that the data show the fire has moved beyond both lines of gas interceptor wells at the "neck" of the landfill, in the direction of the OU-1 radiological area. Drs. Sperling and Abedini also concluded that Republic Services "was negligent in aggressively over-extracting the gas system well outside industry best practices." They note that oxygen intrusion caused by over-extraction the leading cause of subsurface fires and smolders in municipal solid waste.
- Todd Thalhamer, a civil engineer from California with extensive experience investigating landfill fires, concluded that what he described as a "catastrophic event" at the landfill "was foreseeable and preventable." He stated that business decisions by the landfill's operators to overdraw gas-collection systems and inadequately maintain th soil cover on the site were factors causing the fire to occur.
- Dr. Timothy Stark, PhD and professional engineer, performed three separate personal inspections of the landfill site. He observed significant slope degradation and area where the waste mass had settled, suggesting the underground waste had been consumed by a smoldering / combustion event.
- Don Wright, a consultant specializing in odor assessment, captured an odor profile from the air surrounding the landfill and was able to identify a dominant odor "emitted by and carried a considerable distance downwind from the Bridgeton Landfill source."
- Kenny Hemmen, a registered geologist at Geotechnology, Inc., conducted a feasibility study to analyze remediation options related to potential groundwater contamination. He examined five alternative approaches with the objective of protecting human health and the environment.

In addition to publicly releasing the reports, the Attorney General's Office forwarded copies to the Environmental Protection Agency, the Missouri Department of Natural Resources, the Missouri Department of Health and Senior Services, and the St. Louis County Public Health Department. Koster encouraged those agencies to carefully review the information in the reports and take further remedial action as appropriate to ensure that the people around the landfill are protected.

"These reports underscore what has been clear from the beginning—Republic Services does not have this site under control," Koster said. "No only does the landfill emit a foul odor, it appears that it has poisoned its neighbors' groundwater and vegetation. The people of Missouri can't afford to wait any longer—Republic needs to get this site cleaned up."

Koster's suit against Republic Services is set for trial in March 2016. He has alleged that Republic's management of the landfill was negligent and that the company has violated the State's environmental laws. The suit seeks penalties, actual damages, and punitive damages as a consequence of Republic's allegedly unlawful conduct.

Full reports:

- West Lake Landfill Organic Pollutant Phytoforensic Assessment - Burken
- Westlake Landfill Phytoforensic Assessment using Gamma Spectroscopy - Usman
- Westlake Landfill Tree Core Analysis – Burken/Usman
- Bridgeton Sanitary Landfill Groundwater Investigation – Price/Wronkiewicz
- Subsurface Self Sustaining Reaction Incident – Sperling/Abedini
- Bridgeton Sanitary Landfill Incident – Thalhamer
- Field Inspection Reports – Stark
- Bridgeton Landfill Downwind Odor Assessment - Wright
- Feasibility Study – Groundwater Remediation – Hemmen

Carter's Valley landfill listed as possible site for radioactivity

Last updated: 5:05 PM, 08/03/2009

Source: The Rogersville Review

By Jim Beller Staff writer | (jbeller@xtn.net)
KINGSPORT - Just when you thought Hawkins County was a safe place to raise a family, think again. Clean water watchdogs announced Thursday that Carter Valley Landfill is leaking into the groundwater and has been accepting nuclear waste. Officials from The Tennessee Clean Water Network (TCWN) and Nuclear Information and Resource Service (NIRS) addressed the media Thursday at Mead Auditorium in the Kingsport Public Library. "People around regular trash landfills will be shocked to learn that radioactive contamination from nuclear weapons production is ending up there, either directly released by the Department Of Energy or via brokers and processors," stated Diane D'Arrigo, NIRS. TCWN Director of Community Organizing, Rachael Bliss, cited the Hawkins County landfill as a prime example of the Tennessee Department of Environment and Conversation's (TDEC) failure to control leaking landfills contaminating ground and surface water. "Thirty-one percent of our landfills are leaking," said Bliss. "Add to this, the Nuclear Information and Resource Service recent report showing that the state of Tennessee is a leader in licensing processors that can release radioactive materials to a municipal landfill. "There are nine landfills in Northeast Tennessee that are leaking and one is accepting special radioactive waste, Carter Valley Landfill in Hawkins County," she said. "Radioactive waste should not be accepted in our municipal dumps since TDEC has already demonstrated an inability to properly protect our water and communities from toxic landfill leachate. "Last year, statistics from TDEC showed of the 225 permitted landfills across the state, 69 or 31% were leaking," Bliss said. "Landfill leachate, contaminates drinking water sources like groundwater and surface water with toxic pollutants that are known to cause birth defects, cancer, learning disabilities and other health problems. "As recent as May of 2006, the Hawkins County landfill was assessed more than $70,000 in damages and penalties by TDEC for groundwater contamination," Bliss said, adding that "this is after two and a half years of warnings and violations notices that failed to resolve the leak problem. "TDEC claimed that communities surrounding the landfill were in no danger from the leak.

Violations range from lack of litter control to leachate leaks in groundwater, leaks migrating into storm water control structure, problems with collection, inadequate erosion control and leaking pipes. "According to the Johnson City TDEC field office there was no deadline set for BFI, who manages the landfill, to complete its repair of the Carter Valley Landfill leaks in exchange for a negotiated settlement with the Solid Waste Disposal Control Board for its violations." Bliss continued: "As of two days ago, the work was still ongoing. In the absence of a remedy to stop the leaks, Carter Valley Landfill is hauling its leachate by trucks to the Eastman Wastewater Treatment Facility. "According to TDEC records, the landfill is still on a monitoring basis of two times a year," Bliss said. "Evidently, TDEC doesn't think this is serious enough to require quarterly monitoring." Bliss said fewer than five of Tennessee's leaking landfills have "any corrective action being taken to stop the toxic landfill leachate." "TDEC's data from 2006 shows 44% of Class I landfills are leaking," she said. "Class I landfills are sanitary municipal landfills, like Carter's Valley. This means approximately 40 percent of Tennessee's landfills that are held the highest existing design standards that are actively accepting waste are leaking." Bliss said action needed by the Department to control Tennessee's leaking landfills include the regulation of landfills according to TDEC's Division of Solid Waste Management. Among these regulations are remediation of groundwater contamination, monitoring groundwater and methane gas. Another step in this process is requiring the 69 leaking landfills to come into compliance with TDEC's regulations. "TDEC's consistent and efficient enforcement of landfill regulations can prevent an entire community's exposure to toxic leaks from landfills and this can improve our ground and surface water and our right to clean water." D'Arrigo is one author of the recently released report, "Out of Control - On Purpose: DOE's Dispersal of Radioactive Waste into Landfills and Consumer Products." The report was commissioned to track if and how the Department of Energy (DOE) releases some of the low radioactive wastes from nuclear bomb production. The report said Tennessee is a leader in licensing processors that can release radioactive materials into our municipal landfills. "The DOE has on its own, actually in contradiction to the federal and Congressional revocation of these kinds of policies in the early '90s, determined its own levels it decided are acceptable for radiation exposure above the normal background. Several systems within the Department Of Energy allow that radioactive waste to go out to regular garbage or to be recycled into the marketplace or re-used. Equipment can be re-used or concrete and asphalt used again." There are four Class I landfills authorized to receive such wastes: Chestnut Ridge in Anderson County, North Shelby County, Middle Point in Rutherford County, and Carter Valley in Hawkins County. Bliss said local residents who prided themselves on the clean water from private wells before the Carter Valley Landfill began operations, finally took up a petition to receive utility district water when people downstream from the landfill discovered their wells were contaminated. TDEC issued civil fines and penalties at Carter Valley Landfill in October 2006 after 2005 groundwater monitoring found contamination in the groundwater. Additionally, TCWN found that of the 69 landfills across the state known to be leaking, TDEC required corrective action for groundwater contamination at less than 5 of those landfills, including Dickson County, Sevier County, City of McKenzie, and Smelter Services Class 2 landfill in Mt. Pleasant. Dickson County's landfill received national attention for what is believed to be the community's exposure to trichloroethene from leachate in drinking water supplies causing birth defects. The contamination occurred despite the landfill being built under stringent EPA guidelines and the old landfill's closure in 2003. Bliss said Hawkins County has the second highest incidence of birth defects in the state. "We should have a concern about Hawkins County. We need to find a reason and work toward mitigating the impact on the environment. We live in a nuclear neighborhood. Oak Ridge is the home of the atom bomb. Tennessee has a number of nuclear processors, including two in Erwin. There's the Aerojet Ordinance Plant in Jonesborough. Now we know nuclear waste is being accepted at Carter's Valley Landfill." For more information visit http://www.tcwn.org . To read Out of Control - On Purpose: DOE's Dispersal of Radioactive Waste into Landfills and Consumer Products visit: http://www.nirs.org/radwaste/outofcontrol/outofcontrol .htm.

Australia: Methane gas landfill leak forces residents to evacuate suburb

By Peter Byrne

25 September 2008

On September 11, Country Fire Authority chief officer Russell Rees advised owners of about 250 houses in the working class outer-Melbourne suburb of Cranbourne to move out after methane levels of 60 to 65 percent were found in some houses. Concentrations of 5-15 percent are considered an explosion risk.

The gas emanated from a closed landfill bordering the Brookland Greens housing development. Since the evacuation notice was issued, it has been revealed that the state government planning review body approved the housing development after ignoring Environmental Protection Agency safety warnings.

Residents were initially advised they would have to stay away for a year, and that it could be as long as 24 months before measures were put in place to fix the leakage problem. While the Victorian state government offered paltry conditional emergency grants of $8,500, it was left up to households to organise their own accommodation. With few options available, only 33 of the 230 households in the affected zone initially moved out. In the past week, at least 21 of those have returned following zero readings from methane gas monitors.

The immediate danger of home gas explosions seems to have passed, but hundreds of residents are now faced with ongoing safety fears and a continuing methane stench. Many, including those with large mortgages, also face a devastating collapse in the value of their homes, threatening their income security and retirement nest-egg.

The land developer, local council and the Victorian state Labor government and its planning regulatory bodies are now engaged in a mutual blame-shifting exercise. But what emerges is the complicity of all those who had material interests in the development project—yet another expression of the impact of a profit-driven system in which the rights of ordinary people to decent, safe and affordable housing are sacrificed to corporate interests. This fundamental problem has been compounded by a lack of rational urban planning. A chronic housing shortage in Melbourne—which has fuelled rents and property prices particularly in inner-city suburbs—has led to a situation in which many working people can only afford to live in housing developments in outlying areas, often with grossly inadequate public transport, recreational facilities, and other critical social infrastructure.

Brookland Greens, located nearly 50 kilometres south-east of Melbourne, adjoins an exhausted sand quarry in Stevensons Road, which the City of Casey operated as a rubbish tip from 1996 to 2005. About 100,000 tonnes of household waste was dumped each year. Contrary to best practice, the landfill was never lined with clay. Instead, the site was capped with a layer of soil and a gas collection and burning system was installed, designed to collect all the methane produced. This is now failing. According to the EPA, an estimated 1,300 cubic metres of methane per hour are produced with a proportion—several hundred—leaking sideways and percolating up through the ground outside the capped area of the landfill site.

The EPA and council have been monitoring gas problems and fielding complaints about the landfill for at least eight years. Residents have reported skin rashes, eye infections, asthma, burning sensations and headaches.

If there was a substantial buffer-zone between the landfill and residential buildings, then the methane would find its way to the surface and (being lighter than air) simply escape through the ground and into the atmosphere. But when the gas is restricted by an impermeable object like a home's concrete floor slab, it can be channelled through a pipe or cabling penetration and then build up to explosive concentrations in unventilated cupboards or wall cavities. This is what happened two weeks ago in Brookland Greens.

EPA safety warning ignored

Western Australian-based developer Peet Limited bought what was then farmland, adjoining the former Stevensons Road landfill site, in June 1998 for $3.5 million and planned Brookland Greens as a staged subdivision with some 800 lots. Revenue was projected at $100 million over a 10-year period.

In 2000 the council rezoned the land for residential subdivision on condition that a 200-metre buffer between houses and the landfill site would be maintained until declared safe by the EPA and the council. But in 2003 Peet Limited applied to have the buffer effectively junked, based on its assertion that because the tipping of rubbish had ceased in some parts, the 200-metre boundary should move to reflect the point of distance from the active area of the site. Had the company waited for the projected 25 years for the methane gas leakage to abate, about one third of the 800 lots in Brookland Greens could have been blocked. This would have had a significant impact on the company's bottom line, which last year recorded an annual profit of $48 million.

Casey City Council initially refused the application to remove the buffer zone. In response, Peet Limited successfully appealed to the Victorian Civil and Administrative Tribunal (VCAT), the state government planning review body.

Established in 1998, VCAT has been utilised by successive Liberal and Labor state governments as a means of fast-tracking developers' appeals against unfavourable council planning decisions. The *Age* newspaper reported: "Angry talkback callers have filled the radio airwaves with their own 'tribunal horror stories' since news broke of the gas emergency. Many of the callers have been upset with what they saw as a lack of accountability and transparency."

The Labor government of Premier John Brumby has denied any responsibility for the situation in Brookland Greens. Its position, however, is untenable. The entire land usage regulatory system presided over by the government is geared towards the corporate developers. Underscoring the close relationship between these interests and the state government, it has emerged that Peet donated $10,000 to the Victorian Labor Party between 2003 and 2005.

The council has similarly denied all responsibility and pointed to its denial of Peet's initial application on the buffer zone. But it has been suggested that the local body had an interest in the development and the additional development contribution fees, taxes and rates it would bring. Ben Hardwick, a lawyer acting for Brookland Greens' residents who are considering a class action suit, noted: "[I]t is common practice, for political reasons, for local councils to refuse developers' applications or decline to make a decision, safe in the knowledge that VCAT will make the hard decision for them."

Details of the 2004 VCAT decision, overruling the local council and the EPA on the need for a buffer-zone, provide a damning portrait of the scant regard shown by official state bodies for public safety. The review body simply dismissed out of hand the EPA's recommendation that the buffer should be increased from 200 metres to 500 metres because of the serious problems with the unlined leaking landfill. The environmental agency had fined tip operator Grosvenor Lodge three times and imposed 19 enforcement actions for odour emissions.

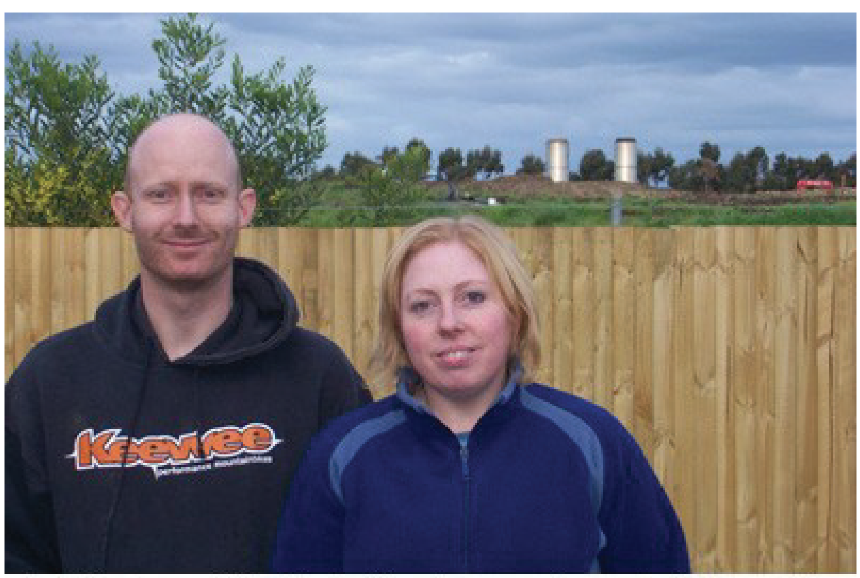
After the successful appeal, Peet Limited quickly built 47 homes in the contested area, garnering revenue of $16.45 million. As the landfill was progressively closed, the buffer was effectively eliminated, with new houses abutting the edge of the capped landfill.

There are indications that Brookland Greens is no isolated incident. The EPA has announced an investigation into dozens of landfill sites in Victoria, while the federal Liberal Party has called on Prime Minister Kevin Rudd to convene a national inquiry and an audit of every landfill site in Australia.

"The land should never have been sold"

The *World Socialist Web Site* spoke to a number of residents whose houses back on to the landfill site. They explained that no government agency warned them of any potential danger before they bought their land.

Andy Rhodes, mechanical engineer, and Nixz Kerr, finance clerk, bought land for $300,000 in March 2007 and moved in later that year.



Andy Rhodes and Nixz Kerr (with methane gas burners in background)

“We liked this particular block because we were told by the developers that the culprit behind us would be a park by about now,” Andy explained. “We specifically asked if there would be any problems or had been any problems, and we were told it’s all behaving as normal, everything’s on schedule. When we bought the land, we were told the tip had been closed for a couple of years. Now the proposed park is years away.”

Nixz said: “I think that the land should never have been sold. They didn’t know that it was going to be 100 percent OK, so they shouldn’t have sold it in the first place. Obviously the developer needs to take some blame because they were already doing monitoring. But we never heard anything until we moved in, although we did ask and were told everything was OK.”

Andy added: “I personally think all three are equally to blame—the developer, the council and VCAT. The council hasn’t done enough to mitigate the problems and deal with their own landfill. Then VCAT probably jumped the gun. The developer probably pushed pretty hard and they made a lot of money out of the land. We’ve heard that this is highly unusual; that this is only one of two rubbish dumps that did this. They’re supposed to line the bottom and sides. When they cap it they put a layer on top that the methane gas can’t come through.

“The smell gets really bad sometimes but we can’t move out. We don’t have the option and haven’t got anywhere to go. We’ve got a [methane gas measure] monitor but haven’t had any positive readings. Technically we’re still in the danger zone and we probably shouldn’t have a house here. We’re worried on a number of counts. What are the health effects? They’ve said it doesn’t harm your health but it can’t be good for you either. There’s obviously other stuff coming out of the ground when it smells. Is that harmful? We’re worried about the potential danger to property if it does explode. And obviously no-one can sell their house. No one’s going to buy here, not for decent market value anyway.”

Another resident, Antony Krause, moved from Sydney six months ago to be closer to his daughter and look after his grandchild. Now retired, he worked for 21 years at the Reckitt Benckiser factory in Sydney, and paid $295,000 for a house that backs onto the landfill site. “I never heard anything about the gas,” he explained. “We do get the smells, the bad egg smells every week or so, only outside. When I bought this house I asked the real estate agent about the tip and he said ‘don’t worry about that, they’re going to build parkland’. And the next day I phoned the council and they sent me a letter that said there’s nothing to worry about, we’re building a park. I didn’t know it was going to be so serious. I can’t move out because I planted all my money here and I don’t have money to buy another house.”


Graeme Hiam

Retired factory manager Graeme Hiam moved into his house 16 months ago. He paid $130,000 for the land and another $190,000 for the house.

“We were never told anything,” he told the WSWS. “From the time we purchased the land there was never any mention of the tip. One would assume they didn’t know or they weren’t telling. Ever since we’ve been here we’ve seen people putting rods down the drains. They first put a [methane gas measure] meter in my house a month ago. The house next door had the high reading that has been reported. My opinion is that blame rests between Peet and VCAT. But everyone’s blaming someone else.”

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http://www.wsws.org/articles/2008/sep2008/mgas-f25.shtml

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Ombudsman's damning report on landfill leak

Tuesday, 20 October 2009
Garth Lamb

Lawyers representing nearly 600 residents of Brookland Greens Estate, who were allegedly effected by landfill gas leaking out of the old Stevensons Road landfill in the Melbourne suburb of Cranbourne last year, have welcomed a damning report by Victoria's independent Ombudsman. Released last week, it found EPA Victoria mainly to blame for the gas migration, which saw hundreds of people evacuated and ongoing claims of depressed property prices.

The Ombudsman traced the problem back to 1992 when the EPA granted works approval for the Shire of Cranbourne (the predecessor of the City of Casey Council). The EPA intended the landfill to be lined with compacted clay if it was to accept putrescible waste – a "favored" but not compulsory practice at the time – but ultimately the regulator bowed to pressure and allowed an unlined facility to be built.

The Ombudsman found the Shire's 1992 contention that a landfill liner would be expensive ($500,000) to install should not have been taken into account by the EPA: "Clearly, environmental standards should not be compromised for the sake of an agency saving money."

While it was the lack of a liner which ultimately saw gas migration become such a high profile issue last September, the Ombudsman was equally scathing about other aspects of site design and operation.

"My investigation identified that the EPA's assessments of the Shire's works approval applications were inadequate," states 289-page, 65-recommendation report, which has been tabled in Parliament.

"The applications contained errors and the EPA failed to properly explore all assertions. The EPA also failed to properly assess the Shire's applications for works approval partly through lack of expertise and partly through allowing the outcome to be the subject of negotiation."

One significant error of the EPA, "was to ignore the condition of the *State Environment Protection Policy (Siting and Management of Landfills Receiving Municipal Waste) 1991* that prohibited landfilling below the level of the water table, 'unless written permission from the Authority has been obtained'".

"Without addressing this condition explicitly in the assessment of the works approvals, the EPA should not have granted permission for the landfill which was not only below the level of the water table, but interrupted a substantial nearby aquifer," states the report.

EPA Victoria CEO Terry A'Hearn rejected claims the EPA did not do its job, telling the *ABC* things hadn't been done perfectly, but "we believe that at all times what we've done is prioritise the safety of the people on the estate".

The Ombudsman was also highly critical of the Shire of Cranbourne and the City of Casey Council, finding "in its narrow focus on the economics of landfilling, the Shire failed to take account of other factors, namely environmental standards".

Perhaps the most acute display of the all round failure of the system is the ongoing series of failures to adequately address the problems, despite multiple opportunities for this to occur.

"I concluded that while there have been significant technological developments in landfill design since the works approval was issued by the EPA in 1992, design standards at the Stevensons Road landfill effectively stood still.

"Essentially, a landfill conceived in the late 1980s, approved in 1992 and licensed in 1996 continued to operate with no landfill liner up until 2005 when it was closed. In the granting of the works approval for an unlined landfill and the subsequent lost opportunities to require a landfill liner, the EPA failed to set conditions for the protection of the environment."

Last November law firm Slater & Gordon launched a class action in the Supreme Court of Victoria seeking unspecified damages from the City of Casey on behalf of residents affected by the gas leak. Lawyer Ben Hardwick said it is now "imperative that the City of Casey and EPA come to the table and try to resolve the matter through mediation".

"Now that the Ombudsman has made his findings, the next step is to fix the problem," he said. "Rather than protracted and expensive legal action through the courts, the City of Casey should sit down and talk with us."

He said the Ombudsman catalogued "a litany of bureaucratic bungling, mismanagement and blame-shifting" and pointed to a particular comment in the report supporting his class action lawsuit.

The Ombudsmand stated, "it is clear to me that the local community has endured considerable anxiety, distress and inconvenience as a result of methane gas leaking from the landfill into the estate and the way that some government agencies handled this issue. On this basis, affected residents should be compensated accordingly".

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AllBusiness

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Scotland board puts end to landfill project

Jun. 8--LAURINBURG -- The Scotland County Board of Commissioners voted Monday night to end a controversial landfill expansion project.

County officials had considered expanding a closed landfill to create a regional dump as a way to bring in revenue for the struggling county.

But many residents opposed the plan, saying it would turn the county into a dumping ground for trash from all over the state.

Monday's meeting officially killed the project, when commissioners unanimously voted on two items meant to quash the plan for good.

J.D. Willis, chairman of the board and proponent of another regional landfill proposal in 2007, issued a motion to stop plans for the landfill at Patterson Road.

Commissioner John Alford, before voting on the motion, asked that it include language to stop all regional landfill proposals in the county.

Willis agreed.

The motion was passed without dissent.

Immediately afterwards, Bob Davis, a longtime opponent of regional landfills in the county, submitted a detailed resolution banning the Patterson Road landfill expansion.

The resolution stated that "Scotland County discontinue the employment of engineering firms, outside legal counsel and all other firms or companies engaged to assist with the condemnation and/or more expansive plans for disposition of waste."

The resolution asked that the county manager notify all waste management companies that Scotland County was, in effect, out of the landfill business.

It, too, was passed unanimously.

Only Commissioner Guy McCook was absent. Willis said McCook had been hospitalized that morning.

Willis said the landfill had become a divisive issue in the county, and that officials would be better served by channeling resources into other things.

"Having said that, it is my opinion that the climate is not conducive to expanding our existing landfill," he said.

Willis, a longtime board member, was defeated in the May primaries, after refusing to say whether he would vote for or against the landfill expansion project.

Many residents believed Willis was in favor of the project.

In 2007, he was one of five of the board's seven commissioners to vote in favor of a dump that was expected to produce about $4 million a year in revenue for the county.

Eddie Carmichael, a farmer who had spoken out against the Patterson Road landfill, said he was pleased with the board's decision, but remained skeptical.

"It's good they finally listened to the people," Carmichael said.

But, he said, with a wary shrug: "It's politics. They could come in next month with a whole, new

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State officials file suit over dump site health hazards

March 11, 2010 - By MARY ANN GREIER

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LISBON - State officials resorted to legal action Wednesday against A & L Salvage in an effort to stop a health threat and environmental hazard caused by the odorous dump outside of Lisbon.

Ohio Attorney General Richard Cordray's office filed the 20-count complaint and preliminary injunction request in Columbiana County Common Pleas Court, asking the court to order A & L Salvage to cover the 42-acre dump site with an additional 12 inches of cohesive earthen material within six weeks of the order.

The preliminary injunction request also asked for immediate access to the site for the Ohio Environmental Protection Agency and its contractors and an immediate elimination of all off-site odors. The case has been assigned to Judge C. Ashley Pike.

The construction and demolition debris landfill stopped operations a year ago, but the odors from hydrogen sulfide remained and became worse in recent months to the point of causing people to become ill with headaches and nausea, a joint press release from the OEPA and OAG said.

The OEPA and OAG offices have been working with the company for a final closure plan to cover the site for over a year with no resolution for a consent decree. OEPA Director Chris Korleski said "enough is enough," according to OEPA spokesman Mike Settles.

"This situation cannot continue as is," Korleski said in a press release. "The odors need to be stopped and the landfill needs to be properly stabilized and closed once and for all."

Residents suffering from the stench have been putting up with the problem for several years, complaining to the Columbiana County Health Board at one point, then going to the OEPA after the state started overseeing C&DD landfills in the county. Settles said Korleski knows how frustrated they've been.

"I am personally grateful for the hard work the OEPA has done. I am also hopeful this court action will finally bring relief for all of us who live around the landfill," state Route 45 resident Don Kibler said in an e-mail.

"We have given A&L Salvage's owners every opportunity to comply with Ohio law and properly close that landfill," Cordray said in the press release. "Instead, they have allowed conditions to deteriorate to a point where we now need the court's help to make things right."

Besides naming A & L Salvage LLC as a defendant, the complaint also named four additional defendants who allegedly own property the OAG has identified as part of the site. Those defendants include Amato Properties LLC, Jack Amato and Jeffrey Aldrich, all of Wellsville, and the Amato Family Trust of East Liverpool.

Dr. Jack Amato serves as chairman of the Columbiana County Health Board, the entity which issued the dump's original permit to operate. A call was made to his home Wednesday evening, but he couldn't be reached for comment.

When asked what those defendants have to do with the dump, OAG spokesman Ali Lehman said they own property that is considered part of the landfill. According to the county Auditor's Web site, A & L Salvage owns about 375 acres along state Route 45 and Black Road. The active part of the dump only covered 42 acres, with the rest being buffer, although the company originally had plans to eventually use the other acreage for dumping.

Fact Box

The OEPA recently asked for help with the site from the U.S. EPA. Those two agencies, the Ohio Department of Health and the Agency for Toxic Substances and Disease Registry are tracking hydrogen sulfide odors around the site and using gas monitoring wells to see if other gases are leaving the site.

Residents experiencing nuisance odors can call the OEPA odor hotline at 1-800-686-6330 ext. 1212. Information about possible health effects from hydrogen sulfide exposure can be obtained from Greg Stein at the ODH at 614-995-7017 or online at www.odh.ohio.gov

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The company and OEPA reached an environmental pact last year, prohibiting the use of any of the property owned by A & L Salvage as any type of dump in the future. The pact also prohibits any future owners from operating a dump on the land.

The county Auditor's Web site lists Amato Properties, Jack Amato and Jeffrey Aldrich as owners of some land on Black Road, but their names weren't listed on the environmental pact filed in the Recorder's Office. Their names also weren't listed on the numerous complaints filed against A & L Salvage for violations of environmental law.

Those violations form the basis for the lawsuit which requests monetary penalties along with the injunctive relief to alleviate the odors. The violations included acceptance of pulverized debris and solid waste, which is prohibited at a C&DD landfill, improper asbestos handling, and creating a nuisance from the hydrogen sulfide, or rotten egg, smell.

The complaint also noted cliffing of debris, which happens when it's not spread out and compacted on the working face of the dump, improper use of unloading zone, failure to manage surface water and allowing a discharge into Patterson Creek, failing to apply weekly cover to debris, failure to comply with Korleski's orders to implement an explosive gas monitoring plan, failure to pay disposal fees, causing a nuisance with dust, failure to properly dispose and bury asbestos or cover asbestos, failure to surround the asbestos disposal site with fencing, failure to display asbestos warning signs, failure to maintain equipment to wet asbestos or prevent dust emissions from asbestos operations, and failure to minimize dust on roads.

The civil penalties being sought exceed $25,000, with no exact estimate available for each violation. Penalties for at least nine violations were listed as $10,000 per day per violation, with the penalties for another 10 violations listed at $25,000 per day per violation. A tax of $300 was requested against each defendant and their property for the statutory nuisance complaint.

The time period for the complaint began in 2005 and continued to the present. The preliminary injunction request said the landfill "is releasing extremely intense odors and has elevated temperatures indicating the possible presence of a subsurface fire."

Jerry Weber, an OEPA environmental specialist responsible for inspections at the site, wrote the OEPA has received at least 350 odor complaints about the site since October 2003, causing him to issue numerous violations. In February, he documented odors which caused him to have a burning throat.

Settles explained that a hydrogen sulfide monitor placed at a nearby residence recorded readings as high as 110 parts per billion. They become concerned about the possible effects to public health when levels exceed 70 parts per billion.

He also said gas monitoring at the site this week showed strong levels of carbon monoxide and a landfill temperature of 191 degrees Fahrenheit, both good indicators that a subsurface fire exists.

By requiring additional soil cover on the site, the odors could be cut down, along with the amount of oxygen fueling a possible subsurface fire, he said.

Mary Ann Greier can be reached at mgreier@salemnews.net

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Bird Flu Virus Can Survive Two Years in Landfill

Posted in: Cold, Flu, and Sinus

Photo: Scott Bauer, US Agricultural Research Service

FRIDAY, June 5 (HealthDay News) — Poultry carcasses infected with the bird flu virus can remain infectious in municipal landfills for as long as two years, say Nebraska researchers.

Hundreds of millions of chickens and ducks infected with bird flu have died or been killed worldwide in an effort to control the spread of the disease, they noted. The remains are disposed of in different ways, including burial in landfills. For example, the carcasses of more than 4 million poultry that were culled or died during a 2002 outbreak in Virginia were placed in municipal landfills, according to a news release from the American Chemical Society.

But the safety of landfill disposal has received little attention, said the researchers who conducted the study. They found that the bird flu virus can survive in landfill leachate — liquid that drains from a landfill — for at least 30 days and up to two years.

Factors that most reduced the virus' survival times were elevated temperatures and acidic or alkaline pH, the news release noted.

"Data obtained from this study indicate that landfilling is an appropriate method of disposal of carcasses infected with avian influenza," concluded Shannon L. Bartelt-Hunt and colleagues, who noted that landfills are designed to hold material for much longer than two years.

The study is to be published in the June 15 issue of the journal *Environmental Science & Technology*.

Department of Justice

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Thursday, August 7, 2008
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Nevada Landfill Operator Agrees to $36 Million Plan to Close Landfill Site

Republic Services to pay $1 Million Civil Fine

WASHINGTON— Republic Services of Southern Nevada, the current operator of the Sunrise Mountain Landfill located in Clark County, Nev., has agreed to construct and operate a comprehensive remedy for the site and to pay a $1 million civil fine in order to resolve alleged violations of the Clean Water Act, the Justice Department and U.S. Environmental Protection Agency announced today.

The consent decree, filed today in U.S. District Court in Las Vegas, requires Republic Services of Southern Nevada to implement extensive storm water controls, an armored engineered cover, methane gas collection, groundwater monitoring, and long-term operation and maintenance.

"Today's settlement will minimize the risk to Clark County residents from polluted water runoff and hazardous waste discharges from the Sunrise Mountain landfill," said Ronald J. Tenpas, Assistant Attorney General for the Justice Department's Environment and Natural Resources Division. "This settlement reflects the federal government's commitment to protecting valuable natural resources like Lake Mead and its watershed."

The settlement will ensure effective long-term control of the landfill, which contains over 49 million cubic yards of waste. The remedy, which is expected to take roughly two years to build, will be designed to withstand a 200-year storm and is expected to cost over $36 million. Upon completion, the remedy is estimated to prevent the release of over 14 million pounds of contaminants annually, including stormwater pollutants, methane gas and landfill leachate.

"Landfill operators must ensure that effective safeguards are in place to protect the environment and nearby communities," said Wayne Nastri, administrator of the EPA's Pacific Southwest region. "With today's agreement, Republic is required to properly close the landfill and ensure long-term waste containment."

Sunrise Landfill, a 440-acre closed municipal solid waste landfill, is located three miles outside of Las Vegas city limits. The landfill cover failed during a series of storms in September 1998, sending waste into the Las Vegas Wash. The landfill is located two miles above the Las Vegas Wash, which discharges directly into Lake Mead -- a primary drinking water resource for southern Nevada, including the Las Vegas metro area, as well as the lower Colorado River, the Phoenix metro area and southern California.

The landfill was operated on behalf of the County by entities related to Republic Services of Southern Nevada from the 1950's through 1993. Following the landfill cover failure in 1998, the EPA ordered Republic Dumpco, a company related to Republic Services of Southern Nevada, and the Clark County Public Works Department to correct violations of the federal clean water laws and to immediately stabilize the site.

Sunrise Mountain Landfill is unlined and contains more than 49-million cubic yards of waste including: municipal solid waste, medical waste, sewage sludge, hydrocarbon-contaminated soils, asbestos, and construction waste.

The proposed consent decree, lodged in the U.S. District Court for the District of Nevada, is subject to a 30-day public comment period and approval by the federal court. A copy of the consent decree is available on the Department of Justice Web site at http://www.usdoj.gov/enrd/open.html.

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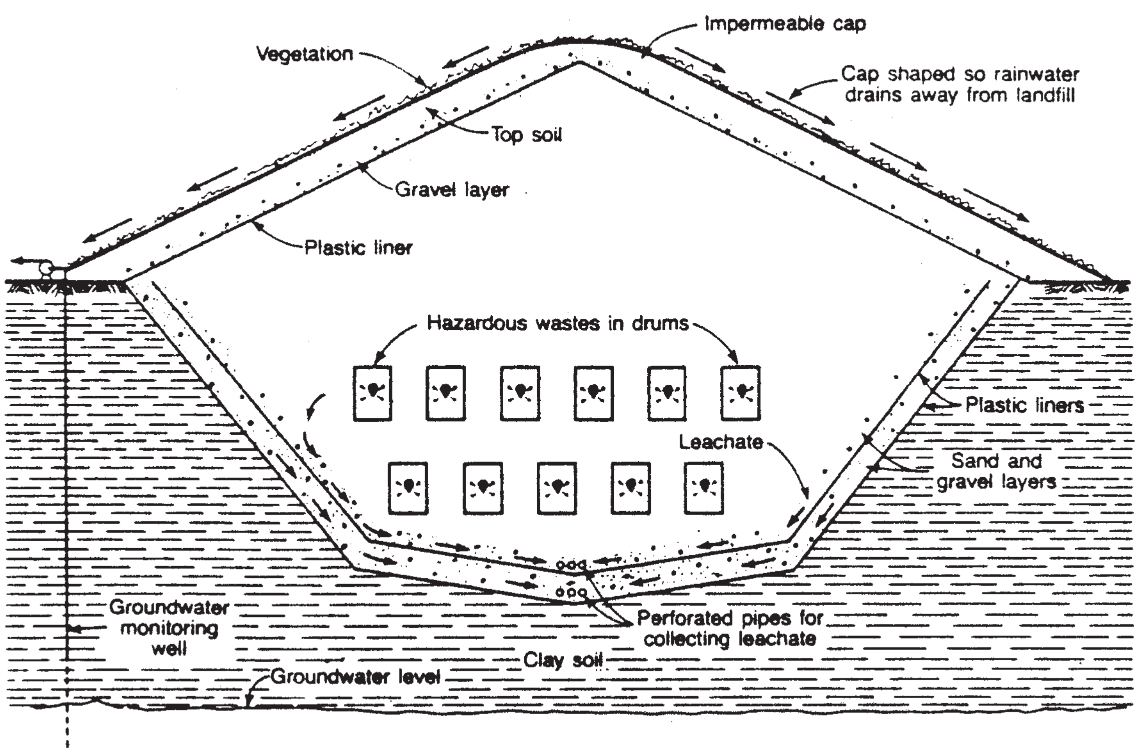

Hazardous waste landfills: some lessons from New Jersey

New Jersey's experience with operational problems at four hazardous-waste landfills points up ways landfill regulations could be improved.

PETER MONTAGUE
Dept. of Chemical Engineering and
Center for Energy and Environmental Studies
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A SECURE LANDFILL IS a carefully-engineered depression in the ground into which hazardous wastes are put. (3,4) The intention is to avoid any hydraulic connection between the wastes and the surrounding environment, particularly the groundwater. To this end, there are four critical elements in a secure landfill: a bottom liner, a leachate collection system, a cover, and the natural hydrogeologic setting.

The *natural setting* can be selected to minimize the possibility of wastes escaping to groundwater beneath a landfill. The other three elements must be engineered. The *bottom liner* may be one or more layers of clay or a synthetic membrane (or a combination of these); the liner effectively creates a bathtub in the ground. The *leachate collection system* consists of sloping the bottom of the landfill and placing pipes in the low places to pump out contaminated water and other fluids (leachate) that accumulate; the pumped leachate is treated at a wastewater treatment plant. The *cover* will generally consist of several sloped layers—clay or a membrane liner (to prevent rain from intruding), overlain by a very permeable layer of sandy or gravelly soil (to promote rain runoff), overlain by topsoil in which vegetation can root (to stabilize the underlying layers of the cover).

Each of these elements is critical to success. If a liner fails, hazardous wastes may migrate directly into the environment. If leachate is not removed from a landfill, fluids can build up in the bathtub; the resulting hydraulic head is the main force that will drive wastes out into the environment if the liner fails. If the cover is not maintained intact, rain will enter the landfill, solubilizing and mobilizing wastes, resulting in buildup of leachate—even to the point where the bathtub can overflow its sides.

Four secure landfills in New Jersey

New Jersey's industries produce roughly 750,000 tons of hazardous wastes annually (9,13) but the state's last commercially-operated chemical landfill closed in 1976. By 1977 five major firms were making plans to operate their own secure landfills for on-site disposal of chemical wastes. All five landfills were eventually constructed and are operating today. However, four of the five have experienced operational problems.

E.I. DuPont de Nemours & Co., Inc.

DuPont applied in April, 1978, to the New Jersey Department of Environmental Protection (DEP) for a permit to operate a 10-acre double-lined secure landfill for chemical waste disposal in Carneys Point, N.J. Two five-acre cells were constructed, each with two liners of 0.03 inch (0.76 mm) nylon-reinforced Hypalon®—a tough polymer film—and each with a leak detector, or telltale, between the two liners.

A leak detector consists of pipes that collect any fluids that accumulate between the two liners. Presence of liquids in the leak detector is a signal that something may be going wrong with the upper liner.

The new landfill went into operation in January, 1979. Three months later DuPont management reported the presence of fluids in the leak detector area, accumulating at 124 gallons (469 liters) per day. The company argued that the fluids were rainwater that had been trapped between the liners during construction. The state feared that the primary liner (the upper liner, closest to the wastes) was leaking. The state immediately restricted the kinds of wastes that could be landfilled at the site, but subsequently relented after reaching an agreement with DuPont.

Under the agreement DuPont would analyze samples of the fluids being collected in the leak detector. (By this time the rate of accumulation had decreased to a steady 50 gallons (189 liters) per day.) DuPont suggested, and the state agreed, that an increase in four indicators—total dissolved solids (TDS), chemical oxygen demand (COD), phenol compounds, and color—would signal a leak occurring as distinct from rainwater accumulating. My statistical analysis of these data indicates that a significant increase has occurred in at least half of the indicators. By the criteria established in the agreement, the landfill's primary liner probably should be judged to be leaking.

New Jersey's experience with hazardous-waste landfills shows that synthetic liners are prone to problems—and that clay liners also have their troubles. Also, landfill covers are vulnerable to attack from: erosion; vegetation; soil-dwelling mammals; sunlight; subsidence; and human activities.

Monsanto Industrial Chemical Corp.

Monsanto Industrial Chemical Corp. sought permission from the DEP in 1977 to establish a 6-acre single-lined landfill for chemical waste disposal in Bridgeport, N.J. The DEP persuaded Monsanto that a double-lined landfill with a leak detector made best sense and the company proceeded with construction.

The Monsanto site had previously been used by the U.S. Army Corps of Engineers for disposal of material dredged from the bottom of the nearby Delaware River. DEP engineers therefore feared that soil on the site would be subject to compaction in the future as the waste load increased in the landfill. Monsanto therefore mechanically compacted the soil to 2700 pounds per square foot and installed a 0.9-inch (23 mm) fabric liner of BIDIM®, a proprietary polyester fiber somewhat like the felt pads that people sometimes put beneath rugs—except that BIDIM is lighter, stronger, and more durable than felt, and water passes through it more easily. Monsanto sells BIDIM to provide subsurface support for roadways, railway roadbeds, and construction sites. Above the BIDIM liner, Monsanto placed 12 in. (30.5 cm) of clay with a coefficient of permeability of 5×10^{-8} cm/sec. Such a coefficient of permeability would permit water to flow through 1.6 cm (0.6 in.) of such clay in a year's time. Above that layer of clay came the leak detector; above that came another 18 in. (45.7 cm) of the same clay.

The new landfill went into operation in mid-August, 1978. Within a month Monsanto officials had written to the DEP saying fluids were collecting in the leak detector area. The accumulation rate varied from 26 gallons (98 liters) to 48 gallons (182 liters) per day.

Monsanto hired consulting hydrologists Geraghty and Miller to help find the leak but after four years the effort has not been successful.

J.T. Baker Chemical Co.

J.T. Baker Chemical Co. of Phillipsburg, N.J., applied to the DEP in 1976 for permission to add several new landfills for disposal of chemical wastes. As finally constructed in summer, 1979, the new landfills consist of two liners of 0.03 inch (0.76 mm) polyvinyl chloride (PVC) film, with a leak detector between them. By October, fluids were collecting in the leak detector area between the liners at the rate of about 3 gallons (11 liters) per day; and DEP officials had ordered the firm to analyze samples of the fluids regularly for 13 characteristics.

There are four key elements in a secure landfill: a bottom liner; a leachate collection system; a cover; and the natural hydrogeologic setting. Each of these elements is critical to success.

Using the same procedure agreed to by DuPont and the state (designating an early set of data as baseline and comparing subsequent data to it, to see if concentrations of contaminants are increasing), statistical analysis of the J.T. Baker sites convinces me that the primary liners of two of the landfills are leaking. J.T. Baker officials continue to believe that the fluids, which are now accumulating at the rate of about 1 gallon (4 liters) per day, represent only rainwater trapped during construction.

Toms River Chemical Corp.

Toms River Chemical (TRC), a subsidiary of Ciba-Geigy, sought permission in 1976 to create a secure chemical landfill in Dover, N.J. As constructed, the lower liner is 0.02 inch (0.5 mm) PVC and the upper liner is 0.03 inch (0.76 mm) PVC with a leak detector between them.

The permit to operate the site requires the firm to add a lithium salt to the wastes as a tracer. If lithium appears in the leak detector area, it is a signal that leakage through the upper liner is occurring. The new landfill began operation in January, 1979. And in April DEP officials visiting the site discovered four feet of liquids standing in the leak detector area. Subsequently, company officials determined that the leak rate averages anywhere from 60 gallons (227 liters) to 131 gallons (495 liters) per day. Lithium has consistently been detected at low levels in the leak detector fluids.

I have described my study of these four landfills in greater detail elsewhere.(11) I must stress here that I have no evidence that any of these landfills is contaminating groundwater or significantly impacting the environment. There are groundwater monitoring wells around each of the sites but I have not yet analyzed the monitoring data.

New Jersey's experience with secure landfills should be of use to people in

What constitutes failure of a hazardous-waste landfill?

From New Jersey's experience I can see other potential problems in the federal program. First, EPA's interim regulations (20, p. 33194) call for groundwater monitoring for four parameters to signal landfill leakage (similar to my study of New Jersey's four landfills). However, EPA's regulations omit a key element: they do not say what will constitute the baseline period, to which "new" observations will be compared. This is an important omission that will cause uncertainty and dispute. As I demonstrated in my study, selection of different baseline periods can change the results of the analysis (11).

Second, it is not clear from the regulations how many monitored parameters must increase before a landfill is declared leaking. If one out of four increases, is leakage occurring? Two out of four? In New Jersey, even with many parameters increasing, owners and operators of landfills cannot believe that their landfill liners have failed.

A related problem is construction of landfills on contaminated sites. At two of the four New Jersey sites I studied, contaminated soil was used in construction of the landfill. This makes it very difficult to discern residual contamination from new landfill leakage. There are many reasons to want to build on contaminated sites but this can only increase the difficulty of monitoring new activities.

A way out of these problems would be to require that a *tracer* be added to the wastes. Many tracers have been proposed; unfortunately, all but one have the advantage that they may be degraded or chemically bound up by wastes, particularly as the waste stream changes unpredictably.

Tritium (radioactive hydrogen), however, does not suffer from these disadvantages. If thoroughly mixed with the wastes, it will travel with the leachate. It is easily detected. It has a half-life of 12.3 years so it will disappear in roughly 120 years. For any landfill that doesn't accept tritium-contaminated wastes, and which is built over an aquifer free of tritium contamination, tritium would seem to be a perfect tracer, easy to distinguish from residual non-radioactive contamination.

Lastly, many states (including New Jersey) require construction of landfills out of "impermeable" materials with impermeable defined as a leak rate of 10^{-7} cm/sec. It became clear in New Jersey, when the state tried to enforce this standard at the Toms River Chemical site, that there is no way to reach agreement on the permeability of a leaking membrane liner. The EPA acknowledges that a 10^{-7} cm/sec permeability standard is not appropriate for membrane liners (21, pp. 2837 and 2838). Yet many states have not recognized the problem. Leakage through a membrane liner will occur through a pinhole or through a tear—a concentrated stream of contamination, which is quite different in effect from a slow permeation through the entire bottom and sides of a clay-lined landfill. Permissible leakage through membrane liners should be specified in gallons (or liters) per unit time.

This matter of defining failure goes to the heart of a regulatory philosophy. Although Congress passed the Resource Conservation and Recovery Act (RCRA) six years ago and although roughly 80% of the nation's hazardous wastes go into landfills(8), the EPA has not yet promulgated final criteria for landfills.

On two occasions the Agency has announced elaborate landfill regulations, only to withdraw them later. The first set of regulations(23) established fairly rigid facility design requirements. The Agency said at the time they were using this approach because "the state-of-the-art for predicting discharges or releases from landfills is poor and [the Agency] thus believes that the only option available to ensure protection or human health and the environment is to prescribe design and operating standards which will provide maximum containment in landfills . . . .[T]he Agency is not aware of any method for designing landfills to allow specific constituent release rates, nor is the Agency aware of any method to determine what release rates would be acceptable."(23, p. 58989)

The Agency prescribed facility design requirements such as, the bottom and sides of a landfill had to have a synthetic membrane liner overlain by 6″ (30 cm) of sand or soil, overlain by 3 feet (1 meter) of soil with a permeability of 10^{-7} cm/sec, overlain by a leachate collection system, and so on. Subsequently the Agency decided this approach was "not completely adequate to assure ground-water protection"(19, p. 66817) and a new approach was announced.

The new approach(19,24) calls for *risk assessment* of any facility. The Agency now acknowledges that all landfills will eventually leak. The question becomes: how much risk is thereby created? The Agency says, ". . . many organic constituents are stable (degrade very slowly); other hazardous constituents (e.g., toxic metals) never degrade. Yet the existing technology for disposing of hazardous wastes on or in the land cannot confidently isolate these wastes from the environment forever." Such wastes "will remain potentially dangerous for many thousands of years". And "[s]ince disposing of hazardous wastes in or on the land inevitable [sic] results in the release of hazardous constituents to the environment at some time, any land disposal facility creates some risk."(24, p. 28315)

Using the new approach, the permitting authority (whether the federal EPA or a state agency that has assumed RCRA duties) would somehow decide how much risk is acceptable from what rates of release of what kinds of hazardous wastes.

As I see it, the major problem with this approach would be our inability to define failure. We do not have quantitative measures of adverse health or environment effects for the vast majority of hazardous wastes. Under this regulatory approach, we would not know when a facility had "failed" until measurable health or environmental damage had occurred and by then it would probably be too late to do anything about it. In any case, the EPA has withdrawn the proposal.

The EPA is under court order to promulgate yet another plan for regulating landfills. It will be among the most difficult regulatory tasks ever undertaken.

other states and to the federal effort to regulate landfills. The main conclusions from that experience:

• (1) Synthetic liners are prone to problems (5,7,14,22 p. 11128, 23 p. 58989, 25); but clay also has problems (1,6,8,12,17).

• (2) Leachate collection systems only work so long as someone is keeping the pumps going and preventing the pipes from clogging (18,24, p. 28324, 22 p. 11128).

• (3) Covers are vulnerable to attack (10,15,16) from at least six sources:

• (a) *Erosion* by natural weathering (rain, hail, snow, freeze-thaw cycles, and wind).

• (b) *Vegetation*, such as shrubs and trees that continually complete with grasses for available space, sending down roots that will relentlessly seek to penetrate the cover;

• (c) *Burrowing or soil-dwelling mammals*, reptiles, and insects, which will present constant threats to the integrity of the cover;

• (d) *Sunlight* (if any of these other natural agents should succeed in uncovering a portion of the umbrella) will dry out clay (permitting cracks to develop), or destroy membrane liners through the action of ultraviolet radiation;

• (e) *Subsidence*—an uneven slumping of the cap caused by settling of wastes or organic decay of wastes, or by loss of liquids from landfill drums—can result in cracks in clay or tears in membrane liners, or result in ponding on the surface, which can make a clay cap mushy or can subject the cap to freeze-thaw pressures;

• (f) *Human activities* of many kinds.

Contingency plans needed

EPA calls for a contingency plan for all failures, including "non-sudden" occurrences (20, p. 33237). The plan must be kept up to date and must spell out who is to do what in the event of any problems. Two key elements, however, have been omitted from these federal regulations:

• (1) There is no requirement that waste generators must have laternative sites to which they can take their wastes. In New Jersey, the regulatory agency has acknowledged pressures in the past not to close sites that are contaminating the environment because the sites are needed—generators say they have no other place to take their wastes. This compromises the regulatory agency, damaging its credibility.

• (2) Federal regulations require a closure fund and a post-closure maintenance fund—money set aside during the operating life of the facility to assure that the owner/operator can afford proper closure and post-closure maintenance for 30 years. What happens to this fund if a facility fails and has to be closed early? The fund will not build up and will not be available for closure or post-closure maintenance. EPA acknowledges that this is a problem (21 p. 2824) but offers no solution. Clearly this will be an inducement for a regulatory agency to allow inadequate facilities to continue operating so that they can build up the closure and post-closure funds. To solve this problem, the closure and post-closure funds could be required *in toto* before the facility begins operation. ▽

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Article

Socio-Environmental and Hematological Profile of Landfill Residents (São Jorge Landfill–Sao Paulo, Brazil)

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Abstract: We are experiencing an unprecedented urbanization process that, alongside physical, social and economic developments, has been having a significant impact on a population's health. Due to the increase in pollution, violence and poverty, our modern cities no longer ensure a good quality of life so they become unhealthy environments. This study aims to assess the effect of social, environmental and economic factors on the hematologic profile of residents of Santo André's landfill. In particular, we will assess the effect of social, economic, and environmental factors on current and potential disease markers obtained from hematological tests. The research method is the observational type, from a retrospective cohort, and by convenience sampling in Santo André in the Greater ABC (municipalities of Santo André, São Bernardo do Campo and São Caetano do Sul, southeast part of the Greater São Paulo Metropolitan Area, Brazil). The study determined a socio-environmental profile and the hematologic diseases screening related to a close location to the landfill. The disease manifests itself within a broad spectrum of symptoms that causes changes in blood count parameters. The objective of this work is to show that there is an association between social, environmental and economic factors and a variety of serious disease outcomes that may be detected from blood screening. A causal study of the effect of living near the landfill on these disease outcomes would be a very expensive and time-consuming study. This work we believe is sufficient for public health officials to consider policy and attempt remediation of the effects of living near a landfill.

Keywords: landfill; waste; socio-environmental impact; hematologic diseases

1. Introduction

Nowadays, due to higher levels of pollution, violence and poverty, cities can no longer ensure a good quality of life for everyone and have become unhealthy environments for a great many local inhabitants [1]. An unprecedented urbanization, along with physical, social and economic developments, is having a significant impact on the health of the population [1,2].

Besides the continuous demographic growth, these factors have an implicit effect on the amount of resources that have to be consumed in order to sustain all citizens of the Earth. This increases waste production, which invariably affects society dynamics in general.

Landfill disposal remains the main destination in waste management, and it is expected to remain so for the next decades [3–5]. It is estimated that at the worldwide scale, over five million people die every year due to waste-related diseases [2]. The adverse effects of municipal solid waste on the environment, not to mention on public and individual health, are widely recognized by several authors [6], who point out a deficiency in the implemented systems and especially the lack of a strong policy emphasizing health safeguards [7].

A few authors state that societies all over the world are focused on consumption, and, therefore, there are significant losses of organic and inorganic materials: waste type [8,9], which would imply an uncertain future for Public Health. The improvement suggestion would be educating the population for a sustainable consumption and a strategic waste management system [9], such as: recycling and treating degraded soils; and to which extent these landfill sites would be usable.

The large amount of waste was not a concern for an extensive period due to the distance between disposal sites and urban areas. Meanwhile, with the population growth, it has been difficult to reduce the distance between them [10]. Another emerging problem linked to population growth is the unsystematic construction of homes in hazardous locations and quite vulnerable environmental areas, which usually lack urban infrastructure (sanitation, electricity), among other things [11,12].

It has been scientifically shown that residences on or near a landfill have impacts on the residents' health and on the environment: air quality, water quality, and soil pollution. The effects of landfills are major public health issues. Consequently, waste, waste treatment and disposal are major sanitary and environmental concerns to cities [3,13,14].

The environmental degradation scenario is unquestionable, and there is a lack of policies to prevent and ameliorate the crisis. The complexity of analyzing all impacts demands studies on the various effects of waste produced daily by the population [15,16]. The first step is to identify any adverse health outcomes using blood tests, which can be an important tool for the evaluation of various situations, such as diagnosis and progression of hematologic diseases, detection of infections and therapeutic monitoring [17].

Therefore, a hemogram can guide the initial suspicions supported by clinical files. The importance of the hematologic analysis is assumed to be an important diagnosis tool, providing useful information for a better handling of these cases.

It is necessary to adopt a set of measures that include politics' globalization, government social efficiency and social participation growth. It is the government's duty to ensure that change is not only possible but always sustained in clear objectives as well in results well defined and with special properly defined interventions [18–20].

Santo André has an area of 174.38 square kilometers and is located in the Greater ABC (municipalities of Santo André, São Bernardo do Campo and São Caetano do Sul, southeast part of the Greater São Paulo Metropolitan Area, Brazil), 18 km from the capital city of São Paulo. The city is strategic for the logistics sector, as it lies in the main economic center of the country. Santo André has 678,486 inhabitants and is the tenth largest city in the state of São Paulo. The landfill of São Jorge (217,000 m^2) is located in Santo André, and is surrounded by the slum São Jorge—about 1400 families. Every month, the landfill receives about 13 thousand tons of household waste and 250 tons of sterilized medical waste [11].

Around the landfill of São Jorge, there are signs that the environment has suffered both physical and social impacts [21,22]. The landfill began to operate in the 1980s and is located in the São Jorge District. Santo André's landfill is a facility that provides treatment and disposal of solid waste produced in the municipality. Therefore, it evolved from a non-official dumping location to a controlled one with good environmental practices. Nowadays, it is an area destined to receive solid waste produced in Santo André and is the most suitable and sustainable destination for the waste.

This study aims to measure the socio-environmental and hematologic profile of residents of Santo André's landfill—the "*Espírito Santo* suburbs"—by using the social and demographic data of the studied area and association between socio-environmental factors and the alterations in hematological parameters as precursors to diseases. This fieldwork will allow better urban planning and Public Health policies for residential areas on and near landfills, as well as a greater degree of social and environmental responsibility for all sectors of society.

2. Method

The research method is observational with a retrospective cohort study where the samples are obtained by convenience in Santo André in the Greater ABC region. The study consists of the elaboration of a demographic and environmental profile and assesses the prevalence of potential diseases identified by hematological screening that may be the result of housing conditions and/or exposure to environmental contaminants from the landfill. The study must be understood as a primary tracking diagnosis, and it will be the kick-off for a transversal study of *Espírito Santo* inhabitants that will be performed in the near future.

The exposed group lives in the vicinity of the landfill. There is a very little knowledge about the reality of this population due to the fact that national entities do not have permission to enter the area to study and help this community. Furthermore, this study got a special permit to develop a campaign for being the spin-off of a more transversal study. The community inhabits a place that was a dumping ground and it is actually contiguous to the landfill; therefore, the study's aim was to establish connections among the location and the community's health.

The study was conducted in two phases. The first phase consisted of a survey and research profile of the residents as the following variables: age, gender, type of house, water treatment, water supply and type of sewage, based on interviews and completing a questionnaire. The second phase consisted of the collection of blood samples into two distinct groups: a group of people living in the community (experimental group) and a group of random people attending a health facility located in the central city (control group).

According to the data obtained, a descriptive and comparative analysis of the differences in hematologic patterns between both groups was made.

The blood samples were collected through peripheral venopunction using the vacuum method. After recovery, the blood was added to the tube with EDTA. The samples were homogenized for 10 min and evaluated through flux cytometry with ABX Pentra 120 equipment (Horiba Medical, Montpellier, France). The serial evaluations were performed in blades using the Leishman method in order to obtain the procedures approached. The analysis was carried out according to good biomedical practices.

Quantitative and qualitative alterations in blood count (viral, bacterial and parasitic) were measured by reading lamina by Fernando Luiz Affonso Fonseca (hematologist)—a blood sample.

A total of 100 blood samples were harvested, but only 62 of them were considered biologically viable. The viability of the blood sample complied with good practices in clinical analyses. Thus, samples hemolyzed with jaundice or still lipemic were not included in the hematological analysis.

Therefore, in a group of inhabitants of the central region, 30 individuals were included (unexposed group). From the group of inhabitants of the vulnerable region (exposed group), 84 were included. However, from these, only 32 consented to having their blood harvested.

The information gathering tool used in this study was a questionnaire taken from the database developed by SEMASA, the Bureau of Environmental Issues of Santo André, São Paulo, Brazil, the institute responsible for the approval of construction, basic sanitation and water supply, as well as for assessing the regularity of housing developments. The applicants were the work's researchers, supervised by the head researcher of the University.

From a total of 100 questionnaires filled out, 84 were considered adequate (valid questionnaires). Thus, 16 were discarded, due to inadequacies in the information provided or a lack of consent from the individuals.

A descriptive analysis of all variables presented was performed in terms of their relative and absolute terms. In order to evaluate the association between the qualitative variables, a chi-square test was used, and/or the exact Fisher test. The level of significance was 5%. The data were processed and treated in the statistics software SPSS 21.0 (Released 2012, IBM SPSS Statistics for Windows, Version 21.0, IBM Corp., Armonk, NY, USA).

At last, an exact Fisher test was applied, in order to evaluate whether there is a connection between the hematological results and the type of exposure, as well as the quantity of hematological changes. The exact Fisher test is used to calculate the association of the analyzed features when the total amount of data is small and when the expected values in one or more of the cells of the 2×2 table is less than or equal to five. Thus, in small samples, this test should be used, since it produces fewer distortions than the chi-square test.

The sample was only gathered after the theme enlightening and authorization of the individuals. Anonymity as well as the confidentiality of the data obtained were guaranteed.

All subjects granted their informed consent for inclusion before participating in the study. The study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by the Ethics Committee of the Secretária Municipal de Saúde, Santo André (1.587.630).

3. Results

3.1. First Phase

Questionnaires were distributed with the purpose of establishing a social, demographic and biographic profile of the location. Table 1 shows the most significant variables of the community.

Table 1. Socio-biodemographic characteristics of the inhabitants.

Variables	Community Sample	
	n	%
Gender		
Female	55	65.5
Male	29	34.5
Age group		
(6–12)	7	8.3
(13–18)	6	7.1
(19–30)	30	35.7
(31–50)	31	36.9
(51–60)	8	9.5
(+60)	2	2.4
House type		
Bricks	53	63.1
Wood	20	23.8
Mix	5	6.0
Another	6	7.1
Income *		
Less than 2	67	79.8
Between 3–5	16	19.0
Between 5–10	1	1.2
Plus 10	0	0.0
Sanitation		
Yes	54	64.3
No	30	35.7
Total	84	100

* Minimum Wage (M.W.) = 724 Reais.

The several variables that were incorporated in the study and tabulated the appropriate statistical program mentioned above are the best ways of reflecting the social and demographic landscape of the target population. It is important to note that the variable "Sanitation" in Table 1 corresponds to the presence of the official public water, sewage and electricity networks.

As can be seen by observing Table 1, there is a predominance of females and the age groups from 19 to 30 and from 31 to 50 are the most prevalent in respondents. It was also verified that the income was below two Brazilian minimum wages (M.W.), which indicates that we face a special group in terms of economic capacity. It is also noted that there is a prevalence of masonry houses (63.1%) and houses with in-door plumbing/sanitation (64.3%).

3.2. Second Phase

In order to obtain plausible conclusions to the case study, it was necessary to compare the effects of the convenience sampling of another group of people that were not exposed to the several harmful environmental factors (Non-Exposed Group) to those who were exposed (Exposed Group).

Of the 84 individuals described in Table 1, 32 were randomly chosen and were designated as the "Exposed Group". The Non-Exposed Group was interviewed at the same time as they did the blood sample. In total, 30 people were interviewed, which corresponds to the amount of blood samples.

As described earlier, in order for the importance of the two groups to share the same characteristics, it appears that the percentages are similar, where the female gender was the most prevalent, with 75% in the "Exposed Group" and 66.7% in "Non-Exposed Group".

Regarding the age, the range between 31–50 years was the most commonly reported, with 11 people (36.7%) in the "Non-Exposed Group" and 19–30 in the "Exposed Group", with 13 persons (40.6%).

It appears that the housing and financial realities are significantly different in each group, where 84.4% of the "Exposed Group" presents an income of less than two minimum wages, while 56.7% of the "Non-Exposed Group" have similar income.

Regarding the "Non-Exposed Group", a greater purchasing power is observable, and, therefore, all of the respondents live in masonry houses and nearly all have sanitation. Table 2 describes the exposure type according to socio-biographic characteristics.

According to the analyzed variables, we observe that both groups have a significant association with the variables' sewage ($p = 0.004$) house type ($p < 0.0001$) and income ($p = 0.025$) with the exception of the variables gender and age group ($p > 0.05$).

It is noted that of the totality of the individuals with sewage (82.3%), 94.4% of them live in the vicinity of the landfill.

According to house type, the totality of the non-exposed live in brick houses, and, from the total of individuals that live in this type ($n = 50$), the majority (62.5%) is exposed to the landfill.

The total of individuals that own an income lower than 2 M.W. is 44 (71%), as 27 of them (84.4%) are exposed to the landfill and (56.7%) correspond to the non-exposed.

In order to verify the association among hematologic changes towards socio-biodemographic characteristics, the next table was prepared (Table 3).

During the analysis of the hematologic changes, no significant association to any variables was observed.

Regarding the age group variable, among the age groups of 6–12 and 51–60, there is a great disparity among changes found. Overall, most (51.6%) do not show hematologic changes.

Regarding the sewage variable, there is a balance in terms of percentages, and we infer that (51.6%) do not have any hematologic changes. As regards the income variable, 44 individuals (71%) have an income lower than two minimum wages.

In order to investigate the existence of an association between exposure type and hematologic changes in individuals, a statistical analysis was carried out. The results of hemogram differences were summarized in Table 4.

Table 2. Association of the socio-biodemographic characteristics with the exposition type.

Socio-Biographic Characteristics		Exposition Type						*p*-Value
		Non-Exposed		Exposed		Total		
		n	%	*n*	%	*n*	%	
Gender	Female	20	66.7	24	75	44	71	0.471
	Male	10	33.3	8	25	18	29	
	Total	30	100	32	100	62	100	
Age Group	(6–12)	2	6.7	6	18.8	8	12.9	0.309
	(13–18)	1	3.3	3	9.4	4	6.5	
	(19–30)	9	30	13	40.6	22	35.5	
	(31–50)	11	36.7	6	18.8	17	27.4	
	(51–60)	5	16.7	3	9.4	8	12.9	
	≥60	2	6.7	1	3.1	3	4.8	
	Total	30	100	32	100	62	100	
Sanitation	Yes	29	96.7	22	84.4	51	82.3	0.004 *
	No	1	3.3	10	15.6	11	17.7	
	Total	30	100	32	100	62	100	
Type of House	Brick	30	100	20	62.5	50	80.6	<0.001 *
	Wood	0	0	12	37.5	12	19.4	
	Total	30	100	32	100	62	100	
Income	Less 2 M.W.	17	56.7	27	84.4	44	71	0.025 *
	Among 3–5 M.W.	9	30	5	15.6	14	22.6	
	Among 5–10 M.W.	4	13.3	0	0	4	6.5	
	Total	30	100	32	100	62	100	

* Statistical significance (chi-square test; exact Fisher).

Table 3. Hematologic changes discovered in individuals' hemograms.

Variable	Description	Hematologic Changes						*p*-Value
		Yes		No		Total		
		n	%	*n*	%	*N*	%	
Gender	Female	20	45.5	24	54.5	44	29.0	0.470
	Male	10	55.6	8	44.4	18	71.0	
	Total	30	45.5	32	54.5	62	100	
Age Group	(6–12)	5	62.5	3	37.5	8	12.9	no assumptions
	(13–18)	2	50.0	2	50.0	4	6.5	
	(19–30)	11	50.0	11	50.0	22	35.5	
	(31–50)	9	52.9	8	47.1	17	27.4	
	(51–60)	2	25.0	6	75.0	8	12.9	
	≥60	1	33.3	2	66.7	3	4.8	
	Total	30	48.4	32	51.6	62	100	
Sanitation	Yes	25	49.0	26	51.0	51	82.3	no assumptions
	No	5	45.5	6	54.5	11	17.7	
	Total	30	48.4	32	51.6	62	100	
House Type	Masonry	25	50.0	25	50.0	50	80.6	0.604
	Timber	5	41.7	7	58.3	12	19.4	
	Total	30	48.4	32	51.6	62	100	
Income	Less 2 M.W.	17	56.7	27	84.4	44	71	no assumptions
	Between 3–5 M.W.	9	30	5	15.6	14	22.6	
	Between 5–10 M.W.	4	13.3	0	0	4	6.5	
	Total	30	100	32	100	62	100	

Table 4. Association among exposure type with hematologic change.

Groups			Hematologic Change		
			Change	No Change	Total
Exposure Type	Non-Exposed	*n*	10	20	30
		% Line	33.3%	66.7%	100.0%
		% Column	33.3%	62.5%	48.4%
		% Total	16.1%	32.3%	48.4%
	Exposed	Count	20	12	32
		% Line	62.5%	37.5%	100.0%
		% Column	66.7%	37.5%	51.6%
		% of Total	32.3%	19.4%	51.6%

$p = 0.022$.

In Table 4, we can observe an association among the variables of Exposure Type and Hematologic Change as being significant from a statistical perspective ($p < 0.05$). We verified a pattern of association between exposure and the presence/absence of hematologic changes ($p = 0.022$).

From the sum of people exposed to landfills (32 cases), the majority had hematological disorders (62.5%). It was found that, from 30 cases where the presence of hematological abnormalities was found, most are exposed to the landfill (66.7%).

As noted in Table 4, there was a 50% increase in changes in the screening performed in the "Exposed Group" compared to the "Non-Exposed Group", which indicates that the population is not in its best health.

The chance of occurrence of hematological disorders is 3.33 times higher in subjects exposed to the landfill compared to those who presented hematological changes in the "Non-Exposed Group". It is recognized, by the observation data, that 10 individuals from the "Non-Exposed Group" showed alterations in parameters, whereas the incidence in the "Exposed Group" was significantly higher, with 20 individuals undergoing changes.

Diseases such as leukocytosis, anemia, lymphocytosis and neutropenia were the major findings, and changes are evident in the "Exposed Group" compared to the "Non-Exposed Group".

4. Discussion

Analyzing the changes in vital functions of living beings, it is possible to know the effects of exposure to pollutants before their occurrence and the existence of any other significant damages [18,23–26].

It is considered that proving the cause–effect connection with environmental exposures that may trigger chronic manifestations in humans requires specific studies that prove to be costly and time-consuming [27–30]. It is necessary for the data to be collected in the field so as to be compared with experimental observations, in order to demonstrate the process and how the interactions occur regarding study dynamics [16].

The effects of human exposure to environmental pollutants are manifested typically in the long term and are masked by other causes. Adding to this, the fact that the probability of harmful elements' synergy and exponentiation of the risk is generally unknown, and it is thus extremely difficult to corroborate it with science based on laboratory tests, without incorporating other relevant factors, such as corporate interests, and industrial or professional regulators who hinder the analysis and detection of any effects on human health [20,24,26,30].

Given these considerations, as well as relying on the limitations of the health system itself in identifying peculiarities in the epidemiological profile of the population, a methodology was defined that aims to fully understand the exposure process. There are five parameters that are difficult to materialize including individual characteristics, duration of exposure, frequency of exposure, average time and "contact rate", always bearing in mind that the characteristics of the individual vary by age, gender, occupation, and body weight [31].

The focus of the study is the exposure of individuals to organisms, as well as to social, economic and environmental processes in anticipation of models that historically focus on the monitoring and maintenance of health [21,22]. Several papers have been published that address the role that the landfill can play in people's health [30–32]. There is no doubt that a landfill should be viewed from a holistic point of view, in that it must manage the direct and indirect effects that it may have [3,18,32].

Despite the existence of federal government programs for vulnerable populations, there do not seem to have been any improvements in the living conditions of this community [13,14]. The hemogram exam (counting blood cells—CBC) is used as a tool to promote the indicative tracking and respective improvements to minimize ongoing risks in analyses of a certain population. Given its great potential as a monitoring method, CBC integrates a set of parameters that describe the number and characteristics of some elements in the blood. The CBC consists of three basic features, namely erythrocyte evaluation (or red series), leukocytes evaluation (white or series), review of erythrocytes and platelets (platelet or series) [33].

Lymphocytosis is characterized by an increase in the number of lymphocytes (sub-group of white blood cells). The disease neutropenia indicates a low number of neutrophils that are a subset of leukocytes originating in the bone marrow, thus revealing an immune susceptibility. The increase of leukocytes is a sign of a viral infection, i.e., people near the landfill tend not to have viral and bacterial infections [33]. The disease leukocytosis reveals an increased number of leukocytes that reveals the existence of an infection, since they are the elements that are linked to immune system defenses against foreign bodies. The greater the leukocytosis is, the more contaminated the landfill will probably be, which can be interpreted as a parameter that reveals and establishes causal links. The disease of anemia is more complex, so the causes are more comprehensive and diversified. This immediately implies a more detailed investigation into these cases [33–35].

The lymphocytosis, neutropenia and leukocytosis diseases can be understood as correlated, although they have opposite directions of growth, as previously conveyed [35].

The results express the presence of discrepancies in the health of the São Jorge population, compared with the other subjects in the study, which requires the completion of further studies to detect the most common causes and the consequences for the residents in order to enable the development of a continuous and systematic supervision program for the residents. The suggestion is to carry out a more in-depth study in order to make improvements in this type of group exposed to potential health hazards, such as those identified in this study, in comparison with the Non-Exposed Group.

The problems derived from municipal solid waste are still present and without a proper solution [36]. There is no alternative but a behavioral change in relation to waste, given the reduction in its production, and in order to gradually implement technologies that are within our technical capabilities and to leverage resources to gradually develop a greater level of control over the environmental and health effects caused by waste [37].

The prevention measures and control of public health consequences of urban solid waste lack information and epidemiological data in which causal relationships can be established. There is a colossal deficiency in studies on the recovery of areas degraded by disposal of urban solid waste. In this context, this article seeks to contribute to a consolidation of the state-of-the-art related to the theme, in order to raise awareness of the elements that improve the quality of urban areas and hence the quality of life of their citizens [31,36].

Supporting research of this kind is a priority. The development of greater technical training, in view of the environmental and health issues, as well as the involvement of professionals in integrated waste management systems, in the medium and long term, may introduce these variables in projects and plans [15,37,38].

Data from this study should be compared to other data, which may involve a characterization of the epigenetic profile of the population [39] and even a characterization of the study areas for the presence of particulate material [40]. The challenge is to continue collecting more valid and reliable data in order to achieve an extrapolation between environmental and respective consequences for the health of population's risk factors to make a comparison on a national and global scale [18]. The study described is the first step in a study involving the whole *Espírito Santo* community.

The data obtained in this tracking study indicate that strategies for prevention and health promotion should include joint actions established between citizens and the management of services and should always be aimed at improving living conditions, particularly urban planning, implementation educational programs, as well as raising awareness about behavioral changes, once isolated actions are considered ineffective in reducing any problems [38,41].

It can be inferred that this study has a purpose of consolidating knowledge, which contributes to the prevention and detection of either known or unknown adverse health effects [40,41] to the public that are related to environmental exposure. The study should be understood as a primary screening indicating some pathologies, which, in addition to enabling us to assess the state of health of the inhabitant, may be indicative of the level of pollution of landfill, insofar as the conditions are reflected on the inhabitants of the landfill.

We must identify priorities at the community level, which is why the understanding of environmental health problems is essential. Sustainable planning may be a possible tool to implement a research-oriented future intervention, and thus to address the issues of greatest importance. However, this process is not simple in communities featuring persistent health disparities and a historical lack of confidence in health professionals [40,41].

The main alterations found in the completed study were anemia, leukocytosis, lymphocytosis and neutropenia. These data show that this is a group with greater immune susceptibility, adding that some elements of the exposed group already have infections, which are consistent with exposure to contaminants, supporting the existence of a pattern. Aiming at the promotion of health, it is suggested that the project should continue to be monitored in order to gather a greater quantity of evidence in support of the result of the tracking work carried out and described [42,43].

Based on the study, the exposed group is 3.33 times more likely to develop hematological abnormalities, taking as reference its exposure to the landfill, as opposed to the group that was not exposed. There is much [8,44] research on urban landfills, but none involving the social and hematological profile have been found in the literature.

Although the results only show the events occurred at the São Jorge landfill, in the Greater ABC region. They also provide important information on the expansion of knowledge concerning the assessment of this risk in residential areas around the planet. The demand for a thorough investigation is urgent in order to spread information related to the potential effects of human exposure to contaminants from multiple sources that affect public health.

A recent bibliographical survey study about the difficulty of assessing the impacts on the health of populations exposed to waste [45] shows that the biggest difficulty is the access to immediate and recent results of studies about biomonitoring of the effects of waste exposure on human health [45]. It is noted that this occurs due to several factors: identifying the profile of the exposed population, characterization and diversity of the analyzed area, socio-economic factors (education, unemployment, home ownership, family structure and access to health services), as well as government interests.

The analysis provides evaluation of quantitative data on the environment. However, the complexity and specificity related to historical and cultural features of this population caused some limitations in this study, such as: it was a convenience sampling, the way people moved to the landfill area, and, mainly, whether these blood changes in people living near the waste were due to their displacement alone. Besides those, there are limited potential confounders, such as population diet, family history and other risk factors that were not controlled in the analyses.

Future investigations may include concepts like nanoparticles and epigenetics, in order to promote a holistic view of the causes, mechanisms and consequences caused by the exposure of humans to a multitude of organisms, thereby complementing the present study and scientific knowledge, eliminating existing cross-limitations.

5. Conclusions

The full blood element count analysis was performed and it found that the blood counts of residents living near the landfill had positive results for hematological changes, and diseases such as leukopenia, anemia, neutropenia and lymphocytosis were the most frequently encountered changes. However, proving the cause-effect relation with environmental exposure factors that may trigger chronic manifestations in humans requires specific studies, which often are very costly and time-consuming.

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Morbidity and mortality of people who live close to municipal waste landfills: a multisite cohort study

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Abstract

Background: The evidence on the health effects related to residing close to landfills is controversial. Nine landfills for municipal waste have been operating in the Lazio region (Central Italy) for several decades. We evaluated the potential health effects associated with contamination from landfills using the estimated concentration of hydrogen sulphide (H_2S) as exposure.

Methods: A cohort of residents within 5 km of landfills was enrolled (subjects resident on 1 January 1996 and those who subsequently moved into the areas until 2008) and followed for mortality and hospitalizations until 31 December 2012. Assessment of exposure to the landfill (H_2S as a tracer) was performed for each subject at enrolment, using a Lagrangian dispersion model. Information on several confounders was available (gender, age, socioeconomic position, outdoor PM_{10} concentration, and distance from busy roads and industries). Cox regression analysis was performed [Hazard Ratios (HRs), 95% confidence intervals (CIs)].

Results: The cohort included 242 409 individuals. H_2S exposure was associated with mortality from lung cancer and respiratory diseases (e.g. HR for increment of 1 ng/m^3 H_2S: 1.10, 95% CI 1.02–1.19; HR 1.09, 95% CI 1.00–1.19, respectively). There were also associations between H_2S and hospitalization for respiratory diseases (HR = 1.02, 95% CI 1.00–1.03), especially acute respiratory infections among children (0–14 years) (HR = 1.06, 95% CI 1.02–1.11).

Conclusions: Exposure to H_2S, a tracer of airborne contamination from landfills, was associated with lung cancer mortality as well as with mortality and morbidity for respiratory diseases. The link with respiratory disease is plausible and coherent with previous studies, whereas the association with lung cancer deserves confirmation.

Key words: waste, landfills, residential cohort study

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Key Messages

- The evidence on the health of people living close to landfills is still controversial; most of the published studies are characterized by poor exposure assessment, use of health data at the aggregate level and limited possibility of adjusting for socioeconomic status.
- We evaluated the potential health effect of living near nine landfills (Lazio region, Italy), using a residential cohort approach and a dispersion model for exposure assessment.
- Exposure to landfills was associated with mortality from lung cancer and respiratory diseases and with hospitalizations for respiratory diseases, both in adults and in children.

Introduction

People who live close to municipal solid waste (MSW) landfills could be exposed to air pollutants emitted by the plants (landfill gas containing methane, carbon dioxide, hydrogen sulphide and other contaminants including volatile organic compounds, particulate matter and bioaresols) or to contaminated soil and water. The possible health effects related to residence close to these sites have been assessed in several original papers[1–9] and evaluated in systematic reviews.[10,11] Excess of mortality for some cancer sites (e.g. liver, pancreas, kidney, larynx) and non-Hodgkin lymphoma has been noted in some studies,[1–3] but the results have not been confirmed in other investigations.[4–6] In addition, some studies have indicated an increase of respiratory symptoms among residents close to biodegradable waste facilities.[12] In 2009, Porta *et al*.[10] concluded that evidence of an association between living close to a landfill and adverse health effects is inconclusive. Most of the published studies have methodological problems, including poor exposure assessment based only on distance from the source, use of health data at the aggregate level and limited possibility of adjusting for socioeconomic status. The quality of the epidemiological studies and scientific knowledge about the issue would be improved by using a residential cohort approach[13] and applying dispersion models to provide a better exposure assessment.[14]

This study aimed at evaluating the association between estimated exposure to hydrogen sulphide (H_2S, produced by anaerobic decomposition of sulphur-containing organic matter in landfills) and mortality and morbidity of a cohort of residents living within 5 km of the nine MSW landfills of the Lazio region (Central Italy, about 5 million inhabitants including the city of Rome). The study was part of a larger project on the characteristics of municipal solid waste treatment plants, their emissions and potential health effects in Lazio (www.eraslazio.it).

Methods

Study areas

Nine municipal solid waste landfills have been operating in Lazio for several decades. Only in the past two decades they were equipped with containments (including leachate collection and treatment, landfill cap construction and landfill gas collection and treatment). The main characteristics of the landfills (together with other potentially relevant environmental factors in the areas, e.g. arsenic contamination)[14] are described in Supplementary Table 1, Landfill characteristics, and in Supplementary Figure 2, Study areas, (available as Supplementary data at *IJE* online). The study area was defined for each landfill as a 5-km radius from the boundary of the landfills assessed using GIS software and regional technical maps with a scale of 1:5000. The World Geodetic System of 1984, with the Universal Transverse Mercator zone 33Nord projection (WGS84_UTM33N) was the reference for the geographical coordinates.

Exposure assessment

H_2S has been considered a surrogate measure of all contaminants emitted by landfills, and the airborne concentrations were predicted using a dispersion model. Dispersion models, such as the one we have been using here, have been recently used to assess the health effects of waste management processes.[15–17] We followed a process in three steps. First, yearly H_2S emissions from each sector of the landfills were estimated using a Landfill Gas Emissions Model.[18] Using several variables (the start and end dates of operations for each sector of the landfills, the waste capacity and waste acceptance rate), the annual emission rates for H_2S were calculated by means of a first-order decomposition rate equation:

$$Q_{H_2S} = \sum_{t=1}^{n} \sum_{j=0.1}^{1} KL_0 \left(\frac{M_t}{10}\right) e^{-kt_{ij}}$$

where:

QH_2S = annual emission rate (m^3/year)

t = age of the jth section of the landfill

i = 1 year time increment

n = (year of the calculation) – (initial year of waste acceptance)

j = 0.1 year time increment

K = hydrogen sulphide generation rate (year-1)

L_o = potential hydrogen sulphide generation capacity (m^3/Mg)

M_t = mass of waste accepted until t (in Mg)

tij = age of the waste mass accepted until the ith year (M_t) at the jth section

Mg = Megagram.

We used inventory defaults parameters derived from the US Environmental Protection Agency (EPA) Compilation of Air Pollutant Emission Factors[19] to define hydrogen sulphide generation rate (K) and potential hydrogen sulphide generation capacity (L_o), and Mt and tij were defined by the Lazio Environmental Protection Agency (EPA) using local data. Second, the EMMA software was used for the temporal and spatial modulation of the estimated emissions. EMMA approximates landfills shape as a regular grid with a resolution of 125 m x 125 m.[20] Finally, we used a Lagrangian particle model (SPRAY ver.5, ARIANET Srl, Italy) to simulate H_2S concentrations around the landfills and to produce maps of annual average concentrations around the sites; 2008 was chosen as the reference year for all the sites. The meteorological data were derived from regional measurements made by Lazio EPA in 2005 (that year is considered representative of the meteorological conditions in the area), and used in connection with RAMS data.[21] The Lagrangian model simulates the transport, dispersion and deposition of pollutants emitted using the orography, the meteorological data, the turbulence and the hourly spatial distribution (horizontal and vertical) of the emissions, based on the characteristics of the single source and on the mass fluxes. The model follows the path of fictitious particles in the atmospheric turbulent flow, and it is able to take into account complex situations, such as the presence of obstacles, breeze cycles, strong meteorological non-homogeneities and non-stationary, calm wind conditions.

Each subject in the cohort (see below) was assigned an H_2S exposure value corresponding to the estimated annual average value from the dispersion model at the baseline address. In other words, no exposure variation over time was considered and each person remained at the same exposure level during the all study period.

Enrolment of the cohort and follow-up procedures

All residents living within 5 km of the borders of the landfill on 1 January 1996, or those who later moved to the areas until 31 December 2008, were enrolled; datasets from 16 municipalities were used. Vital status was assessed using local registries until 31 December 2012. We considered subjects at risk until they died or moved out of the municipality.

Health outcomes

We analysed natural and cause-specific mortality and hospital admissions for cardiorespiratory diseases. The underlying cause of death for deceased subjects was retrieved from the Regional Registry of Causes of Death, and hospital admissions were obtained from the Regional Hospital Information System which collects information related to all hospital admissions that occur each year in public and private hospitals. Causes of death and diagnoses of hospitalization were coded according to the ICD 9 revision. For each subject, only the principal diagnosis that was the reason for the hospitalization was used and the event (i.e. failure in the Cox model) was defined at the time of the first hospitalization for a specific cause that occurred in the study period. Respiratory hospital admissions for children (residents under 14 years) were also analysed.

Covariates

We considered for each subject an area-based socioeconomic position (SEP) index, based on several characteristics at the census tract level (around 400 inhabitants) such as education level, occupation, housing conditions, family size and country of origin, classified into five levels (high, middle-high, medium, middle-low, low).[22] Modelled outdoor PM_{10} concentrations (μg/m^3) from primary emissions were assigned to the residential addresses of the cohort participants as a measure of background air quality.[23] The dispersion model was based on the integration between the meteorological Regional Atmospheric Modelling System [21] and the Eulerian Flexible Air Quality Regional Model (FARM, ARIANET Srl, Italy). As an additional indicator of long-term exposure to traffic-related air pollution at the baseline address, we used the Functional Road Class (FRC) (included in the TeleAtlasMultiNet road network) to classify the type of street: motorway (FRC = 0) and major traffic roads (FRC = 1–5). Presence of an industrial plant in the 2-km buffer from the residence was also considered. Information on individual lifestyle factors was not available.

Statistical analysis

The association between landfill H_2S exposure and mortality and hospital admissions was evaluated using Cox proportional hazard regression models [hazard ratios (HRs), 95% confidence intervals (CIs)], with age as the underlying time variable.

For mortality we defined a latency period of 5 years; therefore we considered all cohort participants who were residents of the area on 1 January 1996 (and started the follow-up on 1 January 2001) and those who subsequently moved to the areaup until 31 December 2003 (starting the follow-up 5 years after enrolment). No latency was allowed for the analyses of cardiorespiratory hospitalizations. We first compared the mortality and hospitalization risk of residents according to quartiles of the H_2S distribution. We then considered H_2S as a continuous variable, using the value of the annual mean exposure at residence. A linear association was estimated for increments equal to 1 ng/m^3 of H_2S. We considered as potential confounders socioeconomic position (SEP), PM_{10} background concentrations, residence within 150 m of main roads, 500 m from highways and within 1 or 2 km of industrial plants. With the exception of PM_{10}, which was a continuous variable, all other covariates were considered in the model as categorical variables. In addition, the analyses were performed stratifying in the Cox analysis by landfill sites, to take into account the possible different background rates in the various local areas, by gender and by calendar period (1996–2000, 2001–04, 2005–08, 2009–12), to take into account possible time-related changes in background rates of mortality and hospitalization. Diagnostic tools were used to check the proportional-hazard assumption for all categorical covariates. If any variable in the individual cohort models violated this assumption, effect estimates were compared with a stratified Cox analysis for that covariate. SAS (SAS Institute, NC) and STATA ver. 12 (StataCorp, TX) software programs were used for the statistical analyses.

Results

A total of 242 409 individuals were enrolled in the cohort from 1996 to 2008 (50.4% females), and H_2S concentrations were estimated for each of them at the address of recruitment. The annual average H_2S exposure levels of the population was rather low, 6.3 ng/m^3 [standard deviation (SD) 22.5]; as expected, people living close to the larger landfills (Latina and Rome) had higher H_2S exposure levels [mean = 32.7 ng/m^3 (SD 76.3) and mean = 45.8 ng/m^3 (SD 59), respectively].

The main characteristics of the study cohort according to H_2S concentrations (divided by quartiles of exposure) are described in Table 1. The distribution of gender, age and vital status was rather similar across exposure categories. However, people living in areas with higher concentrations of H_2S were more likely to be of lower SEP compared with people living in areas with lower exposure. PM_{10} background concentrations were higher in the most exposed group compared with those in the low exposure category. People in the higher exposure category tended to live farther from high traffic roads (500 m) but closer to highways and industrial plants (0–1 km). There was a good correlation between distance from landfill and H_2S exposure.

At the end of the follow-up there were 18 609 deaths (7.7%), and for 40 740 subjects (16.8%) the follow-up ended at the time of move away from the municipality of residence.

Table 2 shows the association between H_2S concentrations and cause-specific mortality; effect estimates are given for the quartile distribution of H_2S (25–50, 50 75 and > 75 percentile of the distribution vs < 25 percentile) and for a linear increase of H_2S equal to 1 ng/m^3. There were associations between H_2S exposure and lung cancer (HR 1.34, 95% CI 1.06–1.71), and respiratory diseases (HR 1.30, 95% CI 0.99–1.70) when comparing residents in areas with H_2S concentrations greater than 75 percentiles to the reference group. These findings were confirmed when we consider H_2S exposure as linear (HR 1.10, 95% CI 1.02–1.19 for lung cancer and HR 1.09, 95% CI 1.00–1.19 for respiratory diseases). No other associations were noted.

Table 3 shows the results for cardiorespiratory hospital admissions. No association was detected for cardiovascular diseases. There was an association between the highest quartile of exposure to H_2S and hospitalizations for respiratory diseases (H 1.05, 95% CI 0.99–1.11) also when considering H_2S exposure as linear (HR 1.02, 95% CI 1.00–1.03). H_2S exposure was linked with respiratory diseases and acute respiratory infection hospital admissions among children (for the highest quartile, HR 1.11, 95% CI 1.01–1.22; HR 1.20, 95% CI 1.04–1.38, respectively) also when we considered H_2S exposure as a linear term in the model. We found an association with paediatric admissions for asthma but with wider confidence intervals.In both mortality and hospitalization analyses, we did not find effect modification by gender (data not shown).

Because of the peculiarity of the urban site in Rome ('Malagrotta') (where a large landfill, an incinerator of medical wastes, and a petrochemical refinery are located within just a few kilometres of each other[3]), we repeated the analyses excluding the subjects who live close to the Malagrotta landfill. There were no important changes in the results (See Supplementary Tables 3 'Mortality excluding Malagrotta landfill' and 4 'Morbidity excluding Malagrotta landfill', available as Supplementary data at *IJE* online). We did perform the same sensitivity analysis excluding each landfill at the time, and again the results were similar (see Supplementary Figures 7 'Lung cancer mortality', 8 'Respiratory mortality', 9 'Respiratory morbidity' and 10 'Respiratory morbidity in children', available as Supplementary data at *IJE* online).

Table 1. Descriptive individual and environmental characteristics of the cohort members by hydrogen sulphide (H_2S) exposure

	Total		H_2S exposure levels (ng/m^3)							
			<25° perc (<0.77)		25°–50° perc (0.77–2.1)		50°–75° perc (2.1–4.2)		>75° perc (>4.2)	
	No.	%	No.	%	No.	%	No.	%	No.	%
Total	242 409	100	60 927	100.0	60 775	100	63 962	100	56 745	100
Gender										
Males	120 232	49.6	29 781	49.0	30 137	49.6	31 979	50.0	28 335	49.9
Females	122 177	50.4	31 146	51.0	30 638	50.4	31 983	50.0	28 410	50.1
Vital status										
Alive	183 060	75.5	48 306	79.3	45 948	75.6	44 673	69.8	44 133	77.8
Migrant	40 740	16.8	8 169	13.4	10 228	16.8	14 446	22.6	7 897	13.9
Dead	18 609	7.7	4 452	7.3	4 599	7.6	4 843	7.6	4 715	8.3
Age at recruitment (years)										
0–14	53 082	21.9	12 246	20.0	13 011	21.4	16 266	25.4	11 559	20.4
15–44	112 754	46.5	27 380	45.0	28 383	46.7	30 661	47.9	26 330	46.4
45–64	50 146	20.7	13 296	22.0	12 584	20.7	11 727	18.3	12 539	22.1
>65	26 427	10.9	8 005	13.0	6 797	11.2	5 308	8.3	6 317	11.1
Area-based socioeconomic position										
High	23 589	9.7	10 012	16.0	6 033	9.9	4 779	7.5	2 765	4.9
Middle-high	41 955	17.3	7 843	13.0	8 834	14.5	9 548	14.9	15 730	27.7
Medium	42 286	17.4	7 447	12.0	8 588	14.1	13 958	21.8	12 293	21.7
Middle-low	50 394	20.8	5 364	9.0	16 816	27.7	17 563	27.5	10 651	18.8
Low	62 157	25.6	22 806	37.0	15 206	25.0	11 906	18.6	12 239	21.6
Missing	22 028	9.1	7 455	12.0	5 298	8.7	6 208	9.7	3 067	5.4
PM_{10} (μg/m^3)										
< 11.99 (<50° perc)	121 222	50.0	44 371	73.0	29 696	48.9	23 986	37.5	23 169	40.8
11.99–17.69 (50°–90° perc)	96 369	39.8	16 556	27.0	28 967	47.7	31 661	49.5	19 185	33.8
> 17.69 (>90° perc)	24 818	10.2	0	0.0	2 112	3.5	8 315	13.0	14 391	25.4
Distance from major roads (metres)										
<= 150 m	114 698	47.3	31 842	52.0	25 876	42.6	34 506	53.9	22 474	39.6
> 150 m	127 711	52.7	29 085	48.0	34 899	57.4	29 456	46.1	34 271	60.4
Distance from highways (metres)										
<= 500 m	9 428	3.9	2 908	5.0	1 087	1.8	744	1.2	4 689	8.3
> 500 m	232 981	96.1	58 019	95.0	59 688	98.2	63 218	98.8	52 056	91.7
Distance from industrial plants (km)										
0–1 km	12 863	5.3	376	1.0	2 676	4.4	1 130	1.8	8 681	15.3
1–2 km	50 503	20.8	1 138	2.0	9 589	15.8	28 809	45.0	10 967	19.3
> 2 km	179 043	73.9	59 413	98.0	48 510	79.8	34 023	53.2	37 097	65.4
Distance from landfill (km)										
0–1 km	5 187	2.1	0	0.0	3	0.0	19	0.0	5 165	9.1
1–2 km	21 475	8.9	2	0.0	4 225	7.0	5 835	9.1	11 413	20.1
2–3 km	65 386	27.0	8 372	13.7	20 588	33.9	23 627	36.9	12 799	22.6
3–4 km	77 722	32.1	19 739	32.4	18 787	30.9	20 217	31.6	18 979	33.4
4–5 km	72 639	30.0	32 814	53.9	17 172	28.3	14 264	22.3	8 389	14.8

An additional analysis was performed using distance from the landfills (0–2 km, 2–3 km vs 3–5 km), instead of estimated H_2S concentration, as the exposure variable. Although the results for mortality using distance were not similar to what has been observed using H_2S concentrations (see Supplementary Table 5 'Mortality by distance', available as Supplementary data at *IJE* online) the results for hospitalizations were similar to those obtained using H_2S concentrations (see Supplementary Table 6 'Morbidity by distance', available as Supplementary data at *IJE* online).

Our final concern was that migration outside the areas could bias the results in the case of migration being associated with the exposure and if residents with pre-existing diseases were more likely to migrate. We compared the characteristics of people who migrated outside the study

Table 2. Associations between hydrogen sulphide (H_2S in quartiles and continuous) and cause specific mortality: number of deaths (No.) hazard ratios (HR) and 95% confidence intervals (95% CI)

Cause of death (ICD-9-CM)	H_2S concentrations															
	<25° percentile[a]	25°–50° percentile				50°–75° percentile				>75° percentile				Linear trend	
	No.	No.	Crude HR	HR	95% CI	No.	Crude HR	HR	95% CI	No.	Crude HR	HR	95% CI	HR	95% CI
Natural causes (001–799)	3 701	3 946	0.98	1.01	(0.96–1.06)	4 254	1.00	1.02	(0.97–1.08)	4 104	0.96	0.98	(0.91–1.05)	1.00	(0.98–1.02)
All cancers (140–239)	1 282	1 307	0.97	0.99	(0.91–1.08)	1 493	1.03	1.05	(0.95–1.16)	1 452	1.00	1.03	(0.91–1.16)	1.01	(0.98–1.05)
Stomach (151)	75	88	1.03	0.98	(0.70–1.37)	108	1.27	1.23	(0.84–1.79)	105	1.00	0.88	(0.54–1.42)	1.00	(0.87–1.16)
Colorectal (153–154,159)	154	170	0.99	1.00	(0.79–1.27)	176	0.96	0.97	(0.74–1.28)	159	0.93	0.91	(0.64–1.28)	0.97	(0.87–1.08)
Liver (155–156)	102	89	0.86	0.83	(0.61–1.13)	106	0.89	0.77	(0.53–1.11)	89	0.74	0.76	(0.48–1.2)	0.90	(0.78–1.05)
Pancreas (157)	68	64	0.92	0.93	(0.64–1.35)	69	0.92	0.95	(0.61–1.49)	72	0.69	0.73	(0.41–1.32)	0.93	(0.77–1.11)
Larynx (161)	17	15	0.81	0.72	(0.33–1.56)	11	0.38	0.40	(0.14–1.14)	23	0.43	0.26	(0.07–0.95)	0.64	(0.43–0.97)
Lung (162)	276	281	0.98	1.06	(0.89–1.27)	360	1.09	1.18	(0.97–1.45)	361	1.19	1.34	(1.06–1.71)	1.10	(1.02–1.19)
Bladder (188)	54	48	0.88	0.89	(0.59–1.36)	56	1.22	1.33	(0.81–2.16)	50	1.01	0.94	(0.5–1.80)	1.03	(0.85–1.26)
Kidney (189)	36	30	0.76	0.85	(0.51–1.43)	36	0.87	0.94	(0.52–1.70)	31	0.70	0.86	(0.41–1.83)	0.96	(0.75–1.22)
Brain (191)	23	29	1.26	1.25	(0.70–2.26)	38	1.63	1.63	(0.84–3.17)	41	1.70	1.76	(0.81–3.81)	1.22	(0.95–1.56)
Lymphatic and haematopoietic tissue (200–208)	108	115	1.03	1.16	(0.87–1.54)	106	0.94	0.96	(0.68–1.35)	102	1.06	1.12	(0.74–1.17)	1.02	(0.89–1.16)
Cardiovascular diseases (390–459)	1 457	1 681	1.02	1.05	(0.97–1.13)	1 676	0.96	1.00	(0.91–1.09)	1 641	0.90	0.91	(0.81–1.02)	0.98	(0.94–1.01)
Ischaemic heart diseases (410–414)	512	570	0.99	1.00	(0.88–1.14)	574	0.86	0.91	(0.78–1.06)	530	0.77	0.78	(0.64–0.95)	0.93	(0.87–0.99)
Respiratory diseases (460–519)	256	244	0.88	0.92	(0.76–1.11)	279	1.15	1.13	(0.90–1.40)	264	1.30	1.30	(0.99–1.70)	1.09	(1.00–1.19)
Digestive diseases (520–579)	158	163	0.93	0.97	(0.77–1.24)	218	1.06	1.09	(0.83–1.41)	186	0.94	0.97	(0.69–1.35)	1.01	(0.91–1.12)
Urinary system diseases (580–599)	58	92	1.49	1.54	(1.08–2.21)	74	1.25	1.28	(0.83–1.97)	67	1.26	1.42	(0.84–2.40)	1.11	(0.94–1.30)

[a]Reference category

Table 3. Associations between hydrogen sulphide (H_2S, in quartiles and continuous) and cardiorespiratory morbidity: number of people hospitalized (No.), hazard ratios (HR) and 95% confidence intervals (95% CI)

Diagnosis (ICD-9-CM)	H_2S concentrations														
	<25° percentile[a]	25°–50° percentile				50°–75° percentile				>75° percentile				Linear trend	
	No.	No.	Crude HR	HR	95% CI	No.	Crude HR	HR	95% CI	No.	Crude HR	HR	95% CI	HR	95% CI
Total cohort															
Cardiovascular diseases (390–459)	6 666	6 090	0.99	0.99	(0.95–1.03)	6 291	0.99	1.00	(0.96–1.04)	6 677	1.03	1.02	(0.97–1.07)	1.00	(0.99–1.02)
Cardiac diseases (390–429)	3 991	3 585	0.99	0.98	(0.93–1.03)	3 580	0.97	0.98	(0.92–1.04)	4 022	1.05	1.04	(0.97–1.11)	1.01	(0.98–1.03)
Ischaemic heart diseases (410–414)	1 393	1 347	1.03	1.02	(0.94–1.10)	1 288	0.94	0.94	(0.85–1.03)	1 426	1.01	0.99	(0.88–1.10)	0.99	(0.95–1.02)
Cerebrovascular diseases (430–438)	1 635	1 482	0.98	0.98	(0.91–1.06)	1 466	0.97	0.97	(0.89–1.06)	1 543	0.97	0.98	(0.88–1.10)	0.99	(0.96–1.03)
Respiratory diseases (460–519)	4 372	4 249	0.98	0.97	(0.92–1.01)	5 628	1.02	1.01	(0.96–1.06)	4 837	1.06	1.05	(0.99–1.11)	1.02	(1.00–1.03)
Acute respiratory infections (460–466,480–487)	1 447	1 441	1.00	0.96	(0.89–1.04)	1 721	1.00	0.97	(0.89–1.05)	1 509	1.09	1.07	(0.97–1.18)	1.02	(0.98–1.05)
COPD (490–492;494;496)	654	592	0.96	0.94	(0.84–1.06)	535	0.92	0.90	(0.78–1.04)	577	1.09	1.06	(0.90–1.25)	1.00	(0.95–1.05)
Asthma (493)	332	355	1.01	1.00	(0.86–1.17)	594	1.16	1.17	(0.99–1.38)	365	1.11	1.09	(0.90–1.33)	1.04	(0.98–1.11)
Children 0–14 years old															
Respiratory diseases (460–519)	1 457	1 522	1.00	0.99	(0.92–1.07)	2 420	1.07	1.08	(0.99–1.17)	1 499	1.10	1.11	(1.01–1.22)	1.04	(1.01–1.07)
Acute respiratory infections (460–466,480–487)	573	669	1.10	1.02	(0.91–1.15)	925	1.15	1.10	(0.97–1.25)	617	1.25	1.20	(1.04–1.38)	1.06	(1.02–1.11)
Asthma (493)	257	267	0.98	0.99	(0.83–1.19)	506	1.23	1.29	(1.06–1.55)	276	1.11	1.13	(0.91–1.41)	1.07	(0.99–1.14)

[a]Reference category

areas (40 740 subjects) with those who remained in the areas until the end of the follow-up (201 669 subjects) See Supplementary Table 11 'Comparison between migrant and not migrant', available as Supplementary data at *IJE* online). We considered gender, age, socioeconomic status and H_2S exposure as fixed variables. Since occurrence of hospitalizations before migration is a time-dependent variable, we compared subjects migrating in the period 2004–12 (19 695 subjects) with all subjects who did not migrate before that period (189 560 subjects), evaluating the occurrence of cardiorespiratory hospitalizations during1998–2003. Migration was associated with male gender, younger age and lower exposure to H_2S; no clear differences of migrants compared with non-migrants were found for socioeconomic status. In a multinomial logistic regression(data not shown), we found no major differences between the two groups for respiratory diseases, whereas migrants were less likely than non-migrants to suffer from two or more hospitalizations for cardiovascular disease (OR, 0. 74, 95% CI 0.57–0.95) before migrating. All these results indicate that bias due to increased susceptibility of migrants is unlikely given that migrants are less exposed and tend to be healthier than non-migrants.

Discussion

We found a positive association between exposure to hydrogen sulphide (H_2S), that we used as a surrogate for all the pollutants co-emitted from the landfills, and mortality for lung cancer and respiratory diseases as well as hospital admissions for respiratory diseases, especially in children.

Previous studies have investigated the association between residence close to landfills and cancer incidence or cause-specific mortality, with conflicting results. A Canadian cohort study compared cancer incidence in males living close to a landfill with that of residents of farther away areas.[1] The distance from the landfill was assigned to each person based on the residential address at diagnosis. Excess risks for non-Hodgkin lymphoma and liver, pancreas and kidney cancers were found in male residents close to the site. Malagrotta (Rome) residents who lived near (in an area about 2 km^2) a large landfill of municipal solid waste, an incinerator and a petrochemical refinery showed an association between proximity to landfill and laryngeal cancer.[2] A more recent residential cohort study of the same area found that H_2S exposure from the landfill was related to higher risk of mortality from laryngeal cancer and bladder cancer in women, as well as hospitalizations for cardiorespiratory diseases.[3] Jarup *et al.* compared cancer incidence (bladder, brain and hepatobiliary cancers and leukaemias) in the population resident within 2 km of 9565 landfills in UK with cancer rates of those who lived more than 2 km away.[4] Despite the large statistical power, the study did not show excess cancer risk associated with proximity to landfill sites. An ecological study compared mortality, hospital admissions and reproductive health of a population living near a landfill site in Wales with another population matched for socioeconomic status.[5] No differences between the two populations were found. A study in Brazil evaluated the association between residence close to solid waste landfill sites and cancer mortality.[6] The exposed areas were defined using a 2-km buffer radius around 15 sites. Standardized mortality ratios were analysed in Bayesian spatial models. The results did not indicate any excess risk for people close to landfills. Some elevated risks of bladder and liver cancer, and death due to congenital malformation were found, although they did not have statistical significance.

The results we found regarding respiratory diseases are consistent with others suggesting a relationship between living close to landfill areas and damage to the respiratory system,[24,25] as highlighted in a recent systematic review.[26] Occurrence of respiratory symptoms was documented among residents living close to waste sites[12] and was linked to inhalation exposure to endotoxin, microorganisms, and aerosols from waste collection and land filling.[27]

Occupational exposure to organic dust, particulate matters from microbial, plant or animal origin, has been associated with an increased risk of lung cancer in a pooled analysis of case-control studies.[25] High lung cancer mortality was found among male residents of Italian National Priority Contaminated Sites with industrial waste landfills or illegal dumps[29] and among residents living near incinerators and landfills of hazardous waste in Spain,[30] but the overall evidence that residing near landfills is associated with increased risk of lung cancer is still inadequate.[10]

This study attempted to overcome some of the limitations of the previously conducted studies, which included issues of study design, exposure assessment and confounding.[11] We used a residential cohort approach to provide a more detailed estimation of the population at risk. To each subject in the cohort we assigned an H_2S exposure value(corresponding to the estimated H_2S concentration at the baseline address). It was not possible to consider indexes of average or cumulative exposure based on the different residences, because only a few municipality databases provided information about changes of residence during the follow-up. For this reason, individual exposure reflects residence at the beginning of the follow-up.

Previous studies have considered distance from landfills as a proxy of exposure.[4,7,9] Distance-to source is easy to understand because it assumes that people living near the landfill are more exposed than people living further away. We used modelled H_2S concentrations as an exposure measure of the landfill gases, on the assumption that the pollution from landfills does not spread uniformly around the site but depends on the quantity of incoming waste, the prevailing winds and the orography of the area.[3] Our results for hospitalizations were confirmed when we used distance from the source as the exposure variable instead of modelled H_2S concentrations. There are, however, several aspects in the exposure assessment process we used that should be considered. H_2S generation rates were taken from EPA published material, and waste acceptance capacity and waste acceptance rates were from derived from legal authorized values. It is likely, then, that the derived absolute emissions data were more accurate for the recent period and less certain for the past. On the other hand, we used the shape of the H_2S concentrations on the ground to rank subjects as more exposed or less exposed, and this shape is of greater importance than the exact absolute values. Of course, the major limitation of our exposure assessment is related to the lack of a validation study with *in situ* measurements. Nonetheless, SPRAY is a consolidated model that has been validated using a 'conventional' validation framework,[31] and its performances and efficiency have been evaluated and validated in multiple real conditions with different orography, size of domain, number of grid cells in the domain, meteorological conditions and emission types.[32–34] The model has been already used in other locations to study health effects of waste management.[3,17] Another aspect of concern is the use of meteorological parameters that greatly influence the dispersion of the pollutants. We considered the year 2005 as representative of the study area meteorological conditions because there were no particular meteorological anomalies in that year. Running the dispersion model with meteorological data for different years could change the landfills footprint only in presence of extreme weather conditions that strongly affect the annual average. In our opinion, the difference among years is generally minimal and the uncertainty associated with the use of specific meteorological data is negligible.

Our results were adjusted for several confounders: age, socioeconomic position and variables related to the environmental context (proximity to roads with heavy traffic, proximity to industrial sites, air quality) that might otherwise distort the study association. In particular, high level of PM_{10} ($>$ 90 percentile of the distribution vs $<$ 50 percentile) was associated in our model with cardiovascular and respiratory hospitalizations (HR 1.08, 95% CI 1.01–1.16 and HR 1.03, 95% CI 0.96–1.12, respectively). However, no data were available on the personal habits of the subjects, which could have had a role in the diseases investigated, especially cigarette smoking but also alcohol use, physical activity and obesity. The collection of this information, through telephone interviews or home visits, would have been prohibitive for such a large cohort, and the lack of this information may have biased the results because of confounding not controlled in the analysis. It should be noted, however, that many personal habits are associated with socioeconomic position. It is therefore reasonable to assume that the analysis that adjusted for socioeconomic index also took into account others individual variables, including smoking. Moreover, excess of hospitalizations for respiratory diseases were found also in children, and no excess mortality/morbidity for cardiovascular diseases (indicative of most of the unmeasured lifestyle factors including smoking) was found, despite the larger statistical power than for respiratory diseases. Therefore, although residual confounding cannot be excluded, it is unlikely that the observed relationship between H_2S exposure and respiratory disturbances could be entirely due to unmeasured smoking habits and other factors.

In conclusion, we found associations between H_2S exposure from landfills and mortality from lung cancer as well as mortality and morbidity for respiratory diseases. The link with respiratory diseases has been observed in other studies and it is potentially related to irritant gases and other organic contaminants. The excess of lung cancer is a relatively new finding.

Supplementary Data

Supplementary data are available at *IJE* online.

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Review

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Systematic review of epidemiological studies on health effects associated with management of solid waste

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Abstract

Background: Management of solid waste (mainly landfills and incineration) releases a number of toxic substances, most in small quantities and at extremely low levels. Because of the wide range of pollutants, the different pathways of exposure, long-term low-level exposure, and the potential for synergism among the pollutants, concerns remain about potential health effects but there are many uncertainties involved in the assessment. Our aim was to systematically review the available epidemiological literature on the health effects in the vicinity of landfills and incinerators and among workers at waste processing plants to derive usable excess risk estimates for health impact assessment.

Methods: We examined the published, peer-reviewed literature addressing health effects of waste management between 1983 and 2008. For each paper, we examined the study design and assessed potential biases in the effect estimates. We evaluated the overall evidence and graded the associated uncertainties.

Results: In most cases the overall evidence was inadequate to establish a relationship between a specific waste process and health effects; the evidence from occupational studies was not sufficient to make an overall assessment. For community studies, at least for some processes, there was limited evidence of a causal relationship and a few studies were selected for a quantitative evaluation. In particular, for populations living within two kilometres of landfills there was limited evidence of congenital anomalies and low birth weight with excess risk of 2 percent and 6 percent, respectively. The excess risk tended to be higher when sites dealing with toxic wastes were considered. For populations living within three kilometres of old incinerators, there was limited evidence of an increased risk of cancer, with an estimated excess risk of 3.5 percent. The confidence in the evaluation and in the estimated excess risk tended to be higher for specific cancer forms such as non-Hodgkin's lymphoma and soft tissue sarcoma than for other cancers.

Conclusions: The studies we have reviewed suffer from many limitations due to poor exposure assessment, ecological level of analysis, and lack of information on relevant confounders. With a moderate level confidence, however, we have derived some effect estimates that could be used for health impact assessment of old landfill and incineration plants. The uncertainties surrounding these numbers should be considered carefully when health effects are estimated. It is clear that future research into the health risks of waste management needs to overcome current limitations.

Introduction

"Waste management", that is the generation, collection, processing, transport, and disposal of solid waste is important for both environmental reasons and public health. There are a number of different options available for the management and treatment of waste including minimisation, recycling, composting, energy recovery and disposal. At present, an increasing amount of the resources contained in waste is recycled, but a large portion is incinerated or permanently lost in landfills. The various methods of waste management release a number of substances, most in small quantities and at extremely low levels. However, concerns remain about potential health effects associated with the main waste management technologies and there are many uncertainties involved in the assessment of health effects.

Several studies of the possible health effects on populations living in proximity of landfills and incinerators have been published and well-conducted reviews are available [1-4]. Both landfills and incinerators have been associated with some reproductive and cancer outcomes. However, the reviews indicate the weakness of the results of the available studies due to design issues, mainly related to a lack of exposure information, use of indirect surrogate measures, such as the distance from the source, and lack of control for potential confounders. As a result, there is great controversy over the possible health effects of waste management on the public due to differences in risk communication, risk perception and the conflicting interests of various stakeholders. Therefore, there is the need for an appropriate risk assessment that informs both policy makers and the public with the information currently available on the health risks associated with different waste management technologies. Of course, the current uncertainties should be taken into account.

Within the EU-funded INTARESE project [5], we aimed to assess potential exposures and health effects arising from solid wastes, from generation to disposal, or treatment. A key part in the health impact assessment was selecting or developing a suitable set of relative risks that link individual exposures with specific health endpoints. In this paper, we systematically reviewed the available epidemiological literature on health effects in the vicinity of landfills and incinerators and among workers at waste processing plants to derive usable excess risk estimates for health impact assessment. The degree of uncertainty associated with these estimates was considered.

Methods

We considered epidemiological studies conducted on the general population with potential exposures from collecting, recycling, composting, incinerating, and landfilling solid waste. We also considered studies of employees of waste management plants as they may be exposed to the same potential hazards as the community residents, even if the intensity and duration of the exposure may differ. However, to limit our scope, we did not consider studies on biomarkers of exposure and health effects.

Relevant papers were found through computerized literature searches of MEDLINE and PubMed Databases from 1/1/1983 through 31/12/2008, using the MeSH terms "waste management" and "waste products" and the subheading "adverse effects". We identified 144 papers with this method. We also conducted a free search with several combinations of relevant key words (waste incinerator or landfill or composting or recycling) and (cancer or birth outcome or health effects), and 285 papers were identified. In addition, articles were traced through references listed in previous reviews [1-3,6-9], and in publications of the UK Department for Environment, Food and Rural Affairs [10]. Finally, we used information from two recent reviews of epidemiological studies on populations with potential exposures from toxic and hazardous wastes for reproductive [4], and cancer [11] outcomes, respectively.

The eligibility of all papers was evaluated independently by three observers, and disagreements were resolved by discussion. As indicated, studies on sewage treatment and on biological monitoring were not included. We also excluded articles in languages other than English, not journal articles, and six studies [12-17] conducted at the municipal level (usually small towns) where it was not possible to evaluate the extent of the population potentially involved and the possibility of exposure misclassification was high.

Papers were grouped according to the following criteria:

• waste management technologies: recycling, composting, incinerating, landfilling (considering controlled disposal of waste land and toxic or hazardous sites);

• health outcomes: cancers (stomach, colorectal, liver, larynx and lung cancer, soft tissue sarcoma, kidney and bladder cancer, non-Hodgkin's lymphoma, childhood cancer), birth outcomes (congenital malformations, low birth weight, multiple births, abnormal sex ratio of newborns), respiratory, skin and gastrointestinal symptoms or diseases.

We have reported in the appropriate tables (in the online additional files) for each paper: study design (e.g. geographical, cohort, cross-sectional, case-control study, etc.), population characteristics (subjects, country, age, sex), exposure measures (e.g. occupational exposure to waste incinerator by-products, residence near a landfill, etc.), and the main results (including control for major confounders) with respect to the quantification of the health effects studied. For each study we have evaluated the potential sources of uncertainty in the results due to design issues. In particular, the possibility that selection bias, information bias, or confounding could artificially increase or decrease the relative risk estimate has been noted in the tables using the plus/minus scale to indicate that effect estimates are likely to be overestimated (or underestimated) up to 20% (+/-), from 20 to 50% (++/--) and more than 50% (+++/---). Uncertainties were graded by two observers (SM and FF), who discussed the inconsistencies.

After a description of the available studies, the overall evaluation of the epidemiological evidence regarding the process/disease association was made based on the IARC (1999) criteria, and two categories were chosen, namely: "*Inadequate*" when the available studies were of insufficient quality, consistency, or statistical power to determine the presence or absence of a causal association; "*Limited*" when a positive association was observed between exposure and disease for which a causal interpretation is considered to be credible, but chance, bias, or confounding could not be ruled out with reasonable confidence. There were no instances where the category "sufficient" evidence could be used. Only when the specific process/disease association was judged as limited (suggestive evidence but not sufficient to infer causality) we decided to evaluate the strength of the association and to measure appropriate relative risks. For this purpose, we considered the set of studies providing the best evidence and assigned an overall level of scientific confidence of the specific effect estimate based on an arbitrary scale: very high, high, moderate, low, very low. This evaluation was made by three assessors (SM, DP, and FF).

Results

A total of 49 papers were reviewed: 32 concerning health effects in communities in proximity to waste sites, and 17 on employees of waste management sites. The majority of community studies evaluated possible adverse health effects in relation to incinerators and landfills. We found little evidence on potential health problems resulting from environmental or occupational exposures from composting or recycling, and very little on storage/collection of solid waste. A description of the main findings follows.

Studies of communities near landfills

One of the main problems in dealing with studies on landfill sites (an to some extent also for incinerators) is the distinction between sites for municipal solid wastes and sites for other wastes. The definition of different types of waste is far from being standardised across the world. The terms hazardous, special, toxic, industrial, commercial, etc, are variously applied in different countries and time periods to designate non-household wastes. In earlier time periods definitions were even less clear and some disposal sites may have switched categories (e.g. if they used to take industrial waste they may now only take municipal waste). Since two systematic reviews were already available for toxic wastes [4,11], we did not replicate the literature search, but summarized the evidence reported in the available reviews and tried to compare and discuss the results with studies where mainly municipal solid wastes were landfilled. The additional file 1 contain several details of the studies reviewed.

Cancer

Russi et al. [11] carried out Medline searches of the peer-reviewed English language medical literature covering the period from January 1980 to June 2006 using the keywords "toxic sites" and "cancer", and identified articles from published reviews. They included 19 articles which fit the following selection criteria: 1) the study addressed either cancer incidence or cancer mortality as an end-point, 2) the study was carried out in a community or a set of communities containing a known hazardous waste site; 3) the study had to address exposure from a specific waste site, rather than from a contaminated water supply resulted from multiple point sources. As the authors recognized, some of the location investigated included both toxic wastes and municipal solid wastes as in the study from Goldberg et al. [18] or Pukkala et al. [19]. There are two investigations considered in this review that are important to evaluate because of the originality of the approach (cohort study, [19] and due to the large size [20].

In Finland, Pukkala et al. [19] studied whether the exposure to landfills caused cancer or other chronic diseases in inhabitants of houses built on a former dumping area containing industrial and household wastes. After adjusting for age and sex, an excess number of male cancer cases were seen, especially for cancers of the pancreas and of the skin. The relative risk slightly increased with the number of years lived in the area. However, some uncertainties were likely to affect the results of the study with regards to the exposure assessment (-), outcome assessment (+) and presence of residual confounding (-).

Jarup et al. [20] examined cancer risks in populations living within 2 km of 9,565 (from a total of 19,196) landfill sites that were operational at some time from 1982 to 1997 in Great Britain. No excess risks of cancers of the bladder and brain, hepato-biliary cancer or leukaemia were found, after adjusting for age, sex, calendar year and deprivation. The study was very large and had high power, however misclassification of exposure could have decreased the possibility of detecting an effect (--).

Based on the findings and on the evaluation of the quality of the studies, Russi et al. [11] concluded that epidemiological studies of populations living in the vicinity of a toxic waste site have not produced evidence of adequate quality to establish a casual link between toxic waste exposures and cancer risk. In our terms, the evidence may be considered as "inadequate".

In addition to the articles reviewed by Russi et al. [11], we reviewed the article by Michelozzi et al. [21], which investigated the mortality risk in a small area of Italy (Malagrotta, Rome) with multiple sources of air contamination (a very large waste disposal site serving the entire city of Rome, a waste incinerator plant, and an oil refinery plant). Standardised Mortality Ratios (SMRs) were computed in bands of increasing distance from the plants, up to a radius of 10 km. No association was found between proximity to the sites and cancer of various organs, in particular liver, lung, and lymph haematopoietic cancer, however, mortality from laryngeal cancer declined with distance from the pollution sources, and a statistically significant trend remained after adjusting for a four-level index of socio-economic status. The main uncertainty of the study is related to the exposure assessment (--) since only distance was considered thus decreasing the possibility of detecting an effect. There are also uncertainties in using mortality to estimate cancer incidence in proximity to a suspected source of pollution (+). On the other hand, even though the authors did adjust for an area-based index of deprivation, residual confounding (+) from socioeconomic status was likely.

In summary, there is inadequate evidence of an increased risk of cancer for communities in proximity of landfills. The three slightly positive studies from Goldberg et al. [18], Pukkala et al. [19] and Michelozzi et al. [21] are not consistent.

Birth defects and reproductive disorders

Saunders [4] reviewed 29 papers examining the relationship between residential proximity to landfill sites and the risk of an adverse birth outcome. The review included either studies on municipal waste or on hazardous waste. Eighteen papers reported some significant association between adverse reproductive outcome and residence near a landfill site. Two of the strongest papers conducted on hazardous waste landfill sites in Europe (EUROHAZCON) found similarly moderate but significant associations between residential proximity (within 3 km) to hazardous waste sites and both chromosomal [22] (Odds Ratio, OR: 1.41, 95%CI: 1.00-1.99) and non-chromosomal [23] (OR: 1.33, 95%CI: 1.11-1.59) congenital anomalies.

Included in the Saunders's review [4] is the national geographical comparison study on landfills in the UK by Elliott et al. [24]. This study investigated the risk of adverse birth outcomes in populations living within two km of 9,565 landfill sites in Great Britain, operational at some time between 1982 and 1997, compared with those living further away (reference population). The sites included 774 sites for special (hazardous) waste, 7803 for non-special waste and 988 handling unknown waste; a two km zone was defined around each site to detect the likely limit of dispersion for landfill emissions, including 55% of the national population. Among the 8.2 million live births and 43,471 stillbirths, 124,597 congenital anomalies (including miscarriage) that were examined, there were: neural tube defects, cardiovascular defects, abdominal wall defects, hypospadias and epispadias, surgical correction of gastroschisis and exomphalos; low and very low birth weights were also found , defined as less than 2500 g and less than 1500 g, respectively. The main analysis, conducted for all landfill sites during their operation and after closure, found a small, but still statistically significant, increased risk of total and specific anomalies (OR: 1.01, 95%CI: 1.005-1.023) in populations living within 2 Km, and also an increased risk of low (OR: 1.05, 95%CI: 1.047-1.055) and very low birth weight (OR: 1.04, 95%CI: 1.03-1.05). Additional analyses were carried out separately for sites handling special waste and non-special waste, and in the period before and after opening, for the 5,260 landfills with available data. After adjusting for deprivation and other potential confounding variables (sex, year of birth, administrative region), there was a small increase in the relative risks for low and very low birth weight and for all congenital anomalies, except for cardiovascular defects. The risks of all congenital anomalies were higher for people living near special waste disposals (OR: 1.07 CI95%:1.04-1.09) compared to non-special waste disposals (OR: 1.02, CI95%:1.01-1.03). There was no excess risk of stillbirth. On these bases, the author [4] concluded that while most studies reporting a positive association are of good quality, over half report no association with any adverse birth outcome and most of the latter are also well conducted. The review considered that the evidence of an association of residence near a landfill with adverse birth outcomes as unconvincing.

After the review by Saunders [4], we considered four additional studies examining reproductive effects of landfill emissions.

Elliot et al. recently updated the previous study [25] in order to evaluate whether geographical density of landfill sites was related to congenital anomalies. The analysis was restricted to 8804 sites operational at some time between 1982 and 1997. There were 607 sites handling special (hazardous) waste and 8197 handling non-special or unknown waste type. The exposure assessment took into account the overlap of the two km buffers around each site, to define an index of exposure with four levels of increasing landfill density. Several anomalies (hypospadias and epispadias, cardiovascular defects, neural tube defects and abdominal wall defects) were evaluated. The analysis was carried out separately for special and non-special waste sites and was adjusted for deprivation, presence or absence of a local congenital anomalies register and maternal age. The study found a weak association between intensity of hazardous sites and some congenital anomalies (all, cardiovascular, hypospadia and epispadias).

The studies conducted in the United Kingdom suffer from the same limitations, namely the possibility that misclassification of exposure could have decreased the relative risk estimates to some extent (--); on the other hand, there are several uncertainties related to the quality of reporting and registration of congenital malformations. In the latter case, a positive bias is more likely (++). For the recent report by Elliott et al. [25], location uncertainties and differential data reliability regarding the sites, together with the use of distance as the basis for exposure classification, limit the interpretation of the findings (--).

In Denmark, Kloppenborg et al. [26] marked the geographical location of 48 landfills and used maternal residence as the exposure indicator in a study of congenital malformations. The authors found no association between landfill location and all congenital anomalies or of the nervous system, and a small excess risk for congenital anomalies of the cardiovascular system. Potential confounding from socioeconomic status is the major limitation of this study (+++).

Jarup et al. [27] studied the risk of Down's syndrome in the population living near 6829 landfills in England and Wales. People were considered exposed if they lived in a two-km zone around each site, people beyond this zone were the reference group. A two-year lag period between potential exposure of the mother and her giving birth to a Down's syndrome child was allowed. The analysis was adjusted for maternal age, urban-rural status and deprivation index. No statistically significant excess risk was found in the exposed populations, regardless of waste type.

Finally, Gilbreath et al. [28] studied births in 197 Native Alaskan villages containing open dumpsites with hazardous waste, scoring the exposure into high, intermediate and low hazard level on the basis of maternal residence. The authors found an association between higher levels of hazard and low birth weight and intrauterine growth retardation. The major limit of the study is the low specificity of the exposure definition.

In summary, an increased risk of congenital malformations and of low birth weight has been reported from studies conducted in the UK. When compared with the results from studies conducted in proximity of hazardous waste sites, studies in proximity of non-toxic waste landfills provide lower effect estimates. The main uncertainty of these studies is the completeness of data on birth defects, the use of distance from the sites for exposure classification, and the classification as toxic and non-toxic waste sites.

Respiratory diseases

A study conducted by Pukkala et al. [19] in Finland evaluated prevalence of asthma in relation to residence in houses built on a former dumping area containing industrial and household wastes. Prevalence of asthma was significantly higher in the dump cohort than in the reference cohort (living nearby but outside the landfill site). Unfortunately, this study has not been replicated and the overall evidence may be considered inadequate.

Studies of landfills workers

Only one study on landfill workers was reviewed. Gelberg et al. [29] conducted a cross-sectional study to examine acute health effects among employees working for the New York City Department of Sanitation, focusing on Fresh Kills landfill employees. Telephone interviews conducted with 238 on-site and 262 off-site male employees asked about potential exposures both at home and work, health symptoms for the previous six months, and other information (social and recreational habits, socio-economic status). Landfill workers reported a significantly higher prevalence of work-related respiratory, dermatological, neurologic and hearing problems than controls. Respiratory and dermatologic symptoms were not associated with any specific occupational title or task, other than working at the landfill, and the association remained, even after controlling for smoking status.

Studies of communities living near incinerators

Twenty-one epidemiologic studies conducted on residents of communities with solid waste incinerators have been reviewed and their characteristics are listed in the additional file 2.

Cancer

Eleven studies have been reviewed on cancer risk in relation with incinerators, usually old plants with high polluting characteristics. The studies are reported below by country.

In the United Kingdom, Elliott et al. [30] investigated cancer incidence between 1974 and 1987 among over 14 million people living near 72 solid waste incinerator plants. Data on cancer incidence among the residents, obtained from the national cancer registration programme, were compared with national cancer rates, and numbers of observed and expected cases were calculated after stratifying for deprivation, based on the 1981 census. Observed-expected ratios were tested for decline in risk up to 7.5 km away. The study was conducted in two stages: the first involved a stratified random sample of 20 incinerators and, based on the findings, a number of cancers were then further studied around the remaining 52 incinerators (second stage). Over the two stages of the study there was a statistically significant ($p < 0.05$) decline in risk with distance from incinerators for all cancers, stomach, colorectal, liver and lung cancer. The use of distance as the exposure variable in this study could have led to some degree of misclassification (--). On the other hand, the same authors observed that residual confounding (+) as well as misdiagnosis (+) might have increased the risk estimates. When further analyses were made, including a histological review of liver cancer cases [31], the risk estimates were lower (0.53-0.78 excess cases per 10^5 per year within 1 km, instead of 0.95 excess cases per 10^5 as previously estimated).

Using data on municipal solid waste incinerators from the initial study by Elliott et al. [30], Knox [32] examined a possible association between childhood cancers and industrial emissions, including those from incinerators. From a database of 22,458 cancer deaths that occurred in children before their 16th birthday between 1953 and 1980, he extracted 9,224 cases known to have moved at least 0.1 km in their life time, and using a newly developed technique of analysis, he compared distances from the suspected sources to the birth addresses and to the death addresses. The childhood-cancer/leukaemia data showed highly significant excesses of moves away from birthplaces close to municipal incinerators, but the specific effects of the municipal incinerators could not be separated clearly from those of nearby industrial sources of combustion. Misclassification of exposure is the main limit of this paper (--).

In France, Viel et al. [33] detected a cluster of patients with non-Hodgkin's lymphoma (NHL) and soft tissue sarcoma around a French municipal solid waste incinerator with high dioxin emissions. To better explore the environmental origin of the cluster suggested by these findings, Floret et al. [34] carried out a population-based case-control study in the same area, comparing 222 incident cases of NHL diagnosed between 1980 and 1995 and controls randomly selected from the 1990 census. The risk of developing lymphomas was 2.3 times higher among individuals living in the area with the highest dioxin concentration than among those in the area with the lowest concentration. Given that a model was used to attribute exposure to cases and controls, a random misclassification could have reduced the effect estimates (--). Based of these results, a nationwide study on NHL was conducted [35]. A total of 13 incinerators in France were investigated and dispersion modelling was used to estimate ground-level dioxin concentration. Information about the exposure levels and potential confounders was available at the census block level. A positive association between dioxin level and NHL was found with a stronger effect among females. Although the study represents an improvement regarding exposure assessment compared to investigations based on distance from the source, it should be noted that the analysis was conducted at the census block level and the possibility of misclassification of the exposure (-) as well as of residual confounding from socioeconomic status (+) remains.

Viel et al. [36] have recently reported the findings from a case-control study on breast cancer. There was no association or even a negative association between exposure to dioxin and breast cancer in women younger or older than 60 years, respectively, living near a French municipal solid waste incinerator with high exposure to dioxin. Design issues and residual confounding from age and other factors (---) limit the interpretations of the study.

In Italy, Biggeri et al. [37] conducted a case-control study in Trieste to investigate the relationship between multiple sources of environmental pollution and lung cancer. Based on distance from the sources, spatial models were used to evaluate the risk gradients and the directional effects separately for each source, after adjusting for age, smoking habits, likelihood of exposure to occupational carcinogens, and levels of air particulate. The results showed that the risk of lung cancer was inversely related to the distance from the incinerator, with a high excess relative risk very near the source and a very steep decrease moving away from it. The main problem of the study is the difficulty to separate the effects of other sources of pollution based on distance, and the possibility of potential confounding from other sources remains (++). An excess risk of lung cancer was also found in females living in two areas of the province of La Spezia (Italy) exposed to environmental pollution emitted by multiple sources, including an industrial waste incinerator [38]. Again in this study the limited exposure assessment could have decreased the risk estimates (--), but positive confounding from other sources is very likely.

A case-control study by Comba et al. [39] showed a significant increase in risk of soft tissue sarcomas associated with residence within two km of an industrial waste incinerator in the city of Mantua, with a rapid decrease in risk at greater distances. There is a slight likelihood that increased attention to the diagnosis for this form of cancer in the vicinity of the plant could have introduced a small bias (+) in the risk estimate. Another case-control study, carried out in the province of Venice by Zambon et al. [40] analyzed the association between soft-tissue sarcoma and exposure to dioxin in a large area with 10 municipal solid waste incinerators. The authors found a statistically significant increase in the risk of sarcoma in relation to both the level and the length of environmental modelled exposure to dioxin-like substances. The results were more significant for women than for men.

In summary, although several uncertainties limit the overall interpretation of the findings, there is limited evidence that people living in proximity of an incinerator have increased risk of all cancers, stomach, colon, liver, lung cancers based on the studies of Elliott et al. [30]. Specific studies on incinerators in France and in Italy suggest an increased risk for non-Hodgkin's lymphoma, and soft-tissue sarcoma.

Birth defects and reproductive disorders

Six studies examined reproductive effects of incinerator emissions (see additional file 2).

Jansson et al. [41] analysed whether the incidence of cleft lip and palate in Sweden increased since operation of a refuse incineration plant began. The results of this register study, based on information from the central register of malformations and the medical birth register, did not demonstrate an increased risk.

A study by Lloyd et al. [42] examined the incidence of twin births between 1975 and 1983 in two areas near a chemical and a municipal waste incinerator in Scotland: after adjusting for maternal age, an increased frequency of twinning in areas exposed to air pollution from incinerators was seen. In the same study areas, Williams et al. [43] investigated gender ratios, at various levels of geographical detail and using three-dimensional mapping techniques: analyses in the residential areas at risk from airborne pollution from incinerators showed locations with statistically significant excesses of female births.

To investigate the risk of stillbirth, neonatal death, and lethal congenital anomaly among infants of mothers living close to incinerators (and crematoriums), Dummer et al. [44] conducted a geographical study in Cumbria (Great Britain). After adjusting for social class, year of birth, birth order, and multiple births, there was an increased risk of lethal congenital anomaly, in particular spina bifida and heart defects.

Subsequently, Cordier et al. [45] studied communities with fewer than 50,000 inhabitants surrounding the 70 incinerators that operated for at least one year from 1988 to 1997 in France. Each exposed community was assigned an exposure index based on a Gaussian plume model, estimating concentrations of pollutants per number of years the plant had operated. The results were adjusted for year of birth, maternal age, department of birth, population density, average family income, and when available, local road traffic. The rate of congenital anomalies was not significantly higher in exposed compared with unexposed communities; only some subgroups of congenital anomalies, specifically facial cleft and renal dysplasia, were more frequent in the exposed communities.

Tango et al. [46] investigated the association of adverse reproductive outcomes with mothers living within 10 km of 63 municipal solid waste incinerators with high dioxin emission levels (above 80 ng international toxic equivalents TEQ/m^3) in Japan. To calculate the expected number of cases, national rates based on all live births, fetal deaths and infant deaths occurred in the study area during 1997-1998 were used and stratified by potential confounding factors available from the corresponding vital statistics records: maternal age, gestational age, birth weight, total previous deliveries, past experience of fetal deaths, and type of paternal occupation. None of the reproductive outcomes studied showed statistically significant excess within two km of the incinerators, but a statistically significant decline in risk with distance from the incinerators was found for infant deaths and for infant deaths with congenital anomalies, probably due to dioxin emissions from the plants.

In sum, there are multiple reports of increased risk of congenital malformations among people living close to incinerators but there are no consistencies between the investigated outcomes. The overall evidence may be considered as limited. The study by Cordier et al. [45] provides the basis for risk quantifications at least for facial cleft and renal dysplasia. Quantification for other reproductive disorders is more difficult.

Respiratory and skin diseases or symptoms

Four studies examined respiratory and/or dermatologic effects of incinerator emissions (see additional file 2).

Hsiue et al. [47] evaluated the effect of long-term air pollution resulting from wire reclamation incineration on respiratory health in children. 382 primary school children who resided in one control and three polluted areas in Taiwan were chosen for this study. The results revealed a decrement in pulmonary function (including forced vital capacity and forced expiratory volume in one second) of those residents in the vicinity of incineration sites.

Shy et al. [48] studied the residents of three communities having, respectively, a biomedical and a municipal incinerator, and a liquid hazardous waste-burning industrial furnace, and then compared results with three matched-comparison communities. After adjustment for several confounders (age, sex, race, education, respiratory disease risk factors), no consistent differences in the prevalence of chronic or acute respiratory symptoms resulted between incinerator and comparison communities. Additionally, no changes in pulmonary function between subjects of an incinerator community and those of its comparison community resulted from the study by Lee et al. [49], based on a longitudinal component from the Health and Clean Air study by Shy et al. [48].

Miyake et al. [50] examined the relationship between the prevalence of allergic disorders and general symptoms in Japanese children and the distance of schools from incineration plants, measured using geographical information systems. After adjusting for grade, socio-economic status and access to health care per municipality, schools closer to the nearest municipal waste incineration plant were associated with an increased prevalence of wheeze and headache; there was no evident relationship between the distance of schools from such plants and the prevalence of atopic dermatitis. The main factors that may have affected the relative risk estimates in this study could be reporting bias (++) and residual confounding from socioeconomic status (++).

In sum, although the intensive study conducted by Shy et al. [48] did not show respiratory effects, there are some indications of an increased risk of respiratory diseases, especially in children. However, the uncertainty related to outcome assessment and residual confounding is very high and the overall evidence may be considered inadequate.

Occupational studies on incinerator employees

Four studies conducted on incinerator employees were reviewed (see additional file 3).

In 1997, Rapiti et al. [51] conducted a retrospective mortality study on 532 male workers employed at two municipal waste incinerators in Rome (Italy) between 1962 and 1992. Standardized mortality ratios (SMRs) were computed using regional population mortality rates. Mortality from all causes resulted significantly lower than expected, and all cancer mortality was comparable with that of the general population. Mortality from lung cancer was lower than expected, but an increased risk was found for stomach cancer: analysis by latency since first exposure indicated that this excess risk was confined to the category of workers with more than 10 years since first exposure.

Bresnitz et al. [52] studied 89 of 105 male incinerator workers in Philadelphia, employed at the time of the study in late June 1988. Based on a work site analysis, workers were divided into potentially high and low exposure groups, and no statistically significant differences in pulmonary function were found between the two groups, after adjusting for smoking status.

A similar study was conducted by Hours et al. [53]: they analysed 102 male workers employed by three French urban incinerators during 1996, matched for age with 94 male workers from other industrial activities. The exposed workers were distributed into 3 exposure categories based on air sampling at the workplace: crane and equipment operators, furnace workers, and maintenance and effluent-treatment workers. An excess of respiratory problems, mainly daily cough, was more often found in the exposed groups, and a significant relationship between exposure and decreases in several pulmonary parameters was also observed, after adjusting for tobacco consumption and centre. The maintenance and effluent group, and the furnace group had elevated relative risks for skin symptoms.

In the same year, Takata et al. [54] conducted a cross-sectional study in Japan on 92 workers from a municipal solid waste incinerator to investigate the health effects of chronic exposure to dioxins. The concentrations of these chemicals among the blood of the workers who had engaged in maintenance of the furnace, electric dust collection, and the wet scrubber of the incinerator were higher compared with those of residents in surrounding areas, but there were no clinical signs or findings correlated to blood levels of dioxins.

In sum, there are some studies that suggest increased gastric cancer and respiratory problems among incinerators workers. However, there are a great number of uncertainties, which make it difficult to derive conclusions.

Epidemiological studies of health effects of other waste management processes

Twelve epidemiologic studies on the potential adverse health effects of other waste management practices are reviewed and listed in additional file 4.

Waste collection

Ivens et al. [55] investigated the adverse health effects among waste collectors in Denmark. In a questionnaire-based survey among 2303 waste collectors and a comparison group of 1430 male municipal workers, information on self-reported health status and working conditions was collected and related to estimated bioaerosol exposure. After adjusting for several confounders (average alcohol consumption per day, smoking status, and the psychosocial exposure measures support/demand), a dose-response relationship between level of exposure to fungal spores and self-reported diarrhoea was indicated, meaning that the higher the weekly dose, the more reports of gastrointestinal symptoms.

In contrast with these results, a study of 853 workers employed by 27 municipal household waste collection departments in Taiwan did not find an excess of gastrointestinal symptoms [56]. The workers answered a questionnaire and were classified into two occupational groups by specific exposures based on the reported designation of their specific task. The exposed group included those working in the collection of mixed domestic waste, front runner or loader, collection of separated waste and special kinds of domestic waste (paper, glass, etc.), garden waste, bulky waste for incineration, and the vehicle driver; the control group included accountants, timekeepers, canteen staff, personnel, and other office workers. No significant differences were found in the prevalence of gastrointestinal symptoms, but results indicated that all respiratory symptom prevalence, except dyspnoea, were significantly higher in the exposed group, after adjusting for age, gender, education, smoking status, and duration of employment.

Composting facilities

In a German cross sectional study by Bünger et al. [57], work related health complaints and diseases of 58 compost workers and 53 bio-waste collectors were investigated and compared with 40 control subjects. Compost workers had significantly more symptoms and diseases of the skin and the airways than the control subjects. No correction was performed for the confounding effect of smoking, as there were no significant differences in the smoking habits of the three groups.

A subsequent study in Germany by Herr et al. [58] examined the health effects on community residents of bio-aerosol, emitted by a composting plant. A total of 356 questionnaires from residents living at different distances from the composting site, and from unexposed controls were collected: self-reported prevalence of health complaints over past years, doctors' diagnoses, as was residential odor annoyance; microbiological pollution was measured simultaneously in residential outdoor air. Reports of airway irritation were associated with residency in the highest bio-aerosol exposure category, 150-200 m (versus residency >400-500 m) from the site, and periods of residency more than five years.

Bünger et al. [59] conducted a prospective cohort study to investigate, in 41 plants in Germany, the health risks of compost workers due to long term exposure to organic dust that specifically focused on respiratory disorders. Employees, exposed and not exposed to organic dust, were interviewed about respiratory symptoms and diseases in the last 12 months and had a spirometry after a 5-year follow-up. Exposure assessment was conducted at 6 out of 41 composting plants and at the individual level. Eyes, airways and skin symptoms were higher in compost workers than in the control group. There was also a steeper decline of Forced Vital Capacity among compost workers compared to control subjects, also when smoking was considered.

Materials recycling facilities

There are no epidemiological studies of populations living near materials recycling facilities; only studies on employees are available.

In the already-quoted study by Rapiti et al. [51] on workers at two municipal plants for incinerating and garbage recycling, increased risk was found for stomach cancer in employees who had worked there for at least 10 years, while lung cancer mortality risk was lower than expected.

In the study by Rix et al. [60], 5377 employees of five paper recycling plants in Denmark between 1965 and 1990 were included in a historical cohort, and the expected number of cancer cases was calculated from national rates. The incidence of lung cancer was slightly higher among men in production and moderately higher in short term workers with less than 1 year of employment; there was significantly more pharyngeal cancer among males, but this may have been influenced by confounders such as smoking and alcohol intake.

Sigsgaard et al. [61] conducted a cross-sectional study to examine the effect of shift changes on lung function among 99 recycling workers (resource recovery and paper mill workers), and correlated these findings with measurements of total dust and endotoxins. Exposure to organic dust caused a fall in FEV_1 over the work shift, and this was significantly associated with exposure to organic dust; no significant association was found between endotoxin exposure and lung function decreases.

The same authors [62] also analysed skin and gastrointestinal symptoms among 40 garbage handlers, 8 composters and 20 paper sorters from all over Denmark, and found that garbage handlers had an increased risk of skin itching, and vomiting or diarrhoea.

In a nationwide study, Ivens et al. [63] reported findings of self-reported gastrointestinal symptoms by self-reported type of plant. A questionnaire based survey among Danish waste recycling workers at all composting, biogas-producing, and sorting plants collected data on occupational exposures (including questions on type of plant, type of waste), present and past work environment, the psychosocial work environment, and health status. Prevalence rate ratios adjusted for other possible types of job and relevant confounders were estimated with a comparison group of non-exposed workers, and an association was found between sorting paper and diarrhoea, between nausea and work at plastic sorting plants, and non-significantly between diarrhoea and work at composting plants.

The health status of workers employed in the paper recycling industry was also studied by Zuskin et al. [64]. A group of 101 male paper-recycling workers employed by one paper processing plant in Croatia, and a group of 87 non-exposed workers employed in the food packing industry was studied for the prevalence of chronic respiratory symptoms, and results indicated significantly higher prevalence of all chronic respiratory symptoms were found in paper workers compared with controls.

Gladding et al. [65] studied 159 workers from nine materials recovery facilities (MRFs) in the United Kingdom. Total airborne dust, endotoxins, (1-3)-beta-D-glucan were measured, and a questionnaire-survey was completed. The results suggest that materials recovery facilities workers exposed to higher levels of endotoxins and (1-3)-beta-D-glucan at their work sites experience various work-related symptoms, and that the longer a worker is in the MRF environment, the more likely he is to become affected by various respiratory and gastrointestinal symptoms.

Choosing relative risk estimates for health impact assessment of residence near landfills and incinerators

The reviewed studies have been used to summarize the evidence available, as indicated in table 1. When the overall degree of evidence was considered "inadequate" we decided not to propose a quantitative evaluation of the relative risk; when we arrived to a conclusion that "limited" evidence was available, relative risk estimates were extracted for use in the health impact assessment process. Table 2 summarizes the relevant and reliable figures for health effects related to landfills and incinerators. For each relative risk the distance from the source has been reported as well as the overall level of confidence of the effect estimates based on an arbitrary scale: very high, high, moderate, low, very low.

Landfills

From the review presented above and following the work already made by Russi et al. [11], it is clear that the studies on cancer are not sufficient to draw conclusions regarding health effects near landfills, both with toxic and non-toxic wastes. The largest study conducted in England by Jarup et al. [21] does not suggest an increase in the cancer types that were investigated. Investigations of other chronic dis-

Table 1: Summary of the overall epidemiologic evidence on municipal solid waste disposal: landfills and incinerators.

Health effect	**Level of evidence**	
	LANDFILLS	**INCINERATORS**
All cancer	Inadequate	Limited
Stomach cancer	Inadequate	Limited
Colorectal cancer	Inadequate	Limited
Liver cancer	Inadequate	Limited
Larynx cancer	Inadequate	Inadequate
Lung cancer	Inadequate	Limited
Soft tissue sarcoma	Inadequate	Limited
Kidney cancer	Inadequate	Inadequate
Bladder cancer	Inadequate	Inadequate
Non Hodgkin's lymphoma	Inadequate	Limited
Childhood cancer	Inadequate	Inadequate
Total birth defects	Limited	Inadequate
Neural tube defects	Limited	Inadequate
Orofacial birth defects	Inadequate	Limited
Genitourinary birth defects	Limited*	Limited**
Abdominal wall defects	Inadequate	Inadequate
Gastrointestinal birth defects§	Inadequate	Inadequate
Low birth weight	Limited	Inadequate
Respiratory diseases or symptoms	Inadequate	Inadequate

"*Inadequate*": available studies are of insufficient quality, consistency, or statistical power to decide the presence or absence of a causal association.
"*Limited*": a positive association has been observed between exposure and disease for which a causal interpretation is considered to be credible, but chance, bias, or confounding could not be ruled out with reasonable confidence.
* Hypospadias and epispadias
** Renal dysplasia
§ The original estimates were given for "surgical corrections of gastroschisis and exomphalos"

Table 2: Relative risk estimates for community exposure to landfills and incinerators

Health effect	Distance from the source	Relative Risk (Confidence Interval)	Level of confidence**
Landfills			
Congenital malformations [24]			
All congenital malformations	Within 2 km	1.02 (99% CI = 1.01-1.03)	Moderate
Neural tube defects	Within 2 km	1.06 (99% CI = 1.01-1.12)	Moderate
Hypospadias and epispadias	Within 2 km	1.07 (99% CI = 1.04-1.11)	Moderate
Abdominal wall defects	Within 2 km	1.05 (99% CI = 0.94-1.16)	Moderate
Gastroschisis and exomphalos*	Within 2 km	1.18 (99% CI = 1.03-1.34)	Moderate
Low birth weight [24]	Within 2 km	1.06 (99% CI = 1.052-1.062)	High
Very low birth weight	Within 2 km	1.04 (99% CI = 1.03-1.06)	High
Incinerators			
Congenital malformations [45]			
Facial cleft	Within 10 km	1.30 (95% CI = 1.06-1.59)	Moderate
Renal dysplasia	Within 10 km	1.55 (95% CI = 1.10-2.20)	Moderate
Cancer [30]			
All cancer	Within 3 km	1.035 (95% CI = 1.03-1.04)	Moderate
Stomach cancer	Within 3 km	1.07 (95% CI = 1.02-1.13)	Moderate
Colorectal cancer	Within 3 km	1.11 (95% CI = 1.07-1.15)	Moderate
Liver cancer	Within 3 km	1.29 (95% CI = 1.10-1.51)	High
Lung cancer	Within 3 km	1.14 (95% CI = 1.11-1.17)	Moderate
Soft-tissue sarcoma	Within 3 km	1.16 (95% CI = 0.96-1.41)	High
Non-Hodgkin's lymphoma	Within 3 km	1.11 (95% CI = 1.04-1.19)	High

*The original estimates were given for "surgical corrections of..". **The following scale for the level of confidence has been adopted: very high, high, moderate, low, very low.

eases are lacking, especially of respiratory diseases, yet there is one indication of an increased risk of asthma in adults [19], but with no replication of the findings. Overall, the evidence that living near landfills may be associated with health effects in adults is inadequate.

A slightly different picture appears for congenital malformations and low birth weight, where limited evidence exists of an increased risk for infants born to mothers living near landfill sites. The relevant results come from the European EUROHAZCON Study [23] and the national investigation from Elliott et al. [24]. In the UK report, statistically significant higher risk were found for all congenital malformations, neural tube defects, abdominal wall defects, surgical correction of gastroschisis and exomphalos, and low and very low birth weight for births to people living within two km of the sites, both of hazardous and non-hazardous waste. Although several alternative explanations, including ascertainment bias, and residual confounding cannot be excluded in the study, Elliott et al. [24] provide quantitative effect estimates whose level of confidence can be considered as moderate.

Incinerators

Quantitative estimates of excess risk of specific cancers in populations living near solid waste incinerator plants were provided by Elliott et al. [30]. We have reported in table 2 the effect estimates for all cancers, stomach, colon, liver, and lung cancer based on their "second stage" analysis. There was an indication of residual confounding from socioeconomic status near the incinerators and a concern of misdiagnosis among registrations and death certificates for liver cancer. The histology of the liver cancer cases was reviewed, re-estimating the previously calculated excess risk (from 0.95 excess cases 10^{-5}/year to between 0.53 and 0.78 excess cases 10^{-5}/year). We then graded the confidence of the assessment for these tumours as "moderate" with the exception of liver cancer (high) since the misdiagnosis was reassessed and the extent of residual confounding was lower. In the study by Elliott et al. [30] no significant decline in risk with distance for non-Hodgkin's lymphoma and soft tissue sarcoma was found. However, the studies of Viel et al. [33] and Floret et al. [34] conducted in France and the studies from Comba et al. [39] and Zambon et al. [40] in Italy provide some indications that an excess of these forms of cancers may be related to emissions of dioxins from incinerators. As a result, we provided effect estimates in table 2 also for non-Hodgkin's lymphoma and soft tissue sarcoma as derived from the conservative "first stage" analysis conducted by Elliott et al. [30]. We graded the level of confidence of these relative risk estimates as "high".

With regards to congenital malformations near incinerators, Cordier et al. [45] provided effect estimates for facial cleft and renal dysplasia, as they were more frequent in the "exposed" communities living within 10 km of the sites. Other reproductive effects, such as an effect on twinning rates or gender determination, have been described; however the results are inadequate.

Conclusions

We have conducted a systematic review of the literature regarding the health effects of waste management. After the extensive review, in many cases the overall evidence was inadequate to establish a relationship between a specific waste process and health effects. However, at least for some associations, a limited amount of evidence has been found and a few studies were selected for a quantitative evaluation of the health effects. These relative risks could be used to assess health impact, considering that the level of confidence in these effect estimates is at least moderate for most of them.

Most of the reviewed studies suffer from limitations related to poor exposure assessment, aggregate level of analysis, and lack of information on relevant confounders. It is clear that future research into the health risks of waste management requires a more accurate characterization of individual exposure, improved knowledge of chemical and toxicological data on specific compounds, multi-site studies on large populations to increase statistical power, approaches based on individuals rather than communities and better control of confounding factors.

List of abbreviations used

EU: European Union; INTARESE: Integrated Assessment of Health Risks of Environmental Stressors in Europe; NHL: non-Hodgkin's Lymphoma; OR: Odds ratio; TEQ: Toxic Equivalent.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

DP participated in the design of the study, conducted the systematic review and drafted the manuscript. SM conducted the systematic review and contributed to draft the manuscript. AIL participated in the systematic review and contributed to draft the manuscript. CAP helped to conceive of the study and to write and revise the manuscript. FF conceived and coordinated the study and helped to write and revise the manuscript. All authors have read and approved the final manuscript.

Additional material

Additional file 1

***Studies on landfills**. The data provided represent a brief description of the studies on populations living near landfills.*
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[http://www.biomedcentral.com/content/supplementary/1476-069X-8-60-S1.XLS]

Additional file 2

***Studies on incinerators**. The data provided represent a brief description of the studies on populations living near incinerators.*
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Additional file 3

***Studies on occupational exposures among incinerators and landfills workers**. The data provided represent a brief description of the studies on workers of waste management plants.*
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[http://www.biomedcentral.com/content/supplementary/1476-069X-8-60-S3.XLS]

Additional file 4

***Studies on other waste management processes**. The data provided represent a brief description of the studies on population living near plants using waste management technologies different from landfills and incinerators.*
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Health Effects of Residence Near Hazardous Waste Landfill Sites: A Review of Epidemiologic Literature

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This review evaluates current epidemiologic literature on health effects in relation to residence near landfill sites. Increases in risk of adverse health effects (low birth weight, birth defects, certain types of cancers) have been reported near individual landfill sites and in some multisite studies, and although biases and confounding factors cannot be excluded as explanations for these findings, they may indicate real risks associated with residence near certain landfill sites. A general weakness in the reviewed studies is the lack of direct exposure measurement. An increased prevalence of self-reported health symptoms such as fatigue, sleepiness, and headaches among residents near waste sites has consistently been reported in more than 10 of the reviewed papers. It is difficult to conclude whether these symptoms are an effect of direct toxicologic action of chemicals present in waste sites, an effect of stress and fears related to the waste site, or an effect of reporting bias. Although a substantial number of studies have been conducted, risks to health from landfill sites are hard to quantify. There is insufficient exposure information and effects of low-level environmental exposure in the general population are by their nature difficult to establish. More interdisciplinary research can improve levels of knowledge on risks to human health of waste disposal in landfill sites. Research needs include epidemiologic and toxicologic studies on individual chemicals and chemical mixtures, well-designed single- and multisite landfill studies, development of biomarkers, and research on risk perception and sociologic determinants of ill health. *Key words*: epidemiology, hazardous waste, health effects, landfill, residence, review. — *Environ Health Perspect* 108(suppl 1):101–112 (2000).
http://ehpnet1.niehs.nih.gov/docs/2000/suppl-1/101-112vrijheid/abstract.html

The disposal of wastes in landfill sites has increasingly caused concern about possible adverse health effects for populations living nearby, particularly in relation to those sites where hazardous waste is dumped. Studies on the health effects of landfill sites have been carried out mainly in North America and existing reviews focus entirely on this literature (*1,2*). Recent publications of large studies both in and outside North America warrant an update of evidence presented in previous reviews. Up-to-date knowledge about epidemiologic evidence for potential human health effects of landfill sites is important for those deciding on regulation of sites, their siting and remediation, and for those whose task it is to respond to concerns from the public in a satisfactory way.

We intend to present a critical discussion of all major epidemiologic studies published since 1980 on health effects related to residence near landfill sites in North America, Europe, and elsewhere. Special attention is paid to recent studies and studies outside the United States that have not been included in previous reviews.

Methods

Throughout this review the term landfill is used for any controlled or uncontrolled disposal of waste to land. Relevant papers were found through computerized literature searches on MEDLINE (MEDLINE Database, National Library of Medicine, Bethesda, MD) (*www.biomednet.com*) and BIDS Databases, Joint Information Systems Committee, University of Bath, Bath, UK (*www.bids.ac.uk*) from 1980 through to 1998 using keywords "landfill" and "hazardous waste site." In addition, articles were traced through references listed in previous reviews. All papers found in this manner that studied health effects in residents near waste landfill sites and that were published in journals available through the British Library and libraries of the University of London were included in this review. A few papers referred to in previous reviews could not be traced because they were published in local journals in the United States. Published reports of recent studies that have not yet appeared in peer-reviewed journals have been included in the review. A few abstracts of European studies have been included, although full research papers of these studies have not been published because they reflect growing concerns about landfill in Europe. A total of 50 papers, reports, and abstracts are reviewed in this article. Investigations of the health risks to those employed in the handling, transport, clean-up, or maintenance of substances at landfill sites are very scarce and have not been included in this review. Many chemicals or groups of chemicals potentially present in landfill sites, including organic solvents, polychlorinated biphenyls (PCBs), and heavy metals, have shown adverse effects on human health or in animal experiments. A discussion of findings from either epidemiologic or toxicologic research on health effects related to specific chemicals is beyond the scope of this review.

Epidemiologic Studies on Health Effects of Landfill Sites

The majority of studies evaluating possible health effects in human populations living near landfill sites investigate communities near one specific waste disposal site (single-site studies), frequently in response to concerns from the public about reported contamination from the site or reported clusters of disease. A small number of studies have addressed the risks of living near waste sites, independent of whether the sites caused concern, by a priori specifying a number of sites for study. These will be referred to as multisite studies. Single- and multisite studies have different methodologic problems and are therefore discussed separately in this paper. Most individual studies are discussed in detail in this article. Where appropriate due to common methodologic issues (e.g., in studies of self-reported health outcomes and clusters of disease) or due to a common landfill site of concern (e.g., in the Love Canal studies and Santa Clara County studies), less emphasis was put on individual studies and more on common issues. Studies included in the review are summarized in Table 1 (single-site studies) and Table 2 (multisite studies). Discussion of individual single- and multisite studies is preceded by a discussion of issues common to the interpretation of all landfill studies.

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Table 1. Single-site studies.

Ref.	Study design	Study subjects	Exposure measure	Health outcomes studied	Reported findings
(7)	Geographical comparison	Love Canal census tract; comparison: New York State	Residence in Love Canal census tract	Cancer: liver, lymphomas, leukemia, other organ sites	No increased incidence
(8)	Cross-sectional	46 exposed residents; comparison: residents in adjacent census tract	Residence in houses where chemicals were detected	SCEs and CAs	No difference in frequency of chromosome changes
(9)	Cross-sectional	523 Love Canal children; 440 control children	Proximity to site; at least 5 months' residence in Love Canal area	Self-reported health problems: seizures, learning problems, hyperactivity, eye irritation, skin rashes, abdominal pain, and incontinence	Increased prevalence of all symptoms
(10)	Cross-sectional	428 Love Canal children; 493 control children	Born in Love Canal and more than 75% of life in Love Canal	Children's stature, weight, weight for stature	Shorter stature for Love Canal children. No difference in weight
(11)	Retrospective follow-up	174 births near site; 443 live births in rest of Love Canal area; all births in New York State	Residence in Love Canal area	LBW	Higher percentage of LBW in exposed area; excess in period of active dumping
(12)	Retrospective follow-up	239 exposed children; 707 unexposed	Residence in Love Canal area during pregnancy	LBW, birth defects	3-fold risk of LBW (homeowners only); increased risk for birth defects (homeowners and renters)
(26)	Retrospective follow-up	2,092 births in proximate area; 6,840 births in control area	Residence at birth in area closest to landfill	Average birth weight, LBW, preterm birth	Significantly lower average birth weight, higher proportion of LBW and prematurity during the time of heaviest pollution
(14)	Retrospective follow-up	25,216 births	Residence in census tract, proximate zone, and frequency of odor complaints	LBW, fetal mortality, infant mortality, prematurity	No difference over entire study period; moderate decrease in birth weight in high odor complaint zone in period of highest exposure
(27)	Case–control	7,977 LBW cases; 7,856 control births	Residence in areas adjacent to landfill and level of estimated exposure to landfill gas	LBW, very LBW, preterm birth, small for gestational age	Excess in LBW and small for gestational age births; no excess in very LBW or preterm birth
(21)	Geographical comparison	Residents of Montreal Island	Residence in areas adjacent to landfill and level of estimated exposure to landfill gas	Cancers of 17 organ sites for men; 20 organ sites for women.	Increase in incidence of stomach, liver, lung and prostate cancer for men, stomach and cervix–uteri cancer for women.
(15)	Cross-sectional	51 residents of exposed village incl. 11 children and 52 control persons	Residence in exposed village	SCEs	Higher frequency of SCEs in exposed population, particularly in children
(28)	Cross-sectional	47 children from exposed village; 45 unexposed children	Residence in exposed village and time of exposure	Chromosomal changes	Chromosome damage frequency returned to background levels after site remediation
(29)	Geographical comparison	Cancer deaths and birth defects compared to Pennsylvania and U.S.	Residence in counties surrounding waste site, incl. Clinton county, PA	Bladder cancer and cancers of other organ sites; birth defects	Increase in bladder cancer deaths in Clinton; increase in number of other cancers in Clinton and 3 surrounding counties; no excess in birth defects.
(16)	Cross-sectional	179 long-term exposed residents; 151 residents in comparison areas	Residence in area near waste site	14 self-reported diseases; 15 self-reported symptoms	Increased prevalence of skin problems and sleepiness
(17)	Cross-sectional	1,049 exposed; 948 unexposed residents	Residence in household close to site	36 self-reported health problems	Increased prevalence of minor respiratory symptoms (wheezing, cough, persistent cold), irregular heart beat, fatigue, bowel complaints
(30)	Retrospective follow-up	614 exposed households; 636 comparison households	Residence within 750 m of edge of site: long-/short-term residence	Self-reported health problems	Increased prevalence of mood disorders, narcotic symptoms, skin and respiratory disorders, eye problems, muscle weakness
(31)	Cross-sectional	403 exposed households; 203 comparison households	Residence in proximate area	19 self-reported diseases, 23 symptoms; mortality, cancer incidence, LBW, birth defects, spontaneous abortions	Increase in majority of self-reported diseases and symptoms. No significant association for mortality, cancer morbidity, reproductive effects
(32)	Cross-sectional	257 residents in exposed zones; 105 in comparison area	Distance based zones: zone 1: < 300 m zone 2: 300–1,000 m	Self-reported diseases and symptoms, miscarriages, stress levels	Increased reporting of majority of symptoms, miscarriages, stress
(18)	Follow-up survey	57 high-, 66 low-, 70 unexposed residents	Exposure zones based on odor zones	22 self-reported health problems	2-fold increase in 64% of reported symptoms
(33)	Cross-sectional	321 high-exposed persons; 351 persons with low/minimal exposure	Cumulative exposure index based on distance from sites and amount of chemicals present at sites	29 self-reported health problems	Excess in reporting of 11 of 29 symptoms: mainly neurologic symptoms

(Continued)

Table 1. *Continued.*

Ref.	Study design	Study subjects	Exposure measure	Health outcomes studied	Reported findings
(*34*)	Cross-sectional	456 exposed residents; 481 comparison persons	Residence near site	14 self-reported health problems	Increased reporting of 11 of 14 symptoms.
(*19*)	Retrospective follow-up	694 residents	Individual exposure index based on concentration of pollutants and daily activity of study subjects	Amount of prescribed medication for selected diseases (respiratory, ophthalmologic, dermatologic, gastrointestinal, neurologic)	No relationship between individual exposure index and drug consumption
(*20*)	Case–control	432 cases; 384 controls	Individual exposure index based on concentration of pollutants and daily activity of study subjects	Dermatologic, respiratory, eye, gastrointestinal diseases, psychologic disorders and other conditions	Relationship between exposure level and existing cases of respiratory and psychologic conditions
(*38*)	Geographical comparison	Three counties adjacent to waste dump compared to whole region	Communities near dump; distance of community to dump	Leukemia, multiple myeloma, malignant lymphoma	Excess in leukemia incidence
(*39*)	Geographical comparison	Ward surrounding landfill compared to whole region	Residence in landfill ward, surrounding wards, area downwind from landfill	All childhood cancers	No excess of childhood cancer
(*40*)	Geographical comparison	5 wards near landfill compared to 22 wards elsewhere	Wards near landfill	Mortality rates, hospital admissions for asthma, cancer, and other conditions, spontaneous abortions, birth defects, drug prescriptions	No consistent differences in mortality rates, hospital admissions, spontaneous abortions. Excess in birth defects before and after start of the landfill. Increase in prescriptions for certain medications
(*41*)	Geographical comparison	Cancer rates in 8 counties in Illinois compared to national rates	Residence in town with contaminated wells	Bladder cancer	Excess in bladder cancer in town with contaminated wells
(*44*)	Geographical comparison	Woburn cancer rates compared to national rates	Residence in Woburn	Childhood leukemia	More than 2-fold excess in childhood leukemia
(*45*)	Case–control	20 leukemia cases; 164 control children	Exposure index based on fraction of water supply in household from contaminated wells	Childhood leukemia	Significant association with exposure index
(*45*)	Retrospective follow-up	4,396 pregnancies; 5,018 children under 18	Exposure index based on fraction of water supply in household from contaminated wells	Childhood disorders; adverse pregnancy outcomes: spontaneous abortions, perinatal death, LBW, birth defects	Increase in eye/ear anomalies, CNS/ chromosomal/cleft anomalies; perinatal deaths; kidney/urinary tract disorders, lung/respiratory disorders
(*46*)	Cross-sectional	28 family members of leukemia cases; 30 healthy controls	Being a family member of a Woburn leukemia case	Immunologic abnormalities, medical examination	Immunologic abnormalities in family members
(*47*)	Retrospective follow-up	Births in exposed census tracts compared to births in the entire county	Residence in census tract served by contaminated water supply	Congenital heart defects	2-fold excess in cardiac anomalies
(*48*)	Retrospective follow-up	Pregnancies in exposed census tract; pregnancies in unexposed census tract	Residence in census tract served by contaminated water supply	Spontaneous abortions, birth defects, LBW	Increase in spontaneous abortions and birth defects; no excess in LBW
(*49*)	Retrospective follow-up	Pregnancies in 2 exposed census tracts; pregnancies in 2 unexposed census tracts	Residence in 2 census tracts served by contaminated water supply	Spontaneous abortions, birth defects, LBW	No excess in spontaneous abortions or malformations in new exposed study area
(*50*)	Retrospective follow-up	Pregnancies in 2 exposed census tracts	% water in census tract from contaminated well; estimated concentration of solvents	Spontaneous abortions, birth defects	No relation between abortion or malformation rate and estimated exposure
(*51*)	Case–control	145 cases with cardiac malformations; 176 nonmalformed control births	Mother's consumption of home tap water	Congenital heart defects	Elevated risk for consumption of more than 4 glasses of tap water compared to none
(*52*)	Retrospective follow-up	349 pregnancies in 1 exposed and 1 unexposed census tract	Mother's consumption of home tap water	Spontaneous abortions, birth defects	Spontaneous abortions: significant trend with number of glasses tap water per day. Birth defects: no trend
(*53*)	Retrospective follow-up	1,016 pregnancies in exposed and unexposed areas	Mother's consumption of home tap water	Spontaneous abortions, birth defects, LBW	Spontaneous abortions: 7-fold risk for any versus no tap water. Birth defects: nonsignificant increase. No association with LBW
(*13*)	Cross-sectional and follow-up	49 exposed residents; 57 unexposed residents	Use of contaminated well water	Liver function	Abnormalities in liver function in exposed residents. Returned to normal 2 months later.
(*54*)	Cross-sectional	676 exposed residents; 778 unexposed residents	Residence in high-exposure area based on groundwater flow	Self-reported disease: cancer, liver disease, respiratory illness, skin disease, seizures	Statistically significant increase in respiratory disease and seizures, not significant after accounting for smoking
(*55*)	Cross-sectional	65 exposed residents; 66 residents from control households	Residence in households with contaminated well water	15 self-reported health symptoms; 14 self-reported diseases	Increased reporting of eye irritation, diarrhea, sleepiness.

Abbreviations: CAs, chromosomal aberrations; CNS, central nervous system; LBW, low birth weight; SCEs, sister chromatid exchanges.

Table 2. Multisite studies.

Ref	Study design	Study sties	Study subjects	Exposure measure	Health outcomes studied	Reported findings
(56)	Geographical comparison	593 NPL waste sites in U.S.	339 counties with waste site, more than 3,000 without	County with site	Cancer mortality	Increased rates of cancer of the lung, bladder, stomach, and rectum
(57)	Case–control	12 sites in New York State	339 deceased lung-cancer cases; 676 deceased controls	Residence in census tract with site; duration of residence	Lung cancer	No association
(58)	Case–control	38 sites with likely landfill gas migration in New York State	9,020 cancer cases; 9,169 deceased controls	Residence within 250 ft	Cancer of liver, lung, bladder, kidney and brain; non-Hodgkin lymphoma, leukemia	Excess of female bladder cancer and female leukemia
(59)	Case–control	300 sites in 1,072 census tracts in California	5,046 birth defects cases and 28,085 control births. 1,904,000 births for birth weight analysis	Residence in census tract with site and potential for human exposure	Birth defects, LBW	1.5-fold increase in risk of heart defects. Other malformations and birth weight not associated
(60)	Case–control	1,281 NPL sites in U.S.	17,407 births	Residence within 1 mile	Birth weight, birth defects, fetal deaths, infant deaths	No association between adverse pregnancy outcomes and living near a NPL site
(61)	Case–control	590 waste sites in New York State	9,313 live births with birth defects; 17,802 normal control births	Residence within 1 mile and hazard score of site	Birth defects	Increased risk for all malformations (12%), integument system, nervous system, musculoskeletal. Indications for dose–response relation with exposure risk
(62)	Case–control	643 waste sites in New York State	473 cases with central nervous system defects; 3,305 musculoskeletal cases; 12,436 control births	Ratings of exposure probability within 1 mile of each site	Central nervous system defects and musculo-skeletal defects	No association between two types of and proximity to waste sites
(64)	Case–control	317 waste sites in New York State	259 cases of end-stage renal disease and 259 controls	Residence within 1 mile, exposure probability; years of residence within 1 mile	End-stage renal disease	Nonstatistically significant increase in risk of renal disease for ever living within 1 mile, having lived within 1 mile for more than 12 years, and a medium/high probability of exposure
(65)	Case–control	105 NPL and 659 non-NPL sites in California	507 neural tube defects, 517 controls; 210 heart defects, 439 oral clefts, and 455 controls	Census tracts: no site, non-NPL site, NPL site; residence within 1 mile and residence within 1/4 mile	Birth defects: neural tube defects, heart defects, and oral clefts	No increased risks relating to residence in census tract with site. Small, nonsignificant increase in risk of NTD and heart defects for living within 1/4 mile
(66)	Case–control	21 sites in 5 European countries	1,089 cases with non-chromosomal birth defects; 2,366 control births	Residence within 3 km	Birth defects	Increased risk for all malformations (33%), NTD, cardiac defects

NTD, neural tube defect.

Issues Common to the Interpretation of Landfill Studies

A general problem in epidemiologic studies of landfill sites, whether studying single or multiple sites, is that there is insufficient information regarding potential human exposures from landfill sites. Although landfill sites are numerous and widespread, very few have been evaluated with respect to both the types of chemicals they contain and the extent to which they may be releasing chemicals. Most such work has been conducted in the United States under the Superfund program (*3*). In other countries, information is largely lacking. Moreover, although chemicals have been found to migrate off site at a number of sites that have been thoroughly investigated (*2*), we know very little about the extent to which residents living near a site are exposed to these chemicals. A few studies that have attempted to measure certain chemicals in blood and urine of populations near waste sites have generally not found increased levels of volatile organic compounds (VOCs) (*4*), mercury (*5*), or PCBs (*6*). Because knowledge of whether and to what extent substances from waste sites reach the human population is still largely lacking, and because resources are rarely available to carry out extensive exposure measurements or modeling, epidemiologic studies have based the assessment of exposure to landfills mainly on surrogate measures such as residence in an area close to a waste site or distance of residence from a waste site. The use of such surrogate, indirect exposure measurements can lead to misclassification of exposure which, if not different for diseased and nondiseased persons, will decrease the sensitivity of the study to find a true effect.

In addition to being hampered by insufficient exposure data, the study of landfill exposures is complicated by the fact that if residential populations are exposed to chemicals from landfill sites, it will generally be to low doses of mixtures of chemicals over long periods of time. Associations with such low-level environmental exposures in the general population are by their nature hard to establish. Low-dose exposures are generally expected to generate small increases in relative risk that will be difficult to distinguish from noise effects introduced by confounding factors and biases.

In most of the landfill studies reviewed in this article, residents near waste sites are studied without knowledge of the exact route(s) of exposure to chemicals from the site. Migration of hazardous substances into groundwater is often an important environmental concern in relation to landfill sites, which may represent a public health problem, especially when a site is located near aquifers supplying public drinking water. However, in many situations the drinking water supply of residents near waste sites does not originate from the local area. For people living in the vicinity of these sites, other routes of exposure may be of more concern. Landfill sites may be a source of airborne chemical contamination via the off-site migration of gases and via particles and chemicals adhered to dust, especially during the period of active operation of the site. Very little is known about the likelihood of air exposure from landfill sites through landfill gases or dust. At some of the sites described below, low levels of volatile organic chemicals have been detected in indoor air of homes near landfill sites (*7–13*), in outdoor air in areas surrounding sites (*14–20*) or in on-site landfill gas (*21*). Other possible routes of exposure include contamination of soil, ground, and surface water, which may lead to direct contact or pollution of indoor air in the case of evaporation of VOCs into basements of nearby houses. Contamination via the food chain may sometimes be of concern for nearby residents in the case of consumption of home-grown vegetables. Drinking water is a possible route of exposure only if water for domestic use is locally extracted. If this is the case, other domestic water uses (bathing, washing) may also lead to exposure via inhalation of evaporated VOCs and/or direct contact (*13*).

Some issues related to specific health outcomes should be noted in both single- and multisite studies. A general problem in studies of cancer incidence is the long latency period between exposure and clinical manifestation of the cancer. Studies may not always allow for a long enough latency period, which reduces their power to pick up long-term effects. Moreover, because of the long latency period, a considerable number of people may have migrated into or out of the exposed areas between time of exposure and time of diagnosis, which will lead to misclassification of exposures. Studies of chromosome changes (chromosome aberrations and sister chromatid exchanges) are undertaken with the assumption that such changes are related to the mechanisms underlying cancer and possibly birth defects. Chromosomal changes are studied as biomarkers of early response or effect of exposure to mutagenic and carcinogenic chemicals. Sorsa et al. (*22*) point out that theoretically it is reasonable to assume that chromosome damage is directly related to cancer etiology, but the number of agents clearly shown to induce such damage in humans is still limited. Increased frequencies of chromosome changes may indicate exposure to mutagens and carcinogens, but it is not clear at present how well they predict cancer risk. Low birth weight is thought to be relatively sensitive to effects of chemical exposures (*23*). It is also relatively easy to collect accurate information on birth weight from birth certificates. However, a large number of risk factors are associated with low birth weight (including smoking, socioeconomic status, nutritional factors, parental height) (*24*), and these may act as confounding factors, giving biased estimates of association with residence close to a site. Birth defects have fewer established risk factors than other reproductive outcomes such as low birth weight, and studies of birth defects may therefore be less affected by confounding factors, although unknown risk factors could still play a confounding role. Also, birth defects represent an etiologically very heterogeneous set of conditions; analyses of the total malformation rate (all defects combined) have the advantage of larger numbers but may not be sensitive enough to pick up increases in risk of specific defects. The grouping of malformations into groups that are etiologically similar is difficult because of lack of knowledge on causes of specific defects. Grouping therefore always entails a compromise between large enough numbers and etiologic specificiry.

Single-Site Studies

The investigation of single landfill sites has been important as a response to community concerns; many of the single-site studies discussed below are prompted by public concerns, often under considerable political pressure. This means that they are prone to recall and reporting biases that may weaken the investigations and partly explain increases in reported health outcomes. Single-site studies have examined a vast range of possible health outcomes, often without a specific disease hypothesis being proposed a priori. Such "fishing expeditions" are thought to be of less scientific value than studies that start with a clear hypothesis (*1*). Including these fishing expeditions in evaluating the consistency of findings across multiple studies is important nevertheless when assessing evidence for health risks.

A less avoidable problem in single-site studies is that the size of populations living near waste sites generally is small and, especially when the outcome is a rare disease, this can seriously limit the statistical power of an investigation.

Single-site studies discussed in this section are grouped into those examining hard end points such as cancer and reproductive outcomes, those studying self-reported health outcomes and symptoms, those following up reported clusters of disease near landfill sites with geographic comparisons of disease rates, and those specifically investigating the contamination of well water used for drinking or other domestic uses in relation to health effects. These last studies were discussed separately to determine whether conclusions can be drawn about specific pathways of exposure.

Studies of cancers, reproductive outcomes, and chromosomal damage. Large quantities of toxic materials (residues from pesticide production) were dumped at the landfill of Love Canal, New York State, during the 1930s and 1940s, followed by the building of houses and a school on and around the landfill in the 1950s. By 1977 the site was leaking and chemicals were detected in neighborhood creeks, sewers, soil, and indoor air of houses. This led to one of the most widely known and publicized incidents of environmental pollution from landfill. Exposure of Love Canal residents, although not well understood, may have occurred via inhalation of volatile chemicals in home air or via direct contact with soil or surface water (*10*). The drinking water supply was not contaminated. Chemicals detected at Love Canal were primarily organic solvents, chlorinated hydrocarbons and acids, including benzene, vinyl chloride, PCBs, dioxin, toluene, trichloroethylene, and tetrachloroethylene. Several studies were conducted to detect whether Love Canal residents suffered adverse health effects.

Janerich et al. (*7*) compared cancer incidence for the Love Canal area with data for the entire state from 1955 to 1977 and found no increase in cancer rates at Love Canal for any organ site. This included leukemia, lymphoma, and liver cancer, which were thought to be the cancers most likely to result from exposures to the chemicals found at the site. The study is limited in that no information was available on confounding factors such as socioeconomic status and smoking. Subsequently, Heath et al. (*8*) compared the frequencies of chromosome changes (sister chromatid exchanges and chromosomal aberrations) in residents who lived in the first ring of houses adjacent to Love Canal in 1978 with those of control persons from socioeconomically similar census tracts. No differences in frequencies of chromosome damage were found. Chromosome changes were measured in 1981 and 1982, a few years after people were evacuated from the first ring of houses and therefore were no longer exposed. The authors point out that chromosome damage may be a reversible effect, which may explain the negative findings.

Infants and children have been the subject of other Love Canal studies. A cross-sectional study (*9*) reported an increased prevalence of seizures, learning problems, hyperactivity, eye irritation, skin rashes, abdominal pain, and incontinence in children living close to the Love Canal site compared to controls from other areas, as reported by the parents of the children. It has been noted in previous reviews (*1,25*) that this study was conducted in 1980, 2 years after the residents of Love Canal had become aware of the hazardous waste problem, when media and public interest were high, and people were being evacuated. This makes it likely that the results were biased by differential reporting of health problems. However, a similar population of children (spending 75% or more of their childhood in the Love Canal area) had significantly shorter stature for their age than control children after allowing for factors such as birth weight, socioeconomic status, and parental height (*10*). Vianna and Polan (*11*) found an excess of low birth weights (less than 2500 g) during the period of active dumping (1940–1953) in areas of Love Canal where exposure had been highest. Rates of low birth weight between 1960 and 1978 after the site had been closed were comparable to those in upstate New York as a whole. It is not clear whether exposure from Love Canal was highest during the active dumping period or during the period after the site was closed, when the building of houses near the site increased and the landfill was leaking. A study by Goldman et al. (*12*) reported a 3-fold risk of low birth weight for children exposed during gestational life to the Love Canal area compared to that for control children born elsewhere from 1965 to 1978. Data were analyzed separately for homeowners and renters so that groups of similar socioeconomic status were compared, and after allowing for confounding factors, the risk of low birth weight was significantly increased for homeowners only. This finding is difficult to interpret because there are no strong reasons to believe that homeowners would be more susceptible than renters to the effects of toxic chemicals. In the same study an increased risk of birth defects was observed for both homeowners and renters. Information on birth defects relied mainly on reports from parents. Some recall bias can therefore be suspected, in particular for defects of lesser severity, but this is unlikely to account for the entire association found for major birth defects.

Berry and Bove (*26*) studied birth weight at the Lipari Landfill in New Jersey, a site for municipal and industrial waste. Leachate from the site migrated into nearby streams and a lake adjacent to a residential area. Inhalation of volatile chemicals emitted from the landfill and contaminated waters was thought to be the most important exposure pathway. The site closed in 1971 after complaints of residents, but the heaviest pollution was estimated to have occurred during the late 1960s to the mid-1970s. The study found a convincing increase in proportion of low birth weight babies (< 2500 g) and a lower average birth weight in the population living closest (within a radius of 1 km) to the landfill in the time period when potential for exposure was thought to be greatest (1971–1975) compared to these factors in a control population. Although information on some confounding variables such as smoking, alcohol consumption, and socioeconomic status was not available, mothers in the exposed area were more highly educated and therefore appeared to be of higher socioeconomic status. One would expect higher birth weights in areas of higher socioeconomic status, so as the authors point out, confounding by socioeconomic status does not explain the lower birth weights found. In time periods before and after heavy dumping and off-site pollution, birth weights were higher in the area closer to the site than in the control area, which supports the hypothesis that pollution from the waste site may have been related to low birth weights in the community close to the site.

A range of reproductive effects including low birth weight was studied around the large BKK hazardous waste disposal site in Los Angeles County, California (*14*), after previous investigations of vital records found that trends in low birth weight and neonatal deaths corresponded closely with times and quantities of dumping at the landfill. Results for the whole study period showed no increase in adverse reproductive effects, but during the period of heaviest dumping, birth weights were significantly lower in exposed areas than in control areas using odor complaint frequency zones to classify exposure. All results were adjusted for education, income, and race. The decrease in mean birth weight found in the high-odor complaint zone was small (59 g) compared to that in the Lipari Landfill study (192 g) and was less than a third of birth-weight reductions caused by smoking during pregnancy (*26*). Odor complaint frequency zones corresponded better with vinyl chloride monitoring data and meteorology around the site than did census tract areas or distance-based (< 0.7 miles) exposure zones, and this was therefore thought to be the most accurate method for classifying exposure. Using census tract or distance-based exposure zones, smaller decreases in mean birth weight were found (35.2 g, p = 0.02 and 20.4 g, p = 0.25, respectively).

Miron Quarry, a large (the third largest in North America) municipal solid waste site in Montreal, Quebec has prompted studies on both reproductive outcomes (low birth weight and preterm births) (*27*) and cancers (*21*). Gas from the site was the main environmental and health concern and a range of VOCs, including a number of recognized or suspected human carcinogens, had been detected in the gas. An excess of 20% in low birth weight was found among babies of mothers who were living in the high-exposure area adjacent to the landfill at the time of delivery, taking account of confounding factors such as education and age of the mother. No excess was found in the low-exposure zone compared to a control area. Exposure zones were based on proximity to the site and accounted for the direction of dominant winds. Control areas were selected that were similar to exposure areas on a number of sociodemographic variables so as to limit the potential for confounding. The cancer study used the same exposure zones and control areas and increases were found in incidences of cancers of the stomach, liver, prostate, and lung for men, and stomach and cervix/uterus for women. Incidences of cancers of other organ sites were not increased in the exposed areas. Age and sex were the only confounders that could be controlled for directly and the authors admit that area matching for sociodemographic factors was based on fairly broad zones. The landfill started operation in 1968 and cancer incidence was studied between 1981 and 1988, which allowed a maximum latency of only 20 years among those residents in the area throughout the period.

In Mellery, Belgium, gases containing a complex mixture of VOCs escaped when the clay seal of a landfill site cracked. Because some of the detected chemicals were known mutagens and/or carcinogens, damage to chromosomes was studied and an increase in chromosome damage (sister chromatid exchanges) was found among Mellery residents but not in unexposed subjects in subgroups of both smokers and nonsmokers (*15*). In children 8–15 years of age, a more marked difference was found between exposed and unexposed groups than among adults. The findings indicated exposures similar to those of occupationally exposed populations. The adult unexposed comparison subjects were recruited from a volunteer blood donor list and may therefore have comprised a group with risk behavior and exposure to possible risk factors for chromosome damage different from those of the general population. They also reported less occupational exposure than the Mellery inhabitants. It is unclear how occupational exposure was defined and results have not been adjusted for it. A follow-up study after site remediation reduced the concentration of the atmospheric pollutants to background levels reported that chromosomal damages in Mellery children had returned to background levels and were no longer different from those for unexposed populations (*28*).

At the Drake Superfund Site, an industrial chemical dump in Pennsylvania, widespread on- and off-site contamination of groundwater, soil, and surface water with organic (benzene, chlorinated benzene, phthalates) and inorganic (arsenic, mercury) compounds prompted a cancer mortality and birth defects study (*29*) and a community health survey (*16*). Air monitoring near the site identified a small number of organic compounds, but the main exposure route was thought to be direct contact with surface waters and soil in recreational areas near the site. Budnick et al. (*29*) found an increase in mortality from bladder cancer (cancer of primary a priori concern because of aromatic amines detected on and off site) in the male population of one of the counties surrounding the waste site compared to average mortality rates in the entire state and the United States. Bladder cancer in females did not show such an effect. The authors point out that an occupational effect for males working in the Drake chemical plant may explain the fact that the association was found in men only. No excess in risk of birth defects was found. The subsequent health survey (*16*) found increased reporting of sleepiness and skin problems in the exposed community and concluded that it was difficult to say whether toxic chemicals from the site, overreporting of symptoms by the exposed community (reporting bias), or other factors such as stress and occupational exposure caused these symptoms.

Studies of self-reported health symptoms. A number of other community health surveys have investigated a wide range of health problems, including respiratory symptoms; irritation of skin, nose, and eyes; gastrointestinal problems; fatigue; headaches; psychological disorders; and allergies. These studies have been conducted in response to concerns from the public, often triggered by smells and odors from the sites. In a number of studies, self-reported health problems were increased in exposed populations (people living close to the waste sites) compared to control populations [Drake Superfund Site (*16*); Lowell, Massachusetts (*17*); Hamilton, Ontario (*30*); Stringfellow, California (*31*); Queensland, Australia (*32*); McColl waste site, California (*18*); Houston, Texas (*33*); Harris County, Texas (*34*)] (see Table 1 for details). The majority of these health surveys rely on residents reporting symptoms and diseases through questionnaires or interviews. The possibility exists that higher reporting rates of symptoms in exposed areas are at least partly explained by reporting and/or recall biases. From a public health point of view, the findings of high symptom reporting, whether or not due to differential self-reporting, may indicate the impact that stress and concerns related to landfill can have on ill health and/or perceived ill health. In the survey by Ozonoff et al. (*17*), residents who indicated they were worried about neighborhood pollution reported more symptoms than those who were not worried, both in the exposed and the control area. Although this does not eliminate the possibility of an effect of toxic chemicals from the site, it suggests that stress and/or recall bias may have been responsible for the findings. Miller and McGeehin (*34*) and Dunne et al. (*32*) found increased symptom prevalence only in residents who indicated they were worried about, or aware of, an environmental problem in their neighborhood. The study by Lipscomb et al. (*18*) showed a 2-fold risk in most symptoms for residents who were worried compared to those who were not worried among the exposed population. The authors concluded that being worried, rather than a toxicologic effect from the site, explained the symptoms. Hertzman et al. (*30*) used medical records to confirm certain symptoms and found no over- or underreporting. They concluded that this finding indicated limited reporting bias; however, only a small proportion of the respondents' records were reviewed. Moreover, seeing a physician (and therefore having a medical record) may itself be related to concerns about the site. Baker et al. (*31*) studied self-reported health problems as well as mortality, cancer incidence, and pregnancy outcomes from medical registers at the Stringfellow waste dump in California. Self-reported diseases and symptoms were the only outcomes that differed between exposed and unexposed areas. Again, a higher perception of threat was related to a higher risk of nearly all self-reported symptoms.

The complicated relation between worry, odor perception, and symptom reporting related to hazardous waste landfill sites is further discussed by several authors (*35–37*).

Two recent studies around the French landfill of Montchanin used records of prescribed medication (*19*) and cases from general practitioners (GPs) (*20*) to define health outcome, in order to avoid biases related to self-reporting of symptoms. Exposure classification in both studies was based on an individual index, taking into account the concentration of airborne pollutants and daily activities of study subjects. High concentrations of VOCs were detected in areas near the site and both leachates and air from the site were reported to be highly toxic in 1988 and 1989, shortly after site closure. Consumption of drugs prescribed for most conditions from 1987 to 1989 did not show a trend with exposure level, although a slight trend was found for drugs taken for ear, nose, and throat, and pulmonary conditions. In the second study, patients with conditions thought to be associated with dump emissions were compared to other GP patients and an association was found for respiratory symptoms and psychological disorders. Again, consulting a doctor for such conditions and subsequent diagnosis of the conditions by the physician may be related to fears of adverse effects from the landfill rather than to toxic chemical effects.

Cluster Investigations. In addition to the above papers, a number of reports are available of geographical comparison studies initiated after high rates (clusters) of specific diseases were reported in the vicinity of landfill sites. For example, increased rates of leukemia found in communities nearest a toxic waste dump in North-Rhine Westfalia, Germany, supported a GP report of a cluster near the site (*38*). A cluster of childhood cancer reported by residents near a landfill site in Walsall, England, was not confirmed in a geographical comparison of rates in the ward containing the site to expected rates based on the regional average (*39*). Only short reports of these two investigations have been published.Concerns from residents and a GP about increased rates of congenital abnormalities (specifically gastroschisis, a defect in the abdominal body wall) among the population living near the Welsh landfill of Nant-y-Gwyddon were supported by the finding that rates of congenital abnormalities in exposed wards were almost 1.9-fold those in unexposed wards over the period from 1990 to 1996 (*40*). However, rates in the exposed wards were already high (1.9-fold those of unexposed wards) between 1983 and 1987 before the site opened, and it is unlikely, therefore, that these increased rates were due to the landfill. Four cases of confirmed gastroschisis indicated a significant 9-fold excess in rates of gastroschisis among exposed wards between 1989 and 1996. A cluster of bladder cancer cases in one town in Illinois in the United States, was observed by researchers and subsequently linked to the presence of two contaminated wells close to a landfill site (*41*).

A general problem in the interpretation of all cluster investigations is that localized areas of high disease density may occur even as part of a random pattern of disease. It is difficult to distinguish clusters derived from this random pattern from those where there is a common underlying local cause (*42,43*). Also, areas with higher disease densities, although part of the random pattern of disease, may be selectively picked for study.

Studies of drinking water contamination incidents. The presence of chemicals in groundwater and drinking water is an important factor in determining the risk posed by landfill sites. However, it does not tell us what effect, if any, the consumption of contaminated water has on human health. Studies of adverse health effects prompted by the contamination of well water used for drinking water and other domestic uses by hazardous substances from waste disposal sites (mainly sites where chemical waste drums were buried) are discussed below. Literature on contaminated water and potential health effects is more extensive than that presented in this section, which focuses only on water contamination directly related to the disposal of waste. The 1991 review by the National Research Council (*2*) gives a more comprehensive review of studies on contamination of domestic water supplies and health effects and concludes that although the available literature is scanty and not conclusive, drinking water contamination could lead to adverse health effects. Most of the studies summarized below have been discussed extensively in previous reviews (*1,2*).

In Woburn, Massachusetts, toxic chemicals (industrial solvents, mainly trichloroethylene) from a waste disposal site were detected in municipal drinking water wells. Residents of Woburn reported a cluster of 12 leukemia cases in children, and a first study confirmed that this number was significantly higher than expected on the basis of national rates (*44*). The problems with cluster analyses are discussed above. Because of lack of information on exposure to the contaminated wells, it was not possible in this first report to link the leukemia cases with exposure to the well water. Lagakos et al. (*45*) followed up these findings by compiling an exposure score for residential zones in Woburn using information on what fraction of the water supply in each zone had come from the contaminated wells annually since the start of the wells. Childhood leukemia incidence, perinatal deaths, congenital anomalies, and childhood disorders were studied in relation to the exposure scores. A significant excess was found again comparing leukemia rates for Woburn with national rates, and an association was found between leukemia incidence and exposure scores. The pregnancy outcome survey found associations with eye/ear congenital anomalies and central nervous system/oral cleft/chromosomal anomalies (mostly Down syndrome) but not with low birth weight or most childhood disorders. Pregnancy outcomes were self-reported in this study, but because residents were not aware of their exact exposure scores, the authors conclude that it is unlikely that this led to substantial differential overreporting. Byers et al. (*46*) undertook a study of 28 family members of patients with leukemia in Woburn. Damage to the immune and nervous systems was found in exposed relatives but not in unexposed controls. Exposure in this study was not measured by exposure to contaminated well water but by being related to a leukemia patient in Woburn, which makes it difficult to interpret the findings. The authors point out that it is impossible to say whether the association is due to an inherited predisposition or to a common environmental exposure of family members to agents that damage the immune system.

A number of studies followed the contamination of two drinking-water wells in Santa Clara County, California, with chlorinated solvents that had leaked from an underground waste storage tank. Residents living near one of the contaminated wells reported a cluster of adverse pregnancy outcomes, mainly spontaneous abortions and congenital heart defects. A first investigation (*47*) confirmed a significant excess of cardiac anomalies in the service area of the water company that operated the contaminated well compared to those among residents of an unexposed area. The excess was found within the potentially exposed time period and not in an unexposed time period after the well was closed. The authors conclude that the solvent leak was an unlikely explanation for the excess of cardiac anomalies found because the excess occurred mainly in the first 12 months of the exposed time period, and there was a significant ($p = 0.03$) deficit of cases during the second 8 months corresponding to the time when exposure was thought to be more certain. However, it is unclear when the leak started and the potentially exposed period was defined beforehand as the full 20-month period. A second study in the same area reported an increased risk of all congenital malformations combined and spontaneous abortions (*48*). A follow-up study including a second exposed area did not observe an increase in either outcome in this second area, even though it was thought to have the same water exposure as the original area (*49*). An exposure study estimating monthly concentrations of solvents in each census tract found no difference in probability of exposure between women with adverse pregnancy outcomes and women with normal births (*50*). Subsequent studies investigating water consumption in Santa Clara County report significant associations between reported tap water consumption and risk of cardiac defects (*51*) and spontaneous abortions (*52,53*), regardless of whether women lived in areas that received contaminated water. As the authors of these studies point out, recall biases cannot be excluded.

In Hardeman County, Tennessee, well water used as drinking water by residents was found to be contaminated with high concentrations of carbon tetrachloride and other chlorinated compounds after complaints were received about the taste of the water. A nearby landfill where 300,000 barrels of pesticide waste had been buried was responsible for the contamination. Analysis of indoor air and bathroom air while showers were running both indicated detectable levels of carbon tetrachloride and other organic compounds in houses that received water from the contaminated wells. Carbon tetrachloride has been identified in toxicologic studies as a strong liver toxin. The investigation, conducted several months after the population had stopped using the water for drinking, showed abnormally high levels of liver enzymes (indicating liver damage) in residents who had used contaminated water compared to controls, who had not (*13*). The authors concluded that these high liver enzyme levels probably resulted mainly from exposure due to washing and toilet water uses, and possibly from previous exposure through drinking and cooking. Two months later, when use of the well had completely stopped, liver function in the exposed population had returned to normal. This study benefited from relatively well-documented exposure information and a clear hypothesis about the possible health effects (i.e., liver disease) related to exposure to carbon tetrachloride.

Leakage from an industrial dump of chemical waste drums in New Jersey caused contamination of groundwater and well water with organic chemicals (including benzene, toluene, trichloroethylene, and lead). Najem et al. (*54*) found higher self-reported prevalence of respiratory disease and seizures but not cancer, liver illness, and skin disease in people living in a high-exposure area estimated on the basis of groundwater flow patterns. Residents in the high-exposure area used private drinking-water wells, ate home-grown food, and smoked more often than populations living in unexposed areas, and when these factors were adjusted for, differences in health outcomes disappeared. Adjusting for possible exposure routes such as local food consumption and use of private wells may have led to overadjustment, however, which would explain why no differences in health outcome were found.

An ex-military base in Dauphin County, Pennsylvania contained drums of toxic chemicals, fly ash, and other waste; well water for homes located on the perimeter of the site was contaminated with trichloroethylene, PCBs, pesticides, and other chemicals (*55*). Residents were instructed to stop using the water. Higher rates of eye irritation, diarrhea, and sleepiness were reported by residents of households with contaminated well water than by residents of households not having contaminated water.

Multisite Studies

The problems with single-site studies prompted by community pressures have increasingly been recognized, and recently several large studies have investigated adverse health effects near sets of hundreds of sites selected independently of community concerns or reported disease clusters (Table 2). These studies have the additional advantage of large numbers of subjects, which would give them enough statistical power to detect small increases in risk of rare diseases such as birth defects and specific cancers. On the other hand, their large scale makes exposure assessment even more complicated than in single-site studies, as adequate information must be collected for each of many sites. A number of the studies discussed below have used the U.S. National Priority Listing (NPL) of hazardous waste sites developed by the U.S. Environmental Protection Agency (U.S. EPA) to select their sites. The NPL ranks all hazardous waste sites in the United States deemed to be of considerable threat to the environment or public health. NPL sites have been relatively well assessed with respect to the potential or actual migration of hazardous chemical substances from the sites through groundwater, surface water, and air (*2*). Most multisite studies, however, were not able to distinguish between different types and pathways of contamination and, in absence of better exposure data, based their assessments of exposure on distance of residence from the sites or residence in an area with a site. Exposure misclassification, if nondifferential, may be expected to dilute true effects in these investigations. Multisite studies mainly investigated cancers and reproductive outcomes.

Cancer studies. Griffith et al. (*56*) identified 593 NPL sites over the entire United States where contamination of groundwater used for drinking water had been detected by laboratory analyses. Cancer mortality rates for counties containing one or more of these NPL sites were compared to those for counties not containing sites and raised levels of lung, bladder, stomach, and rectum cancer were found. These results were not adjusted for confounding factors such as socioeconomic status and smoking and are therefore difficult to interpret.

A case–control study in New York State (*57*) examined lung-cancer in relation to residence in a census tract with a waste site. Twelve waste sites known to contain suspected lung carcinogens were studied. A questionnaire survey among next of kin of the deceased cases and controls attempted to collect information on factors such as smoking, diet, education, and residential history. Smoking was significantly more frequent among cases, but there was no association between having lived in or duration of living in an exposed census tract and risk of lung cancer. Low response rates (around 60%) and possible recall bias limit this study.

A recent study in New York State (*58*) investigated cancer risks near 38 landfills where migration of landfill gas through soil was likely. Migration of soil gas could result in indoor exposure in nearby houses to hazardous VOCs carried with the landfill gas. Potential exposure areas were defined around each site, and extended 250 ft from the landfill at 36 sites and 500 ft at 2 sites. Incident cases of cancer collected from the New York State Cancer Registry were compared with a random selection of deaths from causes other than cancer, matched by age and sex. Only cancers of the liver, lung, bladder, kidney, and brain, and non-Hodgkin lymphoma and leukemia were studied, as they were regarded potentially sensitive to chemical exposures. Statistically significant excesses in the defined exposure areas were reported only for bladder cancer in women and leukemia in women. The results were adjusted for sociodemographic characteristics of the areas of residence. No information was available on individual factors such as smoking or on how long cases and controls had been living at certain addresses. The use of deceased controls makes interpretation of this study extremely complicated. The deceased population from which controls were selected may differ from the population from which the cases were drawn on a number of variables, including their residence locations.

Studies of reproductive outcomes. Shaw et al. (*59*) conducted a study on the risk of congenital malformations and low birth weight in areas with landfills, chemical dump sites, industrial sites, and hazardous treatment and storage facilities in the San Francisco Bay, California area. Census tracts were classified as *a*) no hazardous site in area, *b*) hazardous site in area but no evidence of human exposure, and *c*) hazardous site and plume in the area with evidence of potential human exposure. A small increase (1.5-fold) in risk was found for heart and circulatory malformations in the areas with potential human exposure. This increased risk was present across chemical classes and exposure routes. Risk of other malformations or low birth weight was not significantly increased. Results were adjusted for some potential risk factors (maternal age, race, sex of child, birth order) but not for socioeconomic status.

Reproductive outcomes have been studied in a number of other multisite studies. Sosniak et al. (*60*) investigated the risk of adverse pregnancy outcomes for people living within 1 mile of a total of 1,281 NPL sites over the entire United States. The risk for low birth weight and other pregnancy outcomes (infant and fetal death, prematurity, and congenital anomaly) was not associated with living near a site after taking into account a large number of potential confounding factors, including socioeconomic variables collected through questionnaires. However, only around 63% of women originally sampled for the study returned the questionnaire and were included in the study. Also, it is unclear how congenital anomalies were defined, and no subgroups of malformations were studied.

Geschwind et al. (*61*) investigated the risk of congenital malformations in the vicinity of 590 hazardous waste sites in New York State. A 12% increase in congenital malformations was found for people living within 1 mile of a site. For malformations of the nervous system, musculoskeletal system, and integument (skin, hair, and nails), higher risks were found. Some associations between specific malformation types and types of waste were evaluated and found to be significant. A dose–response relationship (higher risks with higher exposure) was reported between estimated hazard potential of the site and risk of malformation, adding support to a possible causal relationship. However, a follow-up study of Geschwind's findings (*62*) found no relation between two selected types of malformations (central nervous system and musculoskeletal) and living near a hazardous waste disposal site. The study did report an increased risk of central nervous system defects for those living near solvent- or metal-emitting industrial facilities. Subjects for the first 2 years of this study were also included in Geschwind's study, and 2 more years were studied. Marshall et al. (*62*) attempted to improve the exposure measurement in the first study by assessing the probability of specific contaminant–pathway combinations in 25 sectors of the 1-mile exposure zones (*63*). The risk of particular pathways or contaminant groups could not be investigated, however, because of limited numbers of cases in each subgroup. Hall et al. (*64*) used the same method of exposure assessment to study renal disease near 317 waste sites in 20 counties in New York State. Increased risks were found for associations between renal disease and residential proximity to a site (within 1 mile), the number of years lived near a site, and a medium or high probability of exposure, although the associations did not reach statistical significance.

A study by Croen et al. (*65*) based exposure measurement on both residence in a census tract containing a waste site and distance of residence from a site. Three specific types of birth defects (neural tube defects [NTDs], heart defects, and oral clefts) were studied; little or no increase in the risk was found using either measure of exposure. Risks of neural tube (2-fold) and heart defects (4-fold) were increased for maternal residence within 1/4 mile of a site, although numbers of cases and controls were too small (between 2 and 8) for these risk estimates to reach statistical significance. Births were ascertained from nonmilitary-base hospitals only, and the authors point out that the increased risk of NTDs may have resulted from lower ascertainment of exposed controls than exposed cases where exposure zones included military bases. Military base residents with pregnancies affected by NTDs may have been more likely to deliver in nonmilitary hospitals than residents with unaffected pregnancies.

A first European multisite study recently reported a 33% increase in all nonchromosomal birth defects combined for residents living within 3 km of 21 hazardous waste sites in 10 European regions (*66*). Neural tube defects and specific heart defects showed statistically significant increases in risk. Confounding factors such as maternal age and socioeconomic status did not readily explain the results. The study included both open and closed sites that ranged from uncontrolled dumps to relatively modern controlled operations. This disparity makes it difficult at this stage to conclude, if indeed the association is causal, whether risks are related to landfill sites in general or whether specific types of sites may be posing the risks.

Conclusions

The presence of large quantities of mixtures of potentially hazardous chemicals in landfill sites close to residential populations has increasingly caused concern. Concerns have led to a substantial number of studies on the health effects associated with landfill sites. From this review we can conclude that increases in risk of adverse health effects have been reported near individual landfill sites and in some multisite studies. Although biases and confounding factors cannot be excluded as explanations for these findings, the findings may indicate real risks associated with residence near certain landfill sites.

For several reasons, evidence is limited for a causal role of landfill exposures in the health outcomes examined despite the large number of studies. Effects of low-level environmental exposure in the general population are by their nature difficult to establish. Also, existing epidemiologic studies are affected by a range of methodologic problems, potential biases, and confounding factors, making the interpretation of both positive (statistically significant increase in risk) and negative (no increase in risk) findings difficult (*67*). Lack of direct exposure measurement and resulting misclassification of exposure affects most studies and can limit their powers to detect health risks.

It is possible that studies not showing associations have been less likely to be included in this review because they may have been less likely to be submitted or selected for publication, thereby causing the review to be biased toward studies that did report positive associations. However, a number of so-called negative studies have been published and included in this review. We feel that most large, good-quality, epidemiologic investigations, particularly those starting with an a - priori hypothesis rather than a specific cluster, would have resulted in publication, whether or not the findings were positive.

An increase in self-reported health outcomes and symptoms such as headaches, sleepiness, respiratory symptoms, psychological conditions, and gastrointestinal problems has been found consistently in health surveys around sites where local concerns were evident (*9,16–18,30–34,54,55*). In these health surveys symptoms were usually reported by the exposed population without further confirmation of the diagnoses by medical examination. It is not possible at this stage to conclude whether the symptoms are an effect of direct toxicologic action of chemicals present in waste sites, an effect of stress and fears related to the waste site, or an effect of reporting bias (the tendency of exposed people to remember and report more symptoms than unexposed people). Several authors have discussed the possibility that odor complaints and related worry about a site may trigger symptoms of stress-related disease or lead to an increased awareness of existing symptoms (*36,37*). Further research in this area is urgently needed to improve our understanding of the impact of social factors and risk perceptions on both actual and perceived ill health in waste site communities. Issues of environmental equity and environmental justice must form an integral part of such research.

Evidence for a causal relationship between landfill exposures and cancers is still weak. Cancers are difficult to study because of long latency periods, as discussed in previous sections. Also, cancer studies have mainly compared incidence or mortality rates between geographic areas without collecting adequate information on confounding factors. Excesses in bladder, lung, and stomach cancer and leukemia were reported in more than one study (*21,29,41,45,56,58*). Well-designed studies with long follow-up and good quality information about confounding factors such as smoking are needed to confirm these findings.

A number of studies have suggested a relationship between residential proximity to landfill sites and adverse pregnancy outcomes. An increase in infants with low birth weights has been the most consistent finding in single-site studies (*11,12,14,26,27*). These were generally well-designed studies and low birth weight is thought to be a sensitive marker of effects of chemical exposures. Small increases in the risk of birth defects and certain specific birth defects (cardiac defects, central nervous system defects, musculoskeletal defects) have been reported, mainly in multisite studies (*12,59,61,65,66*). Studies are still too few, however, to draw conclusions regarding causality. Fetuses, infants, and children are generally thought to be more vulnerable and therefore experience toxic effects at lower doses than the adult population (*25*). The finding of shorter stature in Love Canal children (*10*) may also be an example of this.

An increased presence of chromosomal changes was reported in the vicinity of a landfill site in Mellery, Belgium (*15,28*), but not in Love Canal (*8*). Findings in Mellery were related to children in particular, which may again be an indication that children are more susceptible to low-level exposures from waste sites. It is not clear at present how well chromosomal changes predict cancer risk in humans.

Other adverse health outcomes such as abnormalities in liver function (*13*) and in renal disease (*64*) have also been reported in relation to hazardous waste exposure, although in single studies only.

For the future planning and regulation of landfill sites it is important to know which types of sites are most likely to entail risks. Landfill sites may differ enormously in the conditions that render them hazardous, and conditions that determine the exposure to and resulting health risks posed by any waste site are likely to be unique to that particular site. Such conditions may include the types, quantities, and age of the waste present; hydrogeologic and metereologic factors; and site management and engineering practices. We have not in this review attempted to relate technical aspects of waste disposal to health effects. Much of the existing epidemiologic work investigates large, old sites, uncontrolled dumps, and sites where heavy off-site migration of chemicals was detected. On the basis of current evidence, we cannot extrapolate findings for these individual sites to landfill sites in general or conclude which landfill sites are more likely than others to affect the health of nearby human populations.

It is also not possible to determine whether sites with airborne or waterborne exposures are more likely to pose a risk to human health. Although drinking water contamination is usually the primary concern related to landfill sites, in most cases local water supplies do not originate from the local area. Most studies, therefore, concern landfill sites where no local drinking-water wells were present and potential exposure was either airborne or through other routes such as direct contact and consumption of home-grown vegetables.

At present information regarding adverse health effects of exposure to landfill sites in European countries is largely lacking.

Further Research Needs

Research into the health effects of landfill sites is relatively immature, and further research could improve our current understanding (*1,2,25,68*). Future studies of landfill sites would greatly benefit from a more interdisciplinary approach, drawing from the fields of landfill engineering, environmental sciences, toxicology, and epidemiology.

Improvements in the base of toxicologic and epidemiologic data on effects of specific chemical exposures would improve our understanding of possible risks of the migration of these chemicals from landfill sites into the environment. Johnson and DeRosa (*69*), in a recent review of toxicologic hazards of Superfund waste sites, conclude that although a large body of toxicologic research is under way to assess the toxicity of chemicals commonly contaminating the environment surrounding waste sites, equally significant work is still to be done before these chemicals have adequate toxicity profiles that can be used by health and risk assessors. Johnson and DeRosa discuss data needs established by the Agency for Toxic Substances and Disease Registry and the U.S. EPA for research of individual chemicals and find these needs mainly in dose–response studies, reproductive studies, and immunotoxicology studies. Improved data on effects of individual chemical exposures would improve the quality of quantitative risk assessments that can be made for landfill exposures. However, quantitative risk assessments are based to a large extent on unverifiable assumptions, and therefore cannot negate the necessity for direct epidemiologic studies of people living near landfill sites.

More research into effects of chemical mixtures and possible interactions between single chemicals is needed to improve understanding of effects of multiple chemical exposures. Such research is complex, but new research initiatives are under way, mainly in the United States. For example, the U.S. EPA MIXTOX database, which contains toxicologic data on interactions of hundreds of pairs of chemicals, is a promising new development (*70*). Research developments and future directions in this field are discussed in detail by a number of authors (*70–72*).

The investigation of single landfill sites is important as a response to community concerns. More multisite studies with large study populations should also be conducted to draw conclusions about more general risks. Ideally, such multisite studies should attempt to classify sites in such a way that risks related to specific site characteristics can be investigated. However, systematic site assessments needed to underpin such classifications are at present totally lacking in Europe. There is little detailed information on waste inputs, especially for old landfills, and monitoring practices vary hugely for factors such as frequency of monitoring, the environmental media monitored, and types of chemicals monitored. Standardized waste-input recording systems and monitoring practices across European countries and the availability of summary reports of waste inputs and monitoring results would aid site classifications for epidemiologic studies as well as risk assessments. A recent report evaluating the use of a risk assessment tool on two U.S. and three U.K. landfill sites concluded that in the United Kingdom it is not possible to characterize the majority of landfills, even to the level at which a simple risk assessment framework can be employed on a site-specific basis. This particularly applies to the characterization of emplaced waste (*73*).

Epidemiology has increasingly made use of so-called biomarkers—biological monitors of either the internal dose of a chemical (biomarkers of exposure) or the biologic response to exposure (biomarkers of early effect). Biomarkers of the first type measure levels of chemicals in human tissue and fluids (e.g., blood, urine). These techniques can generally measure only a small number of chemicals, and their use is limited to situations in which environmental monitoring data indicate specific landfill chemicals that are of particular concern. The presence of chemicals in the body is currently difficult and costly to measure, but this may change. Biomarkers of the second type measure biological responses such as chromosomal changes (sister chromatid exchanges) and molecular changes (DNA adducts), and could be seen as early effect manifestations. Interpretation of these effect biomarkers is difficult; their link with clinically overt disease remains unclear, but their use could give studies much greater statistical power than studies of rare disease outcomes. Biomarker techniques have been used mainly in occupational settings and there has been less discussion of their use in environmental studies (*74,75*). Collaboration is required between epidemiologists and basic scientists to further develop biomarker techniques for use in studies of environmental exposures.

Specific areas of further research likely to prove most useful are

- The study of vulnerable groups—groups of the population likely to develop adverse health effects at levels of exposure lower than those of the general population. Such groups include: fetuses, infants, and children; elderly people; and people with impaired health.
- The study of people with higher exposures, for example, children (because they come into higher contact with potentially contaminated soil); people who eat local food products; workers at waste sites; people with life-styles (possibly socioeconomically determined) that lead to higher exposures.
- The study of worst-case landfills. In the absence of adequate exposure data, it is difficult to define worst-case sites. Ranking systems are in use, e.g., in the Superfund program (*76*), to rank waste sites according to their hazard potential, but their application generally requires extensive site investigations. Few epidemiologic studies would have the resources to carry out such investigations. It could be argued that identification of worst-case landfills should form part of regulatory practice in Europe. However, in the absence of systematic investigation of this kind, the study of sites where high off-site contamination has been detected and sites that have been subject to less regulation (possibly sites in developing countries or Eastern Europe) could be suitable for the study of worst-case scenarios provided appropriate health data can be collected.

It is possible with suitable investment to improve levels of understanding about risks of hazardous wastes to human health. However, because of the complicated nature of the exposure, it is likely that there will always remain a degree of uncertainty regarding health effects of landfill sites.

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Risk of adverse birth outcomes in populations living near landfill sites

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Abstract

Objective To investigate the risk of adverse birth outcomes associated with residence near landfill sites in Great Britain.

Design Geographical study of risks of adverse birth outcomes in populations living within 2 km of 9565 landfill sites operational at some time between 1982 and 1997 (from a total of 19 196 sites) compared with those living further away.

Setting Great Britain.

Subjects Over 8.2 million live births, 43 471 stillbirths, and 124 597 congenital anomalies (including terminations).

Main outcome measures All congenital anomalies combined, some specific anomalies, and prevalence of low and very low birth weight (< 2500 g and < 1500 g).

Results For all anomalies combined, relative risk of residence near landfill sites (all waste types) was 0.92 (99% confidence interval 0.907 to 0.923) unadjusted, and 1.01 (1.005 to 1.023) adjusted for confounders. Adjusted risks were 1.05 (1.01 to 1.10) for neural tube defects, 0.96 (0.93 to 0.99) for cardiovascular defects, 1.07 (1.04 to 1.10) for hypospadias and epispadias (with no excess of surgical correction), 1.08 (1.01 to 1.15) for abdominal wall defects, 1.19 (1.05 to 1.34) for surgical correction of gastroschisis and exomphalos, and 1.05 (1.047 to 1.055) and 1.04 (1.03 to 1.05) for low and very low birth weight respectively. There was no excess risk of stillbirth. Findings for special (hazardous) waste sites did not differ systematically from those for non-special sites. For some specific anomalies, higher risks were found in the period before opening compared with after opening of a landfill site, especially hospital admissions for abdominal wall defects.

Conclusions We found small excess risks of congenital anomalies and low and very low birth weight in populations living near landfill sites. No causal mechanisms are available to explain these findings, and alternative explanations include data artefacts and residual confounding. Further studies are needed to help differentiate between the various possibilities.

Introduction

Waste disposal by landfill accounts for over 80% of municipal waste in Britain.[1] Human exposure to toxic chemicals in landfill (which include volatile organic compounds, pesticides, solvents, and heavy metals[2–4]) may occur by dispersion of contaminated air or soil,[2] leaching or runoff,[5] or by animals and birds, although evidence for any substantial exposures is largely lacking.[6] Excess risks of congenital anomalies and low birth weight near landfill have been reported,[6–9] including from recent European and UK studies,[10 11] although some have reported less significant[12] or negative findings.[13] The aim of our present study was to examine risk of adverse birth outcomes associated with residence near landfill using data on all known sites in Great Britain.

Methods

Classification of populations near landfill sites

Data provided by the national regulatory agencies were merged in a geographical information system to give a database containing 19 196 sites. Data on boundaries were unavailable for most sites, so point locations had to be used. These comprised the site centroids for 70% of sites and, for the remainder, the location of the site gateway at the time of reporting. Data for site locations were of low accuracy (often rounded to 1000 metres), and data on area were inadequate to allow estimation of the extent of most sites. Landfill sites also change considerably over time as old areas are closed and new areas develop, while postcodes (used to define the location of cases and births) give only an approximation of place of residence, accurate to 10-100 metres in urban areas but > 1 km in some rural areas; also, landfill sites are highly clustered, so that individual postcodes may lie close to 30 or more sites. Therefore, distance from nearest landfill site was not regarded as a meaningful proxy for exposure. As a compromise between the need for spatial precision and the limited accuracy of the data, we constructed a 2 km zone around each site (figure), giving resolution similar to or higher than that of previous studies,[10 11] and at the likely limit of dispersion for landfill emissions.[14] Postcodes within the 2 km buffer zone were classified hierarchically by operational status, year on year, such that sites still operating took precedence over those closed earlier in the study period, which took precedence over sites opening later in the study period.[15] People living more than 2 km from all known landfill sites during the study period comprised the reference population.

Because of concerns about the quality of landfill data for earlier years, and because health data were available only to 1998, we excluded 9631 sites (25% of the population) that closed before 1982 or opened after 1997 (to allow a one year lag period for the birth outcomes) or for which there were inadequate data. The remaining 9565 sites comprised 774 sites for special (hazardous) waste, 7803 for non-special waste, and 988 handling unknown wastes. The 2 km surrounding these sites included 55% of the national population; 20% were included in the reference area.

Health and denominator data

We used national postcoded registers held by the Small Area Health Statistics Unit. These comprised the National Congenital Anomaly System in England and

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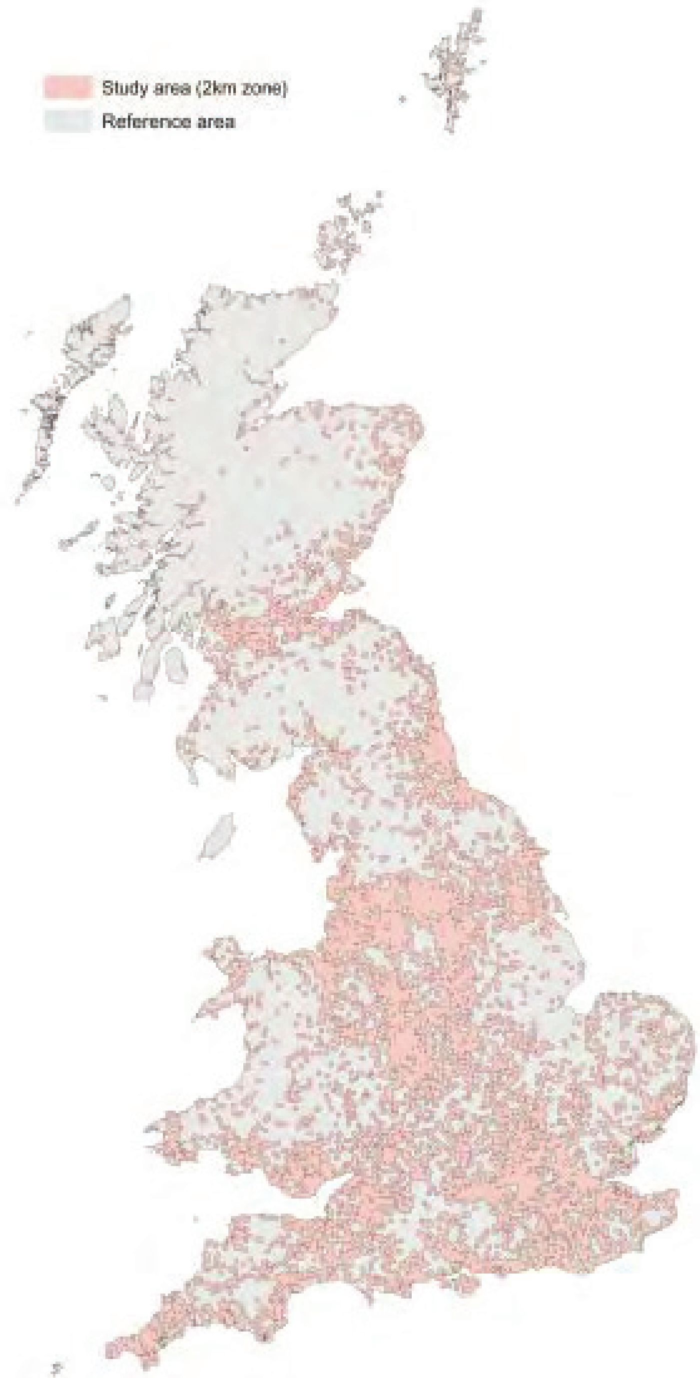

Map of Great Britain showing 2 km zones around landfill sites and reference area

Wales, 1983-98, and data on terminations, 1992-8, performed for "grounds E" of the 1967 Abortions Act ("where there is a substantial risk that if the child were born it would suffer from such physical or mental abnormality as to be seriously handicapped"); congenital anomaly and terminations data for Scotland, 1988-94; hospital admissions data for England and Scotland, 1993-8 (Welsh data were considered unreliable); and national births and stillbirths data, 1983-98.

Cases were coded to ICD-9 (international classification of diseases, ninth revision) from 1983 to 1994, and to ICD-10 thereafter. Outcomes were all congenital anomalies combined (ICD-9 740-59; ICD-10 Q00-Q99); neural tube defects (ICD-9 740.0-740.2, 741.0-741.9, 742.0; ICD-10 Q00.0-Q00.2, Q05.0-Q05.9, Q01.0-Q01.9); cardiovascular defects (ICD-9 745.0-747.9; ICD-10 Q20.0-Q28.9); abdominal wall defects (ICD-9 756.7; ICD-10 Q79.2-Q79.4); hypospadias and epispadias (ICD-9 752.6; ICD-10 Q54.0-Q54.9, Q64.0); surgical correction of hypospadias and epispadias (M731, M732); and surgical correction of gastroschisis and exomphalos (T281). Multiple anomalies were counted under each outcome (once only for all anomalies combined).

Surgical corrections (England and Scotland only) were analysed by date of birth, not date of surgical procedure. For hypospadias and epispadias, we included only procedures carried out before the age of 3 years, and, for gastroschisis and exomphalos, in the first year of life only. Low and very low birth weights were defined as <2500 g and <1500 g respectively. The relevant denominators and years of analysis are shown in table 1.

Statistical methods

We calculated risks for the population within 2 km of landfill relative to the reference population by indirect standardisation, assuming a common relative risk for all landfill sites. We used model predictions from Poisson regression of data from the reference area to provide standard rates. The regression function included year of birth, administrative region ($n=10$), sex (for birth weight and stillbirths), and deprivation. We obtained deprivation by assigning postcodes to tertiles of the national distribution of the Carstairs' deprivation index[16] based on 1991 census statistics at enumeration district level (we used tertiles rather than quintiles of the Carstairs index because of the small number of events for the rarer outcomes in the most deprived part of the reference area). We used a descending stepwise selection procedure starting from the fullest model including all possible interactions. This was repeated without deprivation, and then the two models were constrained (where necessary) to differ only in terms of deprivation (table 2). For the hospital admissions data (where there were fewer years), unadjusted and deprivation-adjusted results only were obtained, and no modelling was done.

Some degree of overdispersion and a widening of the confidence intervals is to be expected if our model assumptions fail to hold (for example, because of data anomalies, unmeasured confounding, or sampling variability of the rates). We therefore calculated Poisson 99% (rather than 95%) confidence intervals, but this does not necessarily ensure that all additional variability has been captured—we emphasise estimation of relative risks and their stability (or otherwise) to choice of model confounders rather than significance testing.

We assessed the sensitivity of our results to model choice by using an alternative model for each birth outcome (table 2). We also included urban or rural status and examined risks for rural areas only, and for birth weight (where data were sufficient) we examined sensitivity to the use of quintiles (rather than tertiles) of the Carstairs index. For abdominal wall defects, we also examined maternal age (<20 and $\geqslant 20$ years, available 1986-98 for England and Wales only).[17]

The main analysis identified at outset was for all landfill sites for the combined period during their

Table 1 Denominators and years for analyses of birth outcomes near landfill sites (within 2 km) and in reference area (⩾2 km from any site), and before opening and during operation and after closure for sites that opened during the study period

Analysis	Denominator	Years	All operating and closed sites by waste type: All	Special waste	Non-special waste	Reference area	Sites that opened during study period (all waste types) by operating status: Before opening	During operation and after closure
Congenital anomalies*	Live births, stillbirths, and terminations	E, W 1983-98; S 1988-94	5 825 575	803 833	4 517 196	2 026 074	429 160	4 150 320
Surgical corrections (hypospadias and epispadias)†	Live male births	E, S 1993-5	585 414	67 281	469 149	199 974	9 982	424 271
Hospital admissions (abdominal wall defects) or surgical corrections (gastroschisis and exomphalos)†	Live births	E, S 1993-7	1 903 892	222 179	1 522 851	646 415	21 282	1 384 135
Stillbirths	Live births and stillbirths	E, S, W 1983-98	6 062 700	825 456	4 725 120	2 177 796	461 776	4 295 686
Low and very low birth weight	Live births	E, S, W 1983-98	6 030 429	821 124	4 699 860	2 166 596	459 358	4 272 510

E=England, W=Wales, S=Scotland.
*Includes terminations for England and Wales 1992-8, for Scotland 1988-94. For hypospadias and epispadias, denominator data are male live births and stillbirths only: numbers are 2 983 963 (all landfill sites), 412 201 (special waste sites), 2 313 135 (non-special waste sites), 1 037 320 (reference area), 220 227 (before opening of sites), 2 125 477 (after opening of sites).
†England and Scotland only.

operation and after closure. Subsidiary analyses examined risks separately for special and non-special waste sites, and in the period before and after opening for the 5260 landfill sites with available data.[17]

Results

Urban or rural status and Carstairs index were strongly correlated. Within the reference area, 49% of the most affluent tertile of areas was classified as rural (7% for the most deprived tertile), while for all outcomes rates were higher in the most deprived areas compared with the most affluent areas: the ratio ranged from 1.02 (surgical correction of hypospadias and epispadias) to 1.52 (very low birth weight).[17] The area within 2 km of the 9565 landfill sites tended to be more deprived than the reference area: 34% (*v* 23%) of the population were in the most deprived tertile of Carstairs score (36% for special waste sites). The area near landfill also had a higher proportion of births to mothers under 20 years of age (7.7% *v* 6.1%) and, among women aged 15-44, included (1991 census) a higher proportion of women of Indian, Pakistani, or Bangladeshi origin (4.8% *v* 3.2%) and a lower proportion of black women (2.0% *v* 3.4%).

Table 3 shows the numbers of cases for each birth outcome and relative risks for the area near landfill compared with the reference area. The relative risk for all congenital anomalies combined was 0.92 (99% confidence interval 0.907 to 0.923) unadjusted, and 1.01 (1.005 to 1.023) adjusted for deprivation and other confounders. After adjustment for deprivation (which reduced excess risks) relative risk was 1.05 (1.01 to 1.10) for neural tube defects, 1.08 (1.01 to 1.15) for abdominal wall defects (and 1.07 (0.98 to 1.18) for hospital admissions), 1.19 (1.05 to 1.34) for surgical correction of gastroschisis and exomphalos, and 1.05 (1.047 to 1.055) and 1.04 (1.03 to 1.05) for low and very low birth weight respectively. The risk was 0.96 (0.93 to 0.99) for cardiovascular defects and 1.07(1.04 to 1.10)

Table 2 Models chosen by the stepwise selection procedure in the reference area for each outcome*

Outcome	Model	No of parameters in chosen model	Terms added in alternative model†
Deprivation unadjusted			
All anomalies	Year+region+region:year	151	—
Neural tube defects	Year+region	25	Region:year
Cardiovascular defects	Year+region	25	Region:year
Hypospadias and epispadias	Year+region	25	Region:year
Abdominal wall defects	Year+region	25	Region:year
Stillbirth	Year+region+sex+region:sex	35	Region:year
Low birth weight	Year+region+sex	26	Region:year
Very low birth weight	Year+region	25	Region:year
Deprivation adjusted			
All anomalies	Deprivation+year+region+region:deprivation+region:year	171	Year:deprivation
Neural tube defects	Deprivation+year+region	27	Region:year
Cardiovascular defects	Deprivation+year+region+region:deprivation	45	Region:year
Hypospadias and epispadias	Deprivation‡+year+region	27	Region:year
Abdominal wall defects	Deprivation+year+region	27	Region:year
Stillbirth	Deprivation+year+region+sex+region:sex	37	Deprivation:year
Low birth weight	Deprivation+year+region+sex+region:deprivation+deprivation:sex	48	Region:year
Very low birth weight	Deprivation+year+region+region:deprivation	45	Deprivation:year

Interactions are denoted by ":"
*No modelling was done for the hospital admissions data.
†Terms added in alternative model used in sensitivity analysis, defined as the most important term excluded at the last step (no alternative is shown for all anomalies combined, deprivation unadjusted, because the model is already saturated).
‡Deprivation not selected by stepwise selection process but was added as a main effect.

Table 3 Risks of congenital anomalies, stillbirths, and low and very low birth weight in populations living within 2 km of a landfill site (all waste types) during operation or after closure compared with those in the reference area (⩾2 km from any site)

	Near landfill (<2 km)		Reference area		Relative risk (99% CI)		
Birth outcome	No of cases	Rate (per 100 000 births)	No of cases	Rate (per 100 000 births)	Unadjusted	Adjusted (but not for deprivation)	Adjusted (and for deprivation)
Congenital anomalies (register and terminations data*)							
All congenital anomalies	90 272	1550	34 325	1694	0.92 (0.907 to 0.923)	1.01 (1.00 to 1.02)	1.01 (1.005 to 1.023)
Neural tube defects	3 508	60	1 140	56	1.07 (1.02 to 1.12)	1.08 (1.03 to 1.12)	1.05 (1.01 to 1.10)
Cardiovascular defects	6 723	115	2 716	134	0.86 (0.83 to 0.89)	0.95 (0.92 to 0.98)	0.96 (0.93 to 0.99)
Hypospadias and epispadias†	7 363	247	2 485	240	1.03 (1.00 to 1.06)	1.07 (1.04 to 1.10)	1.07 (1.04 to 1.10)
Abdominal wall defects	1 488	26	448	22	1.16 (1.08 to 1.23)	1.14 (1.06 to 1.22)	1.08 (1.01 to 1.15)
Congenital anomalies (hospital admissions)							
Hypospadias and epispadias‡	1 503	257	536	268	0.96 (0.90 to 1.02)	—	0.96 (0.90 to 1.02)
Abdominal wall defects	755	40	227	35	1.13 (1.03 to 1.24)	—	1.07 (0.98 to 1.18)
Gastroschisis and exomphalos‡	467	25	126	19	1.26 (1.12 to 1.42)	—	1.19 (1.05 to 1.34)
Stillbirths and birth weight							
Stillbirths	32 271	532	11 200	514	1.04 (1.02 to 1.05)	1.05 (1.03 to 1.06)	1.00 (0.99 to 1.02)
Low birth weight	422 149	7000	137 958	6367	1.10 (1.095 to 1.104)	1.11 (1.102 to 1.111)	1.05 (1.047 to 1.055)
Very low birth weight	62 191	1031	20 858	963	1.07 (1.06 to 1.08)	1.08 (1.07 to 1.09)	1.04 (1.03 to 1.05)

See table 1 for denominators and years of analysis and table 2 for adjustments.
*Terminations included for England and Wales 1992-8, Scotland 1988-94.
†Excludes terminations (3 cases).
‡Surgical corrections.

and 0.96 (0.90 to 1.02), respectively, for hypospadias and epispadias and their surgical correction (for which deprivation adjustment had little or no effect).

Table 4 summarises findings (adjusted for deprivation) for the special and non-special waste sites, and for the sites that opened during the study period. For special waste sites, risks above one were found for all but two outcomes, ranging up to 1.11 (1.03 to 1.21) for cardiovascular defects and for hypospadias and epispadias. For the specific anomalies, except neural tube and cardiovascular defects, risks were higher in the period before opening of a landfill site compared with after opening, especially for hospital admissions for abdominal wall defects. For birth weight and stillbirth, risks were higher after opening.

Sensitivity analysis showed that the risk estimates were robust to the different models used.[17] Urban or rural status did not materially alter results with deprivation included, though modelling of data for rural areas only (where numbers of cases were much lower than in the main analysis) did reduce risk estimates for neural tube defects and hypospadias and epispadias—relative risks (for all waste types, deprivation adjusted) were 0.99 (0.89 to 1.10) and 1.01 (0.94 to 1.09) respectively. Inclusion of maternal age as a confounder had only a small effect on risk of abdominal wall defects.[17]

Discussion

This is by far the largest study of associations between residence near landfill and adverse birth outcomes. We found a small excess risk of neural tube defects, abdominal wall defects, surgical correction of gastro-

Table 4 Estimated relative risks (99% confidence intervals) of birth outcomes for populations living within 2 km of a landfill site, adjusted for deprivation and other variables* according to waste type and to operating status for those sites that opened during the study period

	All operating and closed sites, by waste type			Sites that opened during study period (all waste types), by operating status†	
Birth outcome	All wastes	Special waste	Non-special waste	Before opening	During operation or after closure
Congenital anomalies (register and terminations data‡)					
All congenital anomalies	1.01 (1.005 to 1.023)	1.07 (1.04 to 1.09)	1.02 (1.01 to 1.03)	1.02 (0.99 to 1.05)	1.00 (0.99 to 1.01)
Neural tube defects	1.05 (1.01 to 1.10)	1.07 (0.95 to 1.20)	1.06 (1.01 to 1.12)	0.98 (0.82 to 1.16)	1.05 (0.99 to 1.10)
Cardiovascular defects	0.96 (0.93 to 0.99)	1.11 (1.03 to 1.21)	0.95 (0.91 to 0.98)	0.92 (0.81 to 1.04)	0.92 (0.88 to 0.95)
Hypospadias and epispadias§	1.07 (1.04 to 1.10)	1.11 (1.03 to 1.21)	1.07 (1.04 to 1.11)	1.08 (0.98 to 1.19)	1.05 (1.02 to 1.09)
Abdominal wall defects	1.08 (1.01 to 1.15)	1.03 (0.86 to 1.25)	1.07 (0.99 to 1.16)	1.24 (0.97 to 1.60)	1.06 (0.98 to 1.14)
Congenital anomalies (hospital admissions)					
Hypospadias and epispadias¶	0.96 (0.90 to 1.02)	0.98 (0.81 to 1.19)	0.96 (0.90 to 1.04)	1.42 (0.94 to 2.16)	0.93 (0.86 to 1.00)
Abdominal wall defects	1.07 (0.98 to 1.18)	1.08 (0.82 to 1.42)	1.05 (0.94 to 1.16)	2.26 (1.23 to 4.15)	1.12 (1.01 to 1.25)
Gastroschisis and exomphalos¶	1.19 (1.05 to 1.34)	1.10 (0.77 to 1.58)	1.18 (1.03 to 1.34)	1.33 (0.46 to 3.81)	1.24 (1.09 to 1.42)
Stillbirths and birth weight					
Stillbirths	1.00 (0.99 to 1.02)	0.99 (0.95 to 1.03)	1.00 (0.99 to 1.02)	1.01 (0.96 to 1.06)	1.02 (1.00 to 1.03)
Low birth weight	1.05 (1.047 to 1.055)	1.05 (1.04 to 1.06)	1.06 (1.052 to 1.062)	1.01 (0.99 to 1.02)	1.07 (1.062 to 1.072)
Very low birth weight	1.04 (1.03 to 1.05)	1.03 (1.00 to 1.06)	1.04 (1.03 to 1.06)	0.98 (0.94 to 1.02)	1.04 (1.03 to 1.05)

See table 1 for denominators and years of analysis.
*See table 2 for other variables adjusted for.
†522 landfill sites with available data for hospital admissions.
‡Terminations included for England and Wales 1992-8, Scotland 1988-94.
§Excludes terminations (3 cases).
¶ Surgical corrections.

schisis and exomphalos, low and very low birth weight. Findings for cardiovascular defects and hypospadias and epispadias were inconsistent, and there was no association with stillbirth. By including all landfill sites in Great Britain and using routine data sources, we avoided the possibility of bias from selective reporting[18 19] and maximised statistical power, but problems with data quality and confounding could have led to spurious associations.[20] These merit further discussion.

Exposure classification and data quality issues

In the absence of information on site or geological factors affecting emissions from landfill, we examined data for special waste sites as a proxy for potential hazard. The UK practice of co-disposal of special and non-special wastes (in contrast, for example, with US "superfund" sites[3]) means that most special waste sites handle small volumes of hazardous wastes. They are subject to stricter management and design standards than other UK sites, while hazardous wastes may have been disposed of, unreported, in non-special sites. Thus exposure risks from special waste sites may be no greater than from other sites. Exposures to environmental contamination from sources other than landfill may also be relevant because sites tend to be located in old mineral or other excavations, often on old industrial or contaminated land or close to current industrial activities.

A key issue was the possibility of misclassification from use of a 2 km zone to define proximity to landfill sites. However, in view of the low spatial resolution of the landfill data (hundreds of metres) and complex nature of landfill sites, using finer subdivisions of the 2 km zone or distance as a continuous measure to examine proxy dose-response relationships would not yield meaningful results. Misclassification of potential exposure to landfill may also have occurred if mothers moved home during the relevant period after conception.[21]

While the data for births and stillbirths are well recorded, the national congenital anomaly system in England and Wales is known to be incomplete[22] (though we found relative over-reporting in Scotland), and there were marked fluctuations in rates of anomalies over the study period, partly because of coding changes[23] and the dates that the terminations data became available. We adjusted for calendar year to deal with fluctuating rates, but ascertainment artefacts could have biased our results (in either direction) if they were differential with respect to landfill locations. Though we had no reason to suspect that this had occurred, such inconsistencies could explain differences of the order detected in this study. On the other hand, we included data on terminations to improve ascertainment, especially for neural tube defects, and included data on hospital admissions and surgical corrections to give an independent source of data for those specific anomalies.

Confounding

We addressed confounding in two ways. Firstly, analysis included potential confounders, with and without adjustment for deprivation. Residual confounding may persist if the adjustment did not account completely for relevant individual characteristics such as smoking,[24] drug use,[25] and infections during pregnancy.[26] As in the Eurohazcon study,[10] maternal age (for risk of abdominal wall defects[27]) did not seem to be a strong confounder, and, unlike in the United States,[28] location of waste sites near ethnic minority communities was not a key feature. Increased risks (about 1.5 to 2) of low and very low birth weight,[29 30] and (more weakly) of certain congenital anomalies (especially neural tube defects[31]) have been reported among offspring of women of South Asian origin,[32] but the higher proportions of women of Indian, Pakistani, or Bangladeshi origin living near landfill sites compared with the reference area would explain only around 1% excess in our study.

Secondly, we examined rates both before and after the opening of landfill sites that opened during the study period. Because this analysis is restricted to one set of areas, it is less subject to confounding by sociodemographic factors than comparisons between different areas—although confounding by temporal trends (which are strong for some of the health outcomes studied here[17]) is possible. Consequently, we did not compare the risks before and after opening directly but estimated each with respect to the reference region. We found excess risks for some specific anomalies in the period before opening (and which were higher than in the period during operation or after closure, especially for hospital admission for abdominal wall defects). This implies that factors other than landfill might be responsible. The Nant-y-Gwyddon study also noted an excess risk of all congenital anomalies combined before the site was opened.[11]

A possible causal association with landfill should also be considered. Given the large heterogeneity between landfill sites and the likelihood that the effect of any emissions would be greatest close to the sites,[33] causal effects related to particular landfill sites might have been greatly diluted. None the less, we know of no causal mechanism that might explain our findings, and there is considerable uncertainty as to the extent of any possible exposure to chemicals found in landfills.[6] Further understanding of the potential toxicity of landfill emissions and possible exposure pathways is needed in order to help interpret the epidemiological findings.

What is already known on this topic

Various studies have found excess risks of certain congenital anomalies and low birth weight near landfill sites

Risks up to two to three times higher have been reported

These studies have been difficult to interpret because of problems of exposure classification, small sample size, confounding, and reporting bias

What this study adds

Some 80% of the British population lives within 2 km of known landfill sites in Great Britain

By including all landfill sites in the country, we avoided the problem of selective reporting, and maximised statistical power

Although we found excess risks of congenital anomalies and low birth weight near landfill sites in Great Britain, they were smaller than in some other studies

Further work is needed to differentiate potential data artefacts and confounding effects from possible causal associations with landfill

We thank the Office for National Statistics, the Department of Health, and the Information and Statistics Division of the Scottish Health Service for providing data on congenital anomalies, births, stillbirths, and hospital admissions. We thank the Environment Agency in England and Wales and the Scottish Environment Protection Agency for providing data on landfill and for their help in resolving discrepancies. The views expressed in this publication are those of the authors and not necessarily those of the funding departments, data providers, or of Office for National Statistics. We thank Sean Reed and Richard Arnold for their help in preliminary analyses and Alex Lewin for help in the statistical analysis.

Contributors: PE and LJ initiated the project and, with DB and SM, drafted the paper. DB, CdH, CH, and IM performed the analysis of landfill sites. SM, CH, and IM performed the statistical analysis, overseen by JW and SR. TKJ contributed to the epidemiological analysis and interpretation. All authors contributed to and approved the final paper. PE is guarantor for the paper.

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Department of Health

News releases

Largest ever study into health of populations around landfill sites published

Published date: 16 August 2001

A major study into the possible health risks for populations living around landfill sites is published today. The Small Area Health Statistics Unit (SAHSU) studied the rates of birth defects, low birthweight, stillbirths, and of certain cancers in populations living within 2km of landfill sites. The group examined 9,565 landfill sites that were in operation between 1982 and 1997. It is the most extensive study into landfill sites anywhere in the world.

The study was commissioned in response to public concerns about the possible health effects of living close to landfill sites. SAHSU, an independent unit funded by government departments, found that 80 per cent of the population lives within 2 kilometres of a landfill site.

Results on birth outcomes of the SAHSU study will be published in the British Medical Journal on 17 August. The key findings are:

- the study found no increase in rates of cancer in populations living close to landfill sites
- the rate of congenital anomalies in populations living within 2km of all landfills is one per cent more than expected
- the rate of congenital anomalies in populations living within 2km of landfill sites containing hazardous waste is seven per cent more than expected
- rates of low birth weight babies are around five per cent higher near to landfill sites, but there is no difference in the rate of stillbirths
- rates of birth defects did not increase, and in some cases reduced, after landfill sites were opened in certain areas

The SAHSU study says that it is not clear at present that landfills are causing these effects and that other explanations are possible. These could include limits in the information available for the study, or the possibility that the study did not completely take into account other factors which increase the risk of birth defects or low birth weight. They recommend that further work is done to distinguish between these possibilities.

The Government's expert advisory Committee on the Toxicity of Chemicals in Food, Consumer Products and the Environment (COT) noted that the findings for the birth outcomes were not consistent and that the study provided no evidence that rates of anomalies increased after landfill sites opened. They commented that this made it difficult to draw conclusions about the possible health effects of landfill sites on the basis of this study. The COT recommended that the finding of a 7 per cent higher rate of congenital anomalies around special waste sites merited further investigation, whether or not it was related to the presence of the landfill sites.

Dr Pat Troop, Deputy Chief Medical Officer, said:

“"This is an important study and the Government is taking it seriously. The results are difficult to interpret and we need to put them into context. We cannot say that there is no risk from landfill sites, but given the small numbers of congenital anomalies and the uncertainties in the findings, we are not changing our advice to pregnant women and they should continue with the recommended ante-natal programme."”

This study is part of an ongoing Government-funded research programme to investigate the possible impact of landfill sites on human health. In response to the recommendation of the COT, SAHSU will be asked to look further at the data to see if it is possible to identify any areas with particularly high rates of birth defects and to further investigate what these might be associated with.

Notes to editor

1. The Small Area Health Statistics Unit (SAHSU) was established in 1987, to investigate the incidence of disease around sources of environmental pollution and to advise government. It is wholly funded by government departments of Health; Environment, Food and Rural Affairs; Health and Safety Executive, Scottish Executive; National Assembly of Wales; Environment Agency; and Northern Ireland Department of Health, Social Security and Public Safety.
2. A full report of the study will be published on the DH website at: www.doh.gov.uk/landh.htm A paper publishing the results of the birth

outcomes analyses is published in the British Medical Journal on 17 August 2001.

3. In summer 1998, a report of the EUROHAZCON study was published in the Lancet. This investigated the incidence of congenital anomaly around 21 hazardous waste landfill sites in 5 European countries. It found an increased risk of congenital anomaly in babies whose mothers live close to the landfill sites. The study did not establish cause and effect, but concluded that there was a need for further work.

4. The SAHSU study was part of ongoing work to look at potential health impacts from landfill sites. Other research underway includes a review of the known causes of birth defects, a review of the potential for substances emanating from landfill sites to cause birth defects, a study of the geographical variation in overall rates of birth defects and the rates of specific anomalies, and a detailed study of emissions from landfill sites.

5. It is Government policy to reduce reliance on landfill. The Government's Waste Strategy 2000 set out a comprehensive strategy to reduce reliance on landfill, to reduce waste, to recycle it and to gain value from waste. The EU Landfill Directive which came into force on 16 July 2001 imposes stringent targets on the UK to reduce the amount of biodegradable municipal waste which it landfills to 35% of that produced in 1995 by 2020. The WS 2000 also sets challenging targets for increasing household recycling and composting and a target to reduce the amount of industrial and commercial waste landfilled. We produce over 100 million tonnes of waste a year from households, commerce and industry alone. Most waste produced in England and Wales goes to landfill. About 83% of municipal waste and 54% of commercial and industrial waste are managed in this way.

6. Landfills are subject to strict controls. The purpose of the licensing system is to ensure that waste is recovered or disposed of in ways which protect the environment and human health. Landfill sites are subject to strict licensing and regulatory controls by the Environment Agency in England and Wales and the Scottish Environment Protection Agency (SEPA) in Scotland. The purpose of the licensing system is to ensure that waste is recovered or disposed of in ways which protect the environment and human health. Details of landfill sites can be found on the public registers of the EA and SEPA, and information about landfill sites in England and Wales can be found at www.environment-agency.gov.uk/yourenv/

7. The EU Landfill Directive will impose additional requirements on landfill including banning some wastes from landfill altogether and requiring that waste is pre-treated before it is landfilled. Regulations to implement the Directive were issued for consultation on 8 August.

8. For further information contact Department of Health media centre on 0207 210570752334860 or DEFRA press office 0207 238 5391

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1: J Occup Environ Med. 1997 Nov;39(11):1103-10.

Health study of New York City Department of Sanitation landfill employees.

Gelberg KH.

New York State Department of Health, Bureau of Occupational Health, Albany 12203, USA.

Employees currently working at a large municipal landfill expressed concern that they experience higher rates of illness than other municipal sanitation workers. Therefore, this study was designed to examine acute health effects among employees working at the New York City Department of Sanitation, with special emphasis upon the landfill workers. Interviews conducted with 238 landfill and 262 off-site male employees asked questions about health symptoms experienced in the six months prior to the interview and about workplace exposures. This study found a higher prevalence among landfill employees of work-related dermatologic, neurologic, hearing, and respiratory symptoms, and sore and itching throats than among off-site employees. The respiratory and dermatologic symptoms were not associated with any specific occupational title or work task, other than working at the landfill. Off-site laborers experienced more neuromuscular symptoms and injuries.

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Relation between malodor, ambient hydrogen sulfide, and health in a community bordering a landfill ☆

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ABSTRACT

Background: Municipal solid waste landfills are sources of air pollution that may affect the health and quality of life of neighboring communities.
Objectives: To investigate health and quality of life concerns of neighbors related to landfill air pollution.
Methods: Landfill neighbors were enrolled and kept twice-daily diaries for 14 d about odor intensity, alteration of daily activities, mood states, and irritant and other physical symptoms between January and November 2009. Concurrently, hydrogen sulfide (H_2S) air measurements were recorded every 15-min. Relationships between H_2S, odor, and health outcomes were evaluated using conditional fixed effects regression models.
Results: Twenty-three participants enrolled and completed 878 twice-daily diary entries. H_2S measurements were recorded over a period of 80 d and 1-h average H_2S=0.22 ppb (SD=0.27; range: 0–2.30 ppb). Landfill odor increased 0.63 points (on 5-point Likert-type scale) for every 1 ppb increase in hourly average H_2S when the wind was blowing from the landfill towards the community (95% confidence interval (CI): 0.29, 0.91). Odor was strongly associated with reports of alteration of daily activities (odds ratio (OR)=9.0; 95% CI: 3.5, 23.5), negative mood states (OR=5.2; 95% CI: 2.8, 9.6), mucosal irritation (OR=3.7; 95% CI=2.0, 7.1) and upper respiratory symptoms (OR=3.9; 95% CI: 2.2, 7.0), but not positive mood states (OR=0.6; 95% CI: 0.2, 1.5) and gastrointestinal (GI) symptoms (OR=1.0; 95% CI: 0.4, 2.6).
Conclusions: Results suggest air pollutants from a regional landfill negatively impact the health and quality of life of neighbors.
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Annotated Resources on Landfills and Health Effects

1. **Porta, D. et al. Systemic Review of Epidemiological Studies on Health Effects Associated with Management of Solid Waste. *Environmental Health* (2009) 8:60-73.**

   This paper provides an overview of the studies in the published literature that evaluated the adverse health effects associated with different waste management methods including landfills. The authors also scored the reported effects in order to derive useable excess risk estimates for health impact assessment. The study design and potential biases in effect estimates were evaluated for each study included in the review. The authors found that for populations living with 2 kilometers of landfills, there was limited evidence of congenital anomalies and low birth weight with an excess risk of 2 percent and 6 percent, respectively. The excess risk tended to be higher when sites handled toxic waste. Many of the studies suffered from various limitations that are described in the review. Despite this, the authors concluded with a moderate degree of confidence that "we have derived some effect estimates that could be used for health impact assessment."

2. **Kouznetsova, M., et al. Increased Rate of Hospitalization for Diabetes and Residential Proximity of Hazardous Waste Sites. *Environmental Health Perspectives* (2007) 115(1): 75-79.**

   This study investigated whether residence near persistent organic pollutants (POPs)-contaminated hazardous waste sites increased rates of hospitalization for diabetes. The authors examined adult diabetes patients 25-74 years of age in New York State from 1993-2000. After controlling for major potential confounders, the study found a statistically significant increase in the rate of hospitalization for diabetes among patients residing in ZIP codes containing POPs-contaminated waste sites versus patients in "clean" sites. These results do not prove a cause and effect relationship; however, this study provides further support for the association between diabetes and exposure to environmental contaminants.

3. **Kuehn, C.M., et al. Risk of Malformations Associated with Residential Proximity to Hazardous Waste Sites in Washington State. *Environmental Research* (2007) 103: 405-412.**

   This study examines the relationship between malformations occurring in infants and maternal residential proximity to hazardous waste sites in Washington State. Maternal residence of infants born with malformations from 1987-2001 was compared to maternal residence of infants who were randomly selected and who were born without malformations during this same time period. The authors found that infants born within 5 miles of a hazardous waste site had an increased risk of malformations compared to infants born more than 5 miles away from a hazardous waste site.

4. **Gilbreath, S and Philip Kass. Adverse Birth Outcomes associated with open dumpsites in Alaska Native Villages. *American Journal of Epidemiology* (2006) 164(4): 518-528.**

   This study evaluates adverse birth outcomes in infants whose birth records indicate that the mothers lived in villages with dumpsites that were potentially hazardous to public health. The authors found that mothers who lived in villages with intermediate and high hazard dumpsite has a higher proportion of low birth weight infants than did mothers in the control group. More infants born to mothers who lived in the intermediate and high hazard villages suffered from intrauterine growth retardation.

5. **Palmer, S. et al. Risk of congenital anomalies after the opening of landfill sites. *Environmental Health Perspectives* (2005) 113(10): 1362-1365.**

This study was conducted to investigate whether there was an increased risk of births with congenital malformations for mothers living near 24 landfill sites in Wales that opened between 1983 and 1997. Expected rates of congenital anomalies were compared to those of mothers living within 2 km of the sites, before and after opening of the landfills. Results showed risk of congenital anomalies for mothers living near the landfills increased when the sites were opened. However, the data could not establish a causal link between the landfills and the malformations because of a variety of biases that may have confounded the relationship. Nonetheless, the increase in risk associated with the opening of sites requires continued surveillance.

6. **Morgan, O., Vrijheid, M., Dolk, H. Risk of low birth weight near EUROHAZCON hazardous waste landfill sites in England. *Archives of Environmental Health* (2004) 59(3): 149-151.**

This study evaluated risk of low birth weight near 10 English hazardous waste sites used in a previous study of congenital anomalies (see below). The authors found a small but not statistically significant increase in risk of low birth weight within 3 km of sites. The findings of this study suggests that previously reported results for congenital anomalies should not be extrapolated to a wider range of reproductive effects but instead evaluated separately for each outcome.

7. **Dummer, T., Dickinson, H., Parker, L. Adverse pregnancy outcomes near landfill sites in Cumbria, northwest England, 1950-1993. *Archives of Environmental Health* (2003) 58(11): 692-697.**

This study evaluated the risks of stillbirth or neonatal death for mothers living near landfills. All stillbirths, neonatal deaths, and lethal congenital anomalies occurring among 287,993 births to mothers in Cumbria, northwest England during the period 1950-1993 were studied. For the period 1970-1993, a small but significant increase in risk of "other congenital anomalies of the nervous system" was found in mothers living near domestic waste landfill sites. This finding was consistent with other researchers, but a casual effect could not be inferred and the possibility that the results occurred by chance could not be ruled out.

8. **Vrijheid et al. Chromosomal congenial anomalies and residence near hazardous waste landfill sites. *Lancet* (2002) 359: 320-322.**

This study revealed that there is an increased risk of chromosomal anomalies in people who live close to hazardous waste landfills. Adjustments were made for maternal age and socioeconomic status. The results of this study suggest that an increase in the risk of chromosomal anomalies is similar to that found for non-chromosomal anomalies.

9. **Elliot, P. et al. Risk of adverse birth outcomes in populations living near landfill sites. *British Medical Journal* (2001) 323: 363-368.**

Between 1982 and 1997, a study was conducted to investigate the risk of adverse birth outcomes associated with residence near landfill sites. Individuals living 2 km from one of 9565 landfill sites throughout Great Britain were sampled. This has been the largest study of associations between residence near landfill and adverse birth outcomes thus far. It was concluded that residents near landfill sites are at risk of having children with congenital anomalies and low birth weight, however, further studies are needed to explain these findings.

10. **McNamee, R., Dolk, H. Editorial: Does exposure to landfill waste harm the fetus? *British Medical Journal* (2001) 323: 351-352.**

This editorial addresses issues concerning the article entitled "Risk of adverse birth outcomes in populations living near landfill sites" by Elliot et al. in the August 2001 edition of the British Medical Journal.

11. **Pukkala, E and Antti Ponka. Increased incidence of cancer and asthma in houses built on a former dump area. Environmental Health Perspectives (2001) 109(11): 1121-1125.**

This study evaluated the health of people who moved into twelve blockhouses in Helsinki, Finland that were built on a former dumpsite. Cancer and other chronic diseases were evaluated. The authors found a statistically significant increase in cancer for both sexes. The relative risk increased slightly with the number of years lived in the area. They also found increases in asthma and chronic pancreatitis. The authors concluded that the "possibility of a causal association between the dump exposure and incidence of cancer and asthma cannot be fully excluded." Nonetheless, the city council decided to demolish all houses in the dump area.

12. **Berger, S., Jones P., White, M. Exploratory analysis of respiratory illness among persons living near a landfill. *Journal of Environmental Health* (2000) 62.6: 19.**

Due to concern expressed by residents in two Staten Island, NY communities, the authors of this study evaluated the severity and frequency of respiratory symptoms occurring over a 12-month period among self-identified residents with asthma, severe breathing, or other respiratory conditions. Responses indicated that residents who lived adjacent to the landfill and those from the north-shore (seven miles from the landfill) had differing health problems, with landfill residents reporting higher rates of certain odors and eye, nose and throat irritation. The authors concluded that further investigation of respiratory illnesses should be conducted, as the study showed high rates of respiratory-related symptoms and conditions.

13. **Vrijheid et al. Health effects of residence near hazardous waste landfill sites: a review of epidemiologic literature. *Environmental Health Perspectives* (2000) 108: (Suppl. 1) 101-112.**

This review is an evaluation of current literature on the adverse health effects due to residence near landfill sites. It is difficult to make a conclusion about direct causes for adverse health effects and risks of landfills in general are hard to quantify. Of the studies reviewed, all proved to have insufficient exposure information. This article suggests that research of exposure to landfill sites needs to take a more interdisciplinary approach. Furthermore, epidemiologic and toxicologic studies need to be conducted for individual chemicals and chemical mixtures in order to understand what their effects may be on a population living near a landfill.

14. **Knox, EG. Childhood cancers, birthplaces, incinerators and landfill sites. *International Journal of Epidemiology* (2000) 29: 391-397.**

A study conducted in Great Britain between 1974 and 1987 found that children living near incinerators, both municipal and medical, were at more risk of getting cancer than those children living near landfill sites. This study targeted the sensitivity of children to carcinogenic emissions, but it failed to take into account the association of additional toxic sources in the vicinity. This study also did not account for the migration of families from areas of high toxicity to areas of low toxicity before, during, or after a child's birth.

15. **State of New York Department of Health, Center for Environmental Health. Investigation of cancer incidence near 38 landfills with soil gas migration conditions: New York state, 1980-1989, 1998. Available from: New York State DOH, 2 University Place, Albany, NY 12203-3399. Phone: 1-800-458-1158.**

Thirty-eight landfills throughout the state of New York were selected for a study to find out if people living near certain landfills had an increased risk of cancer compared to people living elsewhere. This study evaluated cancer incidence among people living around these 38 landfills between 1980 and 1989. All cases of leukemia, non-Hodgkin's lymphoma, liver, lung, kidney, bladder and brain cancer were identified and located on a map. Although this study had many limitations, it still found that women living near the landfills had a higher incidence of bladder cancer and leukemia. In comparison, men did not show an increased risk of any type of cancer despite their proximity to a landfill.

16. **Dolk, H. et al. Risk of congenital anomalies near hazardous-waste landfill sites in Europe: the EUROHAZCON study. *Lancet* (1998) 352: 423-427.**

This study examined seven regional registers of congenital anomalies in five different countries in Europe to determine if exposure from hazardous chemicals at landfills increased the risk of birth defects. Twenty-one sites were examined overall and among those sites mothers within a 3 km radius showed a significantly raised risk of having children with congenital anomalies. The results of this study were adjusted for maternal age and socioeconomic status. However, this study's findings are limited by a lack of information on exposures.

17. **Berry, M., and Bove, F. Birth weight reduction associated with residence near a hazardous waste landfill. *Environmental Heath Perspectives* (1997) 105(8): 856-861.**

Twenty-five years of birth certificate information (1961-1985) was collected in order to examine the relationship between birth weight and mother's residence near the Lipari Landfill located in New Jersey. The results indicated that there was a significant impact to infants born to residents who lived near the landfill during the time they would have been at greatest risk of exposure to hazardous chemicals. Many factors, including maternal health, cigarette and alcohol consumption during pregnancy, and socioeconomic status were not available for this study.

18. **Goldberg, M. et al. Incidence of cancer among persons living near a municipal solid waste landfill site in Montreal, Quebec. *Archives of Environmental Health* (1995) 50(6): 416-424.**

In a Canadian study, researchers from the Public Health Department in Montreal evaluated cancer incidence rates in people living around the Miron Quarry municipal landfill. Thirty-five volatile organic chemicals were identified in the landfill gases sampled, including known human carcinogens. When evaluating cancer incidence rates among persons living near the landfill, it was concluded that there might have been increased risks for certain cancers, such as stomach, liver, lung, prostate, and cervix uteri. The researchers also concluded that there were too many unknown factors to make any conclusions as to whether cancer incidence and proximity to the landfill were directly related.

19. **Shaw, G. et al. Congenital malformations and birth weight in areas with potential environmental contamination. *Archives of Environmental Health* (March/April 1992) 47: 147-154.**

Due to the public's increasing concern about reproductive damage as a result of exposure to environmental contamination, a study was conducted to determine if mothers living near contaminated sites were at a greater risk of having children with congenital malformations. This study did not reveal lower birth weight or increased risks

for most malformations among women who lived in contaminated areas. It did, however, show an elevated risk for infants with malformations of the heart and circulatory system.

20. Upton, A. et al. Public health aspects of toxic chemical disposal sites. *Annual Review of Public Health* (1989) 10:1-22.

This article provides a summary and overview of past health studies conducted around toxic waste disposal sites. The results of 16 published epidemiological studies of residential exposures to toxic waste sites are summarized in this report, many of which are landfills operated by local, state or federal agencies. Although many weaknesses were identified in this review, several adverse health impacts were also identified. These included decreased weight at birth, increase in the frequency of congenial malformations, increase in the occurrence of certain forms of cancer, decrease in the growth and maturation of children, and increased prevalence of central nervous system symptoms. Overall, this article provides evidence that health problems associated with exposure to toxic waste disposal sites are underestimated and poorly studied.

21. Hertzman, C. et al. Upper Ottawa Street landfill site health study. *Environmental Health Perspectives* (1987) 75:173-195.

As of 1987, there were few health studies conducted that found health problems in communities living around landfills that were published in the medical or scientific literature. To this day, there is still a lack of conclusive studies giving evidence that adverse health effects are caused by landfills alone. In a study conducted by Clyde Hertzman et al. a number of health problems in workers and residents living near the Upper Ottawa Street Landfill in Hamilton, Ontario were identified. A few of the problems found with the highest credibility included clusters of respiratory, skin, narcotic, and mood disorders. Evidence is presented in their study that supports the hypothesis that vapors, fumes or particulate matter emanating from the landfill site, as well as direct skin exposure, may have lead to the health problems found in excess in this particular area.

22. Paigen, B. et al. Growth of children living near the hazardous waste site, Love Canal. *Human Biology* (June 1987) 59(3): 489-508.

This is the third of a series of three studies that were conducted on children living near the Love Canal landfill. This study examined whether living near a hazardous waste site had an adverse impact on the growth patterns of children. Children are especially vulnerable to environmental contamination and it was hypothesized that exposed children would be smaller in comparison to control groups of children within a similar socioeconomic status. In earlier studies it was found that there was a significant effect between health problems and the closeness of homes near Love Canal, but in this study the difference in stature associated with birth and residence near Love Canal was not statistically significant. These findings suggest that length of exposure to chemicals may be more important to study rather than point of exposure.

23. Goldman, L., and Paigen, B. Low birth weight, prematurity and birth defects in children living near the hazardous waste site, Love Canal. *Hazardous Waste & Hazardous Materials* (1985) 2(2):209-223.

This is the second of a series of three studies that were conducted on children living near the Love Canal landfill. This study assessed birth weight, prematurity, gestational age, and birth defects in 239 children who were living in the Love Canal neighborhood before and shortly after birth. Overall the results showed no significant difference in prematurity, but there was an increase in low birth rate and birth defects. The outcomes of this study suggest that low birth weight is a good indicator of adverse health effects caused by exposure to low levels of chemicals.

24. Paigen, B., and Goldman, L. Prevalence of health problems in children living near Love Canal. *Hazardous Waste & Hazardous Materials* (1985) 2(1):23-43.

This is the first of a series of three health studies that were conducted on children living near the Love Canal landfill. This particular study looked at the overall health of children. The parents of 523 Love Canal and 440 control children were given questionnaires. It was found that children that lived near Love Canal had an increased prevalence of seven major health problems including, seizures, learning problems, hyperactivity, eye irritation, skin rashes, abdominal pain, and incontinence. This paper addresses many of the difficulties involved with conducting community health studies and recognizes the limitations of science when there are so many variables to contend with.

Updated September 2010

CHEJ Center for Health, Environment & Justice

USEFUL WEBSITES ABOUT LANDFILLS

Please note that web addresses change frequently. We apologize if you are not able to access a particular site and hope that you are still able to gain useful information from the other materials provided in this Fact Pack.

- Zero Waste, Landfill Page: http://www.zerowasteamerica.org/Landfills.htm

  Zero Waste America (ZWA) is an Internet-based environmental research organization that promotes the recycling of all materials back into nature or the marketplace. ZWA's Landfill page highlights the hazards associated with landfills and provides evidence as to why landfills always fail. This page has excellent statistics and provides links to numerous organizations, experts, and publications.

- Grassroots Recycling Network, End Landfilling Page: http://www.grrn.org/landfill/index.html

  The Grassroots Recycling Network helps to promote corporate accountability and encourages public policies to manage resources in order to achieve zero waste. This web page outlines how landfills are flawed and makes the argument that landfills are just wasting our resources and polluting our environment. GRRN has several campaigns and resources that are described on this site as well.

- Dr. Fred Lee's Home Page: http://www.gfredlee.com/

  Dr. G. Fred Lee and Dr. Anne Jones-Lee have prepared professional papers and reports about various issues surrounding domestic water supply, water quality, water and wastewater treatment, water pollution control, and the evaluation and management of the impacts of solid and hazardous wastes. Their web page allows readers to download the papers and reports they have written, many of which relate to the failures and risks of landfills.

- The Basics of Landfills: http://www.ejnet.org/landfills/

  This site is maintained by the Activists' Center for Training in Organizing and Networking and provides a basic understanding of what landfills are and why they fail. This page hasseveral links to useful articles and organizations that deal with landfill issues.

- The Alliance for a Clean Environment: http://www.acereport.org/

  The Alliance for a Clean Environment (ACE) is a local group from Pottstown, PA that has been fighting for the health and safety of their community, which is being threatened by a local hazardous waste landfill. Their site provides an example of how a local group can make a difference and provides proof that "people power" is effective in winning a fight.

- Concerned Citizens of Cattaraugus County, Inc. Home Page: http://www.homestead.com/concernedcitizens

  Concerned Citizens of Cattaraugus County is a larger than local nonprofit corporation located in New York State that advocates for clean air, soil and water through the implementation and enforcement of laws and policies that promote a clean and healthful environment. CCCC's main goal is to keep the public informed, especially about issues concerning waste disposal on the local and state level. Their web site addresses several of the issues being addressed in NY surrounding landfills and waste problems in general.

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Ralph Nader

“CHEJ has been a pioneer nationally in alerting parents to the environmental hazards that can affect the health of their children.”

New York, New York

CHEJ

Center for Health, Environment & Justice
P.O. Box 6806, Falls Church, VA 22040-6806

From:	Joel Geier
To:	Benton Public Comment
Subject:	LU-24-027 Additional document on issue of landfill liner failures and difficulty of leak detection
Date:	Tuesday, July 1, 2025 11:42:09 AM
Attachments:	cherry_gw.pdf

CAUTION: This email originated from outside of the organization. Do not click links or open attachments unless you recognize the sender and know the content is safe.

Dear Chair Fowler and members of the Planning Commission:

Here is a relatively brief paper by Dr. John A. Cherry, one of the most eminent figures in the field of hydrogeology. Among his many accomplishments, Dr. Cherry as the author of one of the most widely used textbooks on hydrogeology. I used his textbook when I taught the senior-level course on hydrogeology in the geosciences department at Oregon State University in 1999.

Please direct your attention to Figure 1 of this paper. This simple drawing illustrate the fundamental problem that limits the effectiveness of the existing monitoring system at Coffin Butte Landfill. It also limits the effectiveness of the Applicant's proposal to enhancements of that system by adding a small number of widely-spaced monitoring wells.

The fundamental problem is summarized by Dr. Cherry in this paragraph:

> *At a landfill where the monitoring network is used for early warning of contamination, a likely prospect for contamination to enter groundwater would be a hole in the liner. The width of the contaminant entry-area to groundwater beneath the landfill would tend to be narrow. Due to weak transverse dispersion the spacing between monitoring wells down-gradient would need to be equally narrow to provide much probability that the network would eventually detect the leak. Consideration of spacing between monitoring wells then becomes almost entirely dependent on estimates of the width of the contaminant entry-area at the source. From this it follows that, at many waste disposal or industrial sites, the spacing of wells in both the vertical and horizontal directions, is too large to detect the main impacts of the type of leakages or spills most likely to cause groundwater contamination (Figure 1). If transverse dispersion were to have as strong a spreading effect as was previously believed, this monitoring problem would be much less severe because plumes would spread out rapidly in the transverse directions as the plume front advances, thereby being at least detectable (but not necessarily mappable) by widely spaced wells.*

I will be submitting additional testimony on this topic prior to the July 8th hearing. Thank you for your efforts to consider the vast amount of testimony that you've received on this application.

Yours sincerely,
Joel Geier, Ph.D.
38566 Hwy 99W
Corvallis OR 97330

Groundwater Monitoring: Some Deficiencies and Opportunities

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INTRODUCTION

In the past decade monitoring for groundwater quality has evolved from a minor endeavor with few techniques and low cost per site. It is now a large industry in North America, involving many new and old techniques, tens of thousands of sites and, in many cases, millions of dollars per site. The capability of the monitoring industry to acquire accurate and reliable data from a well has improved immensely. However, severe deficiencies in overall monitoring capability remain. This paper addresses some of these deficiencies and their causes and implications.

A decade ago, it was common if not prevalent for groundwater monitoring at waste disposal or industrial sites to be accomplished using a small number of conventional wells with long sand packs and screens. A long screened well offered large cost savings over the alternative of the day, which was a nest or cluster of wells at different depths at each location. Groundwater monitoring networks comprised largely of long screened wells were a two-dimensional attempt to monitor three-dimensional systems. Recent experience at numerous sites shows that pathways for contaminant migration are typically complex in three dimensions. Monitoring well networks have become much more three dimensional as recognition of the nature of hydrogeologic systems grows. The monitoring network of today is more sophisticated and expensive than in past decades but whether it is actually accomplishing proper site characterization and early warning detection, and providing adequate data for remedial design or remedial performance assessment is problematic. The designer of monitoring networks is caught in a conundrum: the need for a large number of wells to satisfy the demands of complex groundwater systems, with the reality of high coat per well often limiting wells in the network to an inadequate number relative to the complexity of the problem.

Mackay (1990) provided a vivid description of the problem facing the designer of groundwater monitoring networks:

"Envision an extremely complex maze in which are lost a variety of chemicals--some concentrated and localized, and some dilute and spread out. Imagine further that the chemicals are all moving at different rates and directions as a result of gravity and/or the flow of air and water through the maze. Then imagine that the internal walls of the maze are porous, like a hedge, and that the chemicals, air or water can move into and even through them at rates that vary throughout the maze. Lastly, imagine that you must find [] all of the chemicals but cannot enter the maze to do so."

In the first part of this paper I consider the implications for groundwater monitoring of some recent studies pertaining to contaminant behavior in groundwater. The overall emphasis is on organic chemicals. The discussion focuses on three facets of site hydrogeology; transverse dispersion in heterogeneous sandy aquifers, fractures in aquitards, and heavier-than-water immiscible industrial liquids. These are the main areas of my site-investigation experience in the past decade.

The term "conventional monitoring well" is used frequently in this paper. This refers to a single well in a single borehole. The well has a screen of moderate or short length at the bottom, a sand or gravel pack is placed around the screen and the entire portion of the borehole annulus above the sand pack is sealed to surface with an impervious material such as cement grout or bentonite slurry.

HYDRODYNAMIC DISPERSION

Dispersion has received much attention from the groundwater research community in the past three decades. Lehr(1988) argued that excessive attention has been paid to this topic and that it is no longer worthy of priority in research. Regardless of the issue of priority, research findings of the past decade on dispersion have immense implications for groundwater monitoring. The following consideration of the topic pertains to contaminant transport in porous media such as sand and gravel rather than fractured rock.

Plumes of dissolved-phase contamination generally travel more or less horizontally through sand or gravel aquifers because these aquifers, as broad geologic deposits, are typically close to horizontal. Therefore, it is convenient to consider dispersion in terms of the following three principle directions: longitudinal, transverse horizontal, and transverse vertical. Dispersion is the process that causes dilution and spreading of plumes, with spreading occurring in the three principle directions.

Three-dimensional natural-gradient tracer tests in sandy aquifers done during the 1980s, with detailed spatial monitoring over long time periods, showed that dispersion is a very weak process in the two transverse directions, horizontal and vertical (Sudicky et. al.1983; Freyberg et. al. 1986; Moltyaner and Killey, 1988; Garabedian et. al. 1991). These experiments provided new insight on dispersion. Recently, this insight was used in the design of monitoring networks for actual contaminant plumes in the three-dimensional detail necessary to determine whether the results of the tracer tests were applicable at the full plume scale. LeBlanc (1984), Robertson et. al.(1991), Robertson and Cherry (in press), and Luba (1991) showed, for several unconfined sandy aquifers of various depositional origins, that contaminant plumes from infiltrated sewage have weak transverse dispersion. Mackay and Cherry (1989) presented maps of several plumes at industrial sites also showing long thin shapes indicative of weak transverse horizontal dispersion. Cherry (1983) and MacFarlane et. al. (1983) presented concentration versus depth profiles indicating weak vertical dispersion in plumes at municipal landfills. These field studies based on detailed monitoring and many other field studies published in recent years indicate that weak transverse dispersion is common in sand and gravel aquifers. In some cases transverse dispersion is not much stronger than the effect of molecular diffusion alone.

Prior to the 1980s studies of dispersion dealt almost exclusively with longitudinal dispersion. Although longitudinal dispersion is of theoretical interest, it is of little practical importance in groundwater monitoring. Longitudinal dispersion influences the arrival time of contaminants at monitoring wells, however the main uncertainty in arrival time involves the hydraulic conductivity distribution and contaminant source condition rather than dispersion.

Prior to the mid 1980s the values of transverse dispersivity used in practical applications of mathematical models to sandy aquifers were generally orders of magnitude larger than the values obtained from the natural gradient tracer tests mentioned above. In most cases dispersivity was used as a smoothing factor in the model, covering the effects of several types of uncertainties including dispersion. This gave the impression that transverse dispersion was a much stronger process than recent tracer tests and detailed plume studies have established. For the designers of monitoring networks these findings on dispersion present a problem not evident a few years ago. The monitoring targets intended for delineation using a well network, such as zones of peak concentration within a complex plume or simply the location of a narrow plume in an aquifer, tend to grow (i.e. expand due to dispersion) only slightly as the plume travels down-gradient from the source. Many plumes are heterogeneous in concentration distribution at the source because of spatially and temporally variable inputs of contamination, and complex site geology. Because of weak dispersion the degree of concentration heterogeneity diminishes very little down gradient, requiring a more dense network of wells. In some plumes the difference between detecting or missing a concentration zone orders of magnitude above a regulatory limit is difference in positioning in depth of the critical well by a only meter or two.

At a landfill where the monitoring network is used for early warning of contamination, a likely prospect for contamination to enter groundwater would be a hole in the liner. The width of the contaminant entry-area to groundwater beneath the landfill would tend to be narrow. Due to weak transverse dispersion the spacing between monitoring wells down-gradient would need to be equally narrow to provide much probability that the network would eventually detect the leak. Consideration of spacing between monitoring wells then becomes almost entirely dependent on estimates of the width of the contaminant entry-area at the source. From this it follows that, at many waste disposal or industrial sites, the spacing of wells in both the vertical and horizontal directions, is too large to detect the main impacts of the type of leakages or spills most likely to cause groundwater contamination (Figure 1). If transverse dispersion were to have as strong a spreading effect as was previously believed, this monitoring problem would be much less severe because plumes would spread out rapidly in the transverse directions as the plume front advances, thereby being at least detectable (but not necessarily mappable) by widely spaced wells.

DENSE NON-AQUEOUS PHASE LIQUIDS

Dense non-aqueous phase liquids (DNAPLs) are now recognized as one of the most common and complex causes of groundwater contamination in industrial regions. A DNAPL site is one where DNAPL, as residual or free-liquid phase, exists below the water table. DNAPLs are a unique threat to groundwater quality because they commonly sink below the water table where they dissolve slowly. DNAPL dissolution causes long-term formation of plumes emanating from

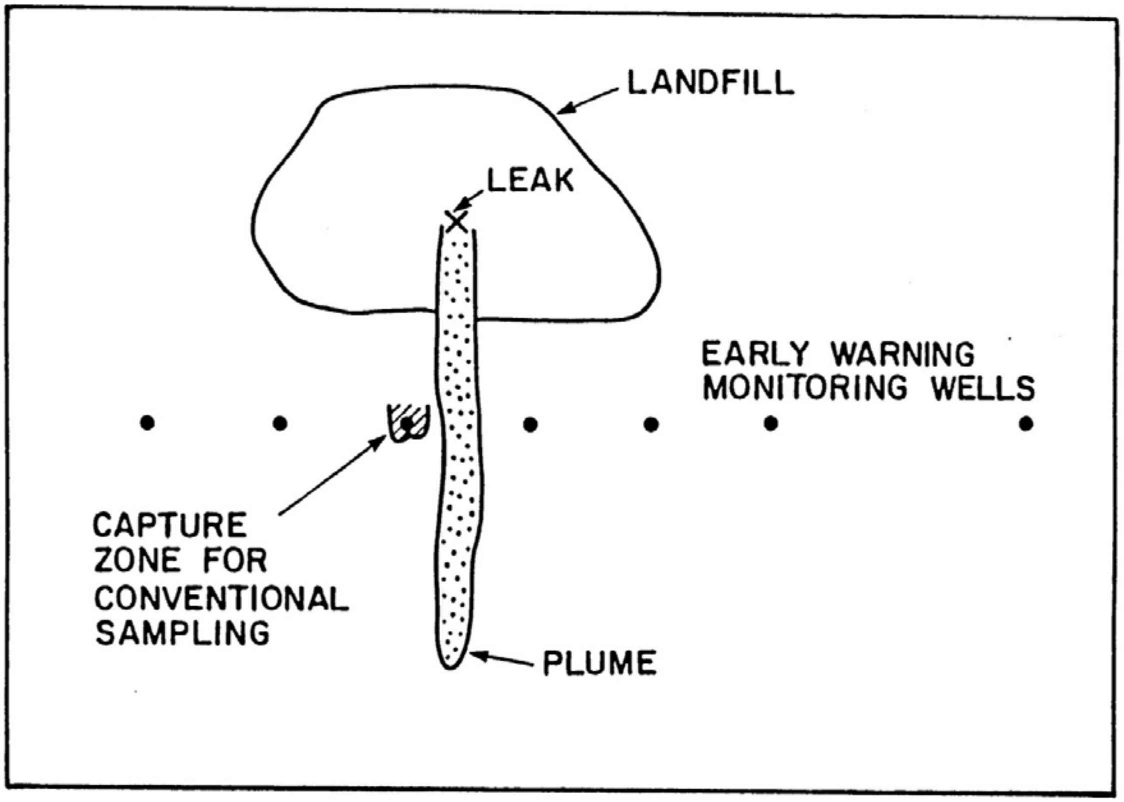

Figure 1

the zones of DNAPL. DNAPL may also exist above the water table but the mass below the water table is usually the cause of most or nearly all of the ground water impact (Figure 2). The important types of DNAPL are chlorinated solvents, creosote/coal tar, PCB oil and some pesticides. Schwille (1988) provided descriptions of the behavior of DNAPL in porous and fractured media. Huling and Weaver (1991) presented a summary of current knowledge about DNAPL behavior in groundwater. Mackay and Cherry (1989) considered the influence of DNAPL on concentrations from pumping wells.

DNAPLs have gotten into aquifers from disposals to pits of industrial liquid wastes, and leakages from drums, distribution lines, sumps, underground tanks, liquid transfer connections, dry wells and highway and rail accidents. The input zones to the water table are often small and therefore the core of dissolved-phase plumes emanating from the DNAPL zones below the water table is typically small in cross sectional view. Some DNAPLs such as the chlorinated solvents(i.e. tetrachloroethylene, trichloroethylene, trichloroethane) have a factor of ten thousand or more between their aqueous solubility and maximum concentration permitted in drinking water (MCLs). DNAPL mass tends to be distributed with exceptional spatial heterogeneity below the water table, thereby producing dissolved-phase plumes with extreme complexity. These complex distributions are often beyond the capability of even unusually expensive networks of conventional monitoring wells to provide the data necessary for reliable risk assessments, design of remedial systems or remediation performance evaluations.

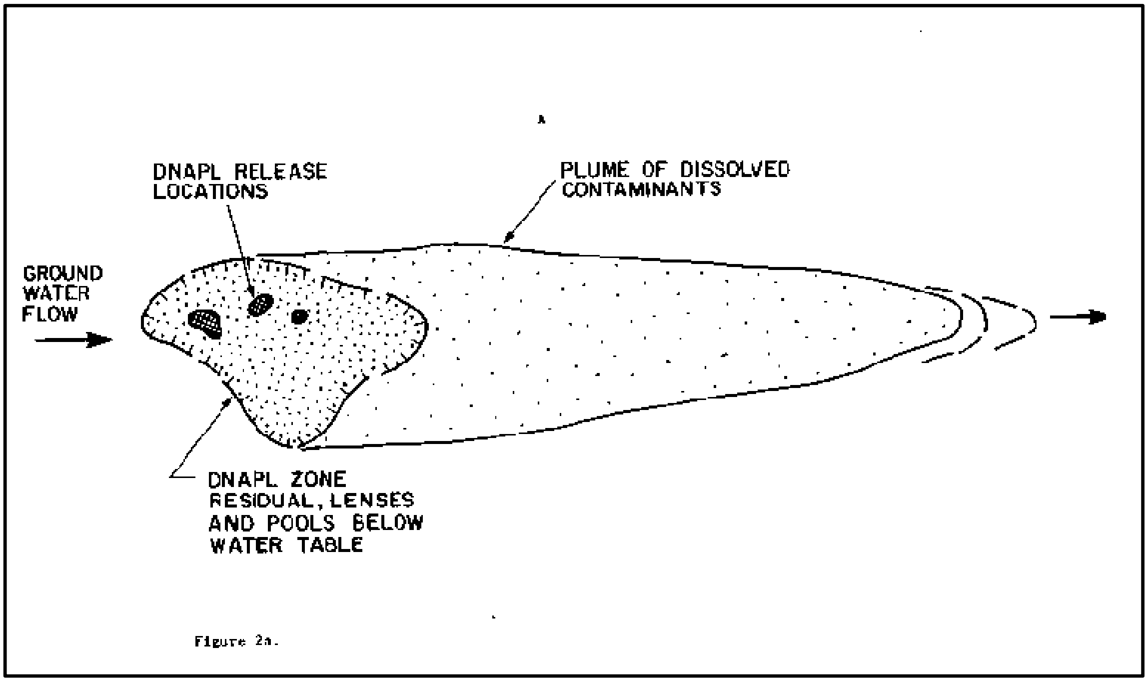

Figure 2

The problems referred to above for DNAPL site monitoring pertain to the spatial and temporal resolution of concentration distributions. However, an even more difficult DNAPL monitoring problem is the installation of monitor wells in areas of DNAPL without causing lenses or pools of DNAPL to drain liquid DNAPL down the borehole or well to deeper levels in the aquifer. Many DNAPLs have a specific gravity between 1.2 and 1.6, low viscosity and low interfacial tension. This gives them strong propensity to move downward through small openings created by drilling or well installation. In hydrogeologic settings where no major aquitard exists into which casing can be keyed at the bottom of a DNAPL pool, there is no proven technology for drilling through such DNAPL zones without draining liquid DNAPL deeper in the aquifer or otherwise inducing artificial complexities in the monitoring data.

The worst circumstances are generally found in fractured rock. Extreme precautions can be taken which may minimize these problems in some cases. However, without detailed prior knowledge of the locations of the lenses or pools of DNAPL the precautions can be futile. Such prior knowledge must derive from drilling, a Catch-22 situation. Considering the inadequacy of present drilling technology in this context it is often inadvisable to drill in areas of known or suspected DNAPL. Unconventional strategies for site investigation should be pursued. Specialized equipment suitable for this challenge is needed.

FRACTURED AQUITARDS

In the simplest conceptualization hydrogeological systems are comprised of aquifers and aquitards. Aquifers are normally the focus of attention because they are the source of water supply and are the zones where large contaminant plumes develop. At waste disposal or industrial sites, however, aquitards are often as important as the aquifers. The problems of monitoring aquitards are much different than those of aquifers.

In sedimentary terrain aquitards typically are strata comprised of silt, clay, siltstone or shale in which nearly all groundwater flows through fractures (the term fracture is used here for all types of secondary openings such as joints, fissures and bedding planes). In many aquitards vertical fractures exist and in situations where the fractures extend from top to bottom, these fractures often provide pathways for contaminants to move through the aquitard into underlying aquifers. One of the reasons why groundwater contamination is now so common in industrial regions is the leakiness of aquitards due to fractures, primarily vertical fractures.

Using numerical simulations Sudicky and McLaren (in press) and Harrison et. al. (in submittal) showed major impacts of dissolved contaminants, such as chloride and trichloroethylene, on an underlying aquifer due to movement through small vertical fractures in an overlying clay aquitard. Vertical fractures as small as 10 or 25 microns were found to be important. To put these aperture sizes in context, twenty microns is approximately the diameter of a human hair and 100 microns is approximately the diameter of a single sheet of writing paper. Kueper and McWhorter (1991) show by theoretical analysis that DNAPL with common physical properties can easily move downward through vertical fractures having apertures of only 5 to 10 microns. Aquitards with moderately or widely spaced vertical fractures having apertures of a few tens of microns or less exhibit very low bulk vertical hydraulic conductivity, even less than 10 minus 7 or minus 8 cm/s. These studies indicate that aquitards that are nearly impermeable in a hydraulic context can be quite transmissive for contaminant migration, including both dissolved phase and immiscible phase contaminants.

In site investigations a frequent goal is to determine the propensity for contaminants to move through a particular aquitard so that proper pathway analyses for risk assessments can be made or for design of remedial action. It is necessary to know whether fractures offer migration pathways because some of the remedial options under consideration may cause mobilization of contaminants from an upper aquifer to a deeper aquifer. One of the most difficult site investigation tasks is the determination of the presence or absence of critical fractures in an aquitard. Present techniques are crude and often provide unreliable answers. This is not surprising considering that today's technology for groundwater monitoring was developed primarily for aquifers and not aquitards.

RECENT ADVANCES IN GROUNDWATER MONITORING

Groundwater monitoring has advanced considerably in the past decade, primarily as a result of the demand for monitoring created by SUPERFUND and RCRA. The improvements have come almost exclusively in areas of conventional monitoring; they allow conventional monitoring to be done better. For example, many conventional monitoring wells are now constructed from materials appropriate for detection of parts per trillion levels of organic compounds. Various new sampling pumps suitable for parts per billion or parts per trillion studies are now available for sampling these wells. New types of drilling equipment can be used to obtain better soil samples and set monitor wells with less formation disturbance. Sophisticated borehole geophysical techniques provide new insight to the details of site geology. Analytical laboratories are now capable of routine detection of many groundwater contaminants at orders of magnitude lower levels than was the case a decade ago.

The 1980s was the decade of development of stringent protocols for groundwater sampling and sample analysis. Gone are the days when field personnel could drop an old bailer down a well for sampling after casual purging and then splash the sample into whatever type of sample bottle that happened to be on hand. There is now much standardization in groundwater monitoring and, with this, much improvement in the quality of data provided by individual monitoring wells. With these improvements in well design, well materials, sampling pumps and field and laboratory screened hollow-stem auger are examples of recent technologies for obtaining head and chemical data at many depths in boreholes as drilling proceeds. The screened auger is used in permeable sand or gravel to depths generally not greater than 40 or 50 meters. The piezo-cone functions best in soft silty or clayey deposits in which the cone can be pushed under heavy load applied at surface. Because these techniques perform well only in a few types of overburden deposits and because of depth limitations, they can only be used in some regions. They offer possibilities for drilling in DNAPL zones because frequent sampling and analysis is done as the hole advances. This provides for drilling to cease when concentrations indicative of DNAPL are encountered. However, these methods, like other drilling methods, do not prevent DNAPL from draining deeper in the hole if the hole penetrates below a DNAPL zone. The piezo-cone and the screened auger have yet to be connected to field analysis equipment to produce laboratory-grade analyses on-site as drilling proceeds.

The technically advanced piezo-cone has sensors positioned near the tip of the drive-point penetrating the geologic material. The advantages of these tip sensors are many. There is a need for other drilling methods to have chemical and pressure sensors on or near the drill bit.

Use of Conventional Monitoring Wells For Contamination Scanning

Sampling of conventional wells using the standard protocol involves purging of several well-casing volumes before sampling. The purging is intended to produce samples of formation water free of artifacts related to reactions with well materials or gas transfer at the top of the water column. Normally, only one sampling is done after purging. The objective of this standard protocol is to produce a sample representative of the formation water in the immediate vicinity of the well screen. This type of sample is referred to here as a point sample. If the monitoring is being done to locate plumes that could be narrow and therefore difficult to locate or to locate local high-concentration zones within large complex plumes, point sampling has minimal probability of accomplishing these objectives.

An alternative use of the conventional monitoring well is to sample the well at the well screen using a down-hole point sampler (e.g. canister or cartridge sampler) or deep pump with a packer to avoid well casing and gas-phase effects and then collect several more samples at the well screen as the well is pumped. This sampling produces concentration versus time data for the well (Figure 3). The longer the well is pumped, the farther from the well the sample is drawn. The pumping scans the aquifer for contamination (Figure 4). When this is done at a number of wells, the concentration versus time data, combined with geological information and mathematical modelling, can be used to gain insight unobtainable from the standard protocol.

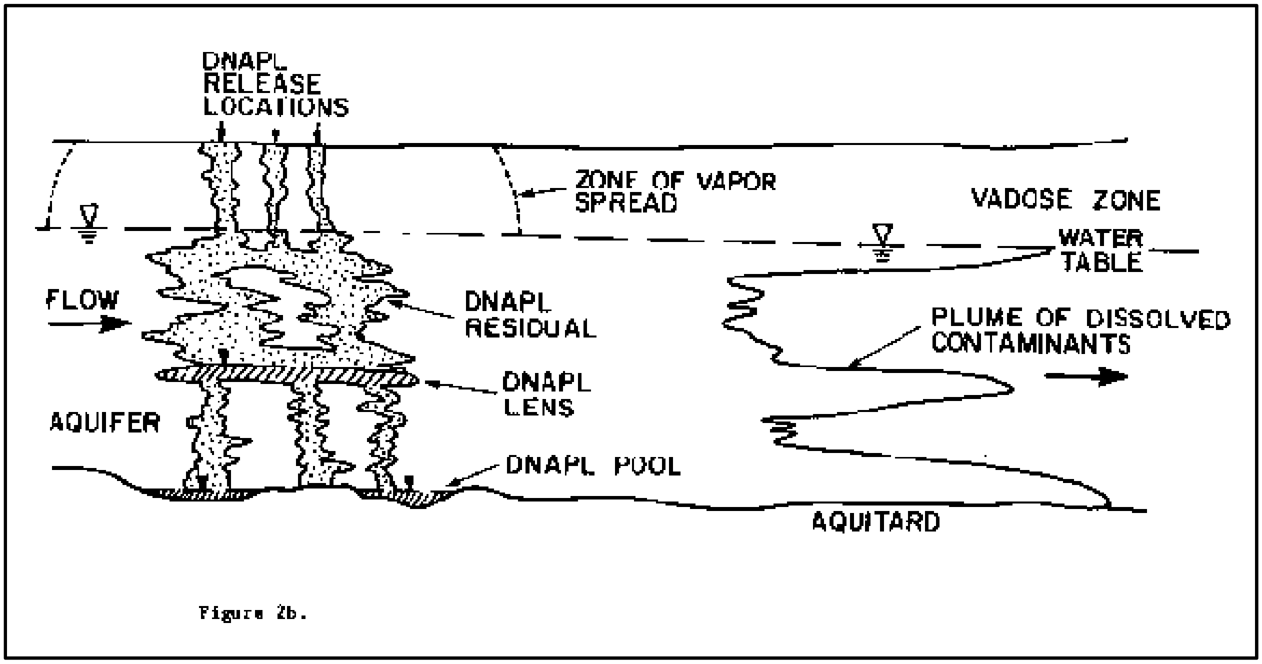

Figure 3

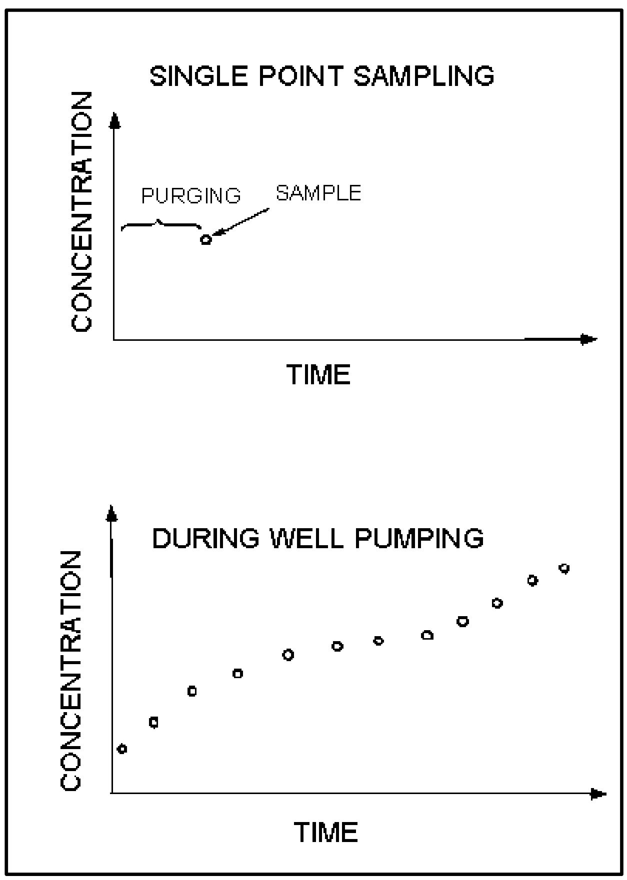

Figure 4

Scan sampling of aquifers is rarely done. The major deterrent is the cost of analyses and the slow turn-around for laboratory analyses. For aquifer scanning to be efficient, rapid accurate analyses are needed in the field at the time of sampling so that sampling frequency and duration of pumping can be adjusted appropriately during the course of the sampling program. T he analyses should have low detection limits because, as distant zones of contamination are drawn to the well, concentrations from the well can be diluted far below their in-situ values. Therefore, potential to use aquifer scanning will be limited until relatively low-cost field analyses with good accuracy and precision become widely available. Automated field-useable analytical equipment for VOC analyses now exists in the prototype stage (e.g. Bianchi-Mosquera et. al., 1991). It is expected that such equipment will soon become commercially available.

Investigation Of Fractured Aquitards

The fractures in aquitards that are generally the most important in groundwater contamination are vertical or near-vertical. The usefulness of vertical boreholes/ vertical monitoring wells is often very limited because of the low probability of detecting the critical fractures. Angle or horizontal boreholes provide much greater probability of obtaining data from critical fractures. In clay or silt aquitards continuous cores from angled holes can be divided into numerous segments for analysis of extracted pore water or solids. The main limitations in this approach are in the drilling. The methods normally available for drilling angle holes in clayey deposits, such as hollow stem augering, provide little control at depth on the angle of the lead augers, and therefore poor information on the subsurface location of the bit. The position of deep cores is poorly known. Technologies solving this problem in the petroleum industry have been little used in hydrogeology. Angled boreholes in clayey aquitards are rare in hydrogeology even though the need is apparent. Technology transfer in this area is lagging. Perhaps this is due to the difficulty of installing monitor wells in angled holes. However in many cases, few wells are needed if sufficient angle cores are taken for analysis of contaminant concentrations in core samples.

Investigations of contaminant migration in vertical or near vertical fractures in fractured-- rock aquitards have much different problems than those in clayey aquitards. Continuous cores of fractured rock usually provide little data on contaminant occurrence on the fracture surfaces. Water or air and water are circulated in the borehole at all times during the coring operation. With available rock coring methods this circulation flushes contaminants from the fracture surfaces. In low matrix-porosity crystalline rock such as granite there is little penetration of contaminants into the rock matrix by molecular diffusion. Therefore, analysis of contaminant concentrations in core samples of low-porosity rock is rarely fruitful. Rocks with larger matrix porosity such as sandstone, siltstone, or shale may have sufficient diffusive penetration of contaminants into the rock matrix for detection in rock slices, thereby providing relevant data from cores even if the fracture faces are flushed free of contaminants during drilling. However, this approach to core use is new to VOC studies and there is a need for establishment of reliable protocols for analysis of core segments or slices.

Multilevel Monitoring In Single Boreholes

To acquire detailed spatial data from fractured rock two approaches are available: first, double-packers, with a sampling port between the packers, inflated temporarily at various levels for sampling and, second, a modular assembly of packers, pipe, and ports for measurement of water pressure and acquisition of water samples. The bulk fracture porosity of nearly all fractured rock except karstic limestone or dolomite is so small, commonly less than 0.1 percent, that the first method produces disturbed chemical data from the fracture network due to purging of the sampling zone before sampling. Purging is necessary because cross circulation from one depth to another in the borehole occurs when the packers are not in the hole, which is most of the time.

Three modular packer-and-port systems for fractured rock are currently used in North America. Early versions of these systems are described by Black et. al., 1986; Welch and Lee 1987, and Dunnicliff (1988). These monitoring systems generally have between five and ten monitoring ports in each borehole; each port is separated from those above and below by two or more packers. The systems are installed permanently or for a long period of time. The systems are improving from year to year, taking advantage of better materials and miniaturized components. Each of these devices provides profiles of hydraulic head and samples for water chemistry. The systems have the exceptional capability to monitor in angled boreholes. They can be easily installed in angled boreholes, which is not the case for conventional wells. By installation of many of these modular systems in vertical and angled holes, exceptionally detailed monitoring can be done. Numerous sampling ports lead to numerous samples for analysis. This results in high analytical costs if the samples are analyzed for long suites of organic compounds, as is the common demand of regulatory agencies in studies of waste or industrial sites.

The modular systems have small ports that yield water for sampling at slow rates. The slow yield is generally advantageous for sampling to avoid excessive disturbance or mixing of the contaminant distribution in the fracture network. The most useful contaminant concentration data are obtained when the ports are sampled several times during slow pumping of each port to obtain concentration versus time relations for the ports. This provides insight on concentration patterns in the fracture network.

The main limiting factor in the use of the modular systems is the cost and turnaround time of analyses. On-site analytical frequently, until the available financial resources are consumed. Typically, this process takes a long time at high cumulative cost.

Recognition of this deficiency has led to increased use of field equipment at the drill site for measurement or estimation of contaminant concentrations. Often, an appropriate objective is to sample the bottom of the hole at many depths as it is drilled. The samples are analysed immediately so that decisions on additional sampling and maximum depth of the hole can be made during drilling. At present the sampling methods are crude or slow. The analyses are done at surface usually using small portable equipment producing data with accuracy and precision far below laboratory values. The data are not accepted by regulatory agencies, except as information facilitating selection of points for installation of conventional monitoring wells for acquisition of data using established protocols.

A goal of monitoring technology development should be establishment of drilling and sampling techniques and associated field analysis equipment and field protocols for production of contaminant concentration data that have the level of acceptability of samples from conventional monitoring wells with full-protocol laboratory analyses. Until this goal is met, expensive studies at many sites will continue to yield inadequate sets of concentration data from complex hydrogeologic systems. By inadequate I refer to spatial coverage of sampling points inadequate for technical resolution of site problems.

Mackay (1990) points out that it is not infrequent in site studies for careful review of expensive GC/MS analyses to show that much less expensive analytical methods would be capable of detecting all of the contaminants, perhaps even at a lower detection limit. He indicates also that there appears to be good reason to conduct a portion of the analytical work in the field. Protocols for field analyses acceptable to regulatory agencies need to be developed so that low-cost field analyses can supplant many laboratory analyses rather than only augment them.

A conventional monitoring well offers the advantage of access for repetitive sampling. Concentration versus time and water level versus time records can be developed over months or years. This is necessary in some cases but in many studies for risk assessment or remedy selection such records are not needed. Detailed spatial snapshots of hydraulic head and groundwater concentrations can often provide an adequate data base for risk assessment or remedy selection because groundwater flow is typically so slow that spatial distributions change little over months or even years. It can be argued that sampling over months is necessary to establish credible analyses following the formation disturbance caused by drilling. The need, however, is for drilling techniques that minimize formation water disturbance so that immediate sampling has validity.

Technically advanced versions of the piezo-cone and the protocols, has come a large increase in the cost of each chemical data point. A major implication in site investigations of the three factors described above (dispersion, DNAPL, and fractured aquitards) is recognition of the need for much more detailed three-dimensional hydraulic and chemical data. The recent advances in monitoring technologies and protocols have done little to fulfill this need. To meet this need the cost per chemical data point must decline rather than continue to increase.

At some sites the cost of a single nest of monitoring wells (several wells in the nest or an equivalent modular multilevel device in a single borehole) with one full chemical data set from the nest exceeds fifty thousand or even one hundred thousand dollars. This includes the cost of handling and disposing of contaminated borehole cuttings and water. If the site is a DNAPL site or is a site on fractured rock, one nest is usually an insignificant step towards achievement of the level of under- standing necessary for a reliable risk assessment or remedy selection. Many tens of nests per site or many more may be necessary to achieve these practical goals. It is entirely feasible at many sites (such as SUPERFUND or RCRA sites) to spend millions of dollars on a monitoring network without producing the site data necessary for the goals to be accomplished. This is not to say that the achievements in monitoring of the past decade have been ill-advised, rather it is that they have been primarily unidirectional, leaving an urgent need for advances of a much different nature in the 1990s.

SOME DIRECTIONS FOR DEVELOPMENT OF NEW TECHNOLOGY

This consideration of needs in monitoring technology and strategy focuses on three dimensional complexities in groundwater systems caused by weak dispersion, fractures or DNAPL or combinations thereof. The challenge is to develop efficient means for achieving adequate spatial and temporal distributions of data so that the level of understanding of the groundwater system is commensurate with the needs of site risk assessment or remedy selection/design. The practical goal should be to reduce the cost per data point and to increase the probability of acquiring data points from the important or essential locations over the most relevant time scale.

Real Time Field Data Acquisition
In the conventional site investigation the locations and depths of wells are specified before arrival of the drill rig on site. The monitor wells are installed. The drill rig then leaves the site and later on the wells are sampled. After considerable delay the analytical results are received from the laboratory and data interpretation commences. It is often found that the monitor network answers some questions at this stage and raises many new ones. At this point another phase of drilling and well installing begins and the site investigation proceeds from phase to phase until the necessary detail of site data is acquired or, more systems that do laboratory-grade analyses with fast turn-around are needed to bring modular monitoring systems into the mainstream of groundwater contamination studies. Until this happens investigations of contaminant occurrence and migration in fractured rock at many sites will remain hampered by inadequate spatial distribution of data points.

The modular systems described above can only be installed in boreholes open from top to bottom at the time the system is lowered down the borehole. Therefore, these systems, like conventional wells, do not circumvent the propensity for DNAPL to run down the borehole if the hole penetrates a zone of free liquid- phase DNAPL.

SUMMARY OF CONCLUSIONS
The major advances in groundwater monitoring at waste disposal and industrial sites made during the past decade pertain primarily to the design, construction and installation of conventional monitoring wells and to the equipment and protocols for sampling these wells. Also, advanced protocols used for routine laboratory analyses, particularly for organic chemicals, have achieved common use. The importance of these advances notwithstanding, little progress has been made in the development of cost-effective technologies for detailed determination of the spatial distribution of contamination in most types of hydrogeologic systems. This deficiency severely impedes progress towards reliable risk assessments of groundwater contamination, selection of site remedies, and monitoring of progress of remedial action. Recent studies of dispersion in sand and gravel aquifers show week transverse dispersion. This magnifies the difficulty of achieving adequate understanding of the spatial distribution of contaminants using conventional wells.

To decrease the cost of chemical analyses in site investigations and to provide greater insight on the location and internal character of contaminant plumes, there is an urgent need for new technologies for reliable and accurate on-site chemical analyses, preferably technologies with a high degree of automation and ease-of-use. These technologies should fulfill many needs such as rapid turn-around time so that field decisions can be made during drilling, development of concentration-versus-time relations for monitor wells and modular multilevel systems, automated analyses for pumping tests and pump-and-treat remediation, and scanning of aquifers for contamination.

Many waste or industrial sites within SUPERFUND and RCRA and other sites such as those on military land have DNAPL in the groundwater zone. The monitoring methods used in DNAPL areas are generally poorly suited for these areas because they typically produce results unrepresentative of the actual site conditions, or worse, cause contamination to spread to greater depth due to drilling effects. The importance of DNAPL in site investigations has only come to light since the mid-1980s and the development of monitoring methods specific to DNAPL problems is in its infancy.

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