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Groundwater Contaminants and Contaminant Sources

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This booklet is part of a series of educational brochures and slide sets that focuses on various aspects of water source protection. The series has been prepared jointly by the University of California Agricultural Extension Service and the California Department of Health Services.

For further information about this and other documents in the series, contact the project team leader (see below) or visit the following website:

www.dhs.ca.gov/ps/ddwem/dwsap/DWSAPindex.htm

Author: **Anthony Saracino and Harrison Phipps**, Saracino-Kirby-Snow, Sacramento, Calif.

Editor: Larry Rollins, Davis, Calif.

Layout crew: Larry Rollins and Pat Suyama

Cover illustration: Treatment system to remove solvents from groundwater beneath the former McClellan Air Force Base, Sacramento, California. Photo from online image archive maintained by California Department of Water Resources and University of California (http://elib.cs.berkeley.edu:80/photos/dwr/).

Project Team leader: Thomas Harter, Department of Land, Air, and Water Resources, University of California at Davis

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This chapter describes some of the contaminants commonly found in groundwater and the sources associated with those contaminants.

Much of the material in this booklet is adapted, with permission, from *California Groundwater Management*, a handbook produced by the Groundwater Resources Association of California (GRA).

Water quality parameters such as pH, dissolved oxygen, and conductivity, applicable to surface water and to groundwater alike, are not discussed here. They are described elsewhere, in the booklet in this series that covers the topic of surface water quality.

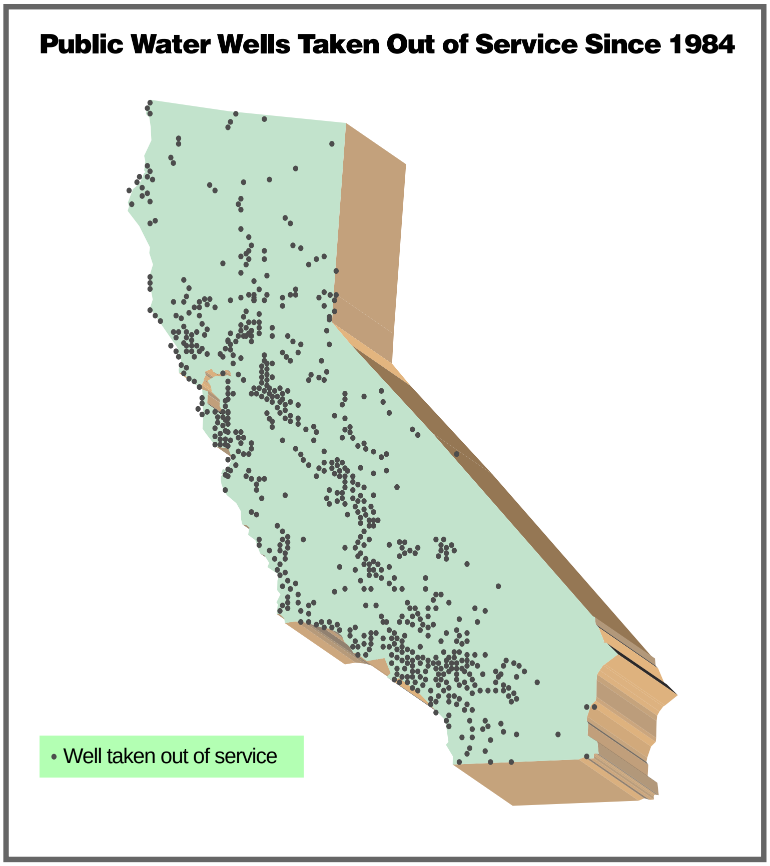

Figure 1: Over 4,000 public drinking-water wells have been shut down since 1984, as a result of groundwater contamination. (Adapted from map that appeared in newspaper article by Bowman (2001). Original source of data: California Department of Health Services.)

Introduction

Any place where surface water makes its way into groundwater, organic chemicals and pathogens potentially can enter (Winter et al., 1998). Inorganic chemicals that occur naturally in soils, sediments, and rocks—for example, dissolved mineral matter—can also degrade the quality of groundwater.

Even though groundwater may be plentiful in a particular area, if the quality of the groundwater has been degraded by the entry of contaminants, the aquifer may not be usable as a water supply. Figure 1 shows the locations of more than 4,000 public water wells in California that have been taken out of service in recent years because of contamination.

Many surface water reservoirs used as drinking water supplies are fenced to keep people from contaminating the water. Signs warn, for example, that the reservoir is a municipal drinking water supply and that no human access is permitted. Unfortunately, groundwater reservoirs typically are not protected this effectively. Often, land is zoned and developed (or farmed) without considering the underlying groundwater aquifers and the necessity of protecting the aquifer's recharge areas. Even aquifers that serve as municipal water supplies for thousands of people often are left mostly or entirely vulnerable.

Contaminants can enter aquifers by several means, including:

- infiltration of surface water through soil, sediments, and rock,
- direct flow from surface water (especially in fractured-rock terrain or karst terrain)
- direct flow through improperly built wells that become conduits for contamination, or
- cross-contamination below the ground surface from other aquifers via the casings (piping) of improperly built wells.

Point source contamination comes from specific locations, such as underground storage tanks, septic systems, and landfills. Nonpoint source contamination arises from an influx of pollutants over a large area, such as can occur from agricultural wastes and urban stormwater runoff.

Naturally-Occurring Contaminants

Water percolating through soils picks up naturally-occurring minerals, salts, and organic compounds. As the water migrates downward, the concentrations of dissolved minerals and salts typically increase, a process known as *mineralization*. In some cases, the percolating water accumulates mineral concentrations high enough that the groundwater no longer can be used as a water supply, or even for irrigation, without treatment.

Some of the more common natural contaminants include hydrogen sulfide, which often originates as a result of decomposition of organic materials, radon, a radioactive gas formed from the natural decay of uranium found in many rocks, and arsenic. The elements iron and manganese also occur naturally in many California groundwaters. In some areas, the concentrations of these two constituents in groundwater exceed federal and state drinking water standards.

Hexavalent Chromium (Chromium VI)

Municipalities and other suppliers of drinking water have been required since the 1970s to monitor for total chromium. Total chromium consists of chromium III, an essential human nutrient, and dissolved chromium VI (hexavalent chromium). Few data exist regarding the toxicity of dissolved chromium VI; however, it is

Chromium

Chromium is a naturally occurring element that is ubiquitous in the environment. It is found in rocks, soil, plants, animals, and in emissions from volcanoes. The average abundance of naturally occurring chromium is approximately 20 ppm in granitic igneous rocks, 120 ppm in shales and clays, and 1,800 ppm in ultramafic igneous rocks. Average concentration in the continental crust is 125 ppm.

Chromium is used for making steel and other alloys, furnace bricks, and dyes, for chrome plating, for leather tanning preserving of wood, and as a rust inhibitor in cooling towers. Chromium is released to the environment through manufacturing processes, disposal of chromium wastes, or burning of fossil fuels (Morry, 1999).

Characteristics

Under normal conditions chromium exists in two stable oxidation states: chromium III (trivalent), and chromium VI (hexavalent). Chromium VI exists as the chromate anion, which is more water soluble and mobile than Chromium III.

The fate of chromium in soil and groundwater depends on the form of chromium present, soil and water pH, and the presence of organic matter and certain minerals.

Chromium VI can be generated in the vadose zone and transferred to groundwater by the natural process of oxidation of chromium III by native manganese oxides. Chromium III may also be oxidized to chromium VI under other naturally occurring oxidizing conditions and during chlorination of drinking water supplies. Chromium IV may be reduced through natural processes to chromium III (Chung et al, 2000).

Toxicology

Chromium III is considered a required nutrient and is not toxic. California EPA Office of Environmental Health Hazard Assessment (OEHHA) does not consider chromium III to be carcinogenic when ingested. Chromium VI particles have been shown to be carcinogenic when inhaled. The damage is thought to be associated with inflammation of the lung tissue due to contact with a chromium VI particle. Inhaling water mist that contains small concentrations of dissolved chromium VI (e.g., in a shower) is not thought to pose the same risk to lung tissue as inhalation of particulate chromium VI. The reasoning is that in a shower, the chromium VI is dissolved and therefore there is no chromium VI particle to cause inflammation and subsequent tissue damage.

Although no persuasive evidence exists, OEHHA assumes chromium VI poses a carcinogenic risk when ingested based on the cancer risks from inhaled chromium VI, and on the results of a single ingestion study in laboratory mice conducted by I. Borneff in 1968 (DHS web page). There seems to be widespread agreement that the Borneff study and its conclusions were seriously flawed. Due to lack of supporting data (they consider the Borneff study too flawed for use), US EPA does not view chromium VI as a carcinogen when ingested (Macler, 2001). When ingested, chromium VI is rapidly reduced to chromium III by gastric juices in the stomach.

Maximum Contaminant Level

In 1977, the California Department of Health Services (DHS) set the Maximum Contaminant Level (MCL) for total chromium in drinking water at 50 mg/L. Total chromium is comprised of chromium III and chromium VI. There is currently no MCL for chromium VI. Effective January 3, 2001, DHS classified chromium VI as an unregulated chemical and monitoring is required. Since OEHHA has established a PHG for chromium, DHS will consider revising the current MCL.

Public Health Goal

OEHHA is required to establish Public Health Goals (PHG) for contaminants with MCLs and contaminants for which DHS intends to adopt MCLs. A PHG is a health protective goal and not a drinking water standard. OEHHA has set a 2.5 mg/L PHG for total chromium and a 0.2 mg/L PHG for chromium VI in drinking water. The PHG for chromium VI was established on the assumption that chromium VI is 7.2% of the total chromium and on extrapolation of data from the Borneff study to calculate the risk of one excess case of cancer per million people over a 70-year lifetime. Recent information indicates that chromium VI is 50 to 90% of the total chromium in many water supplies (Morry, 1999).

Arsenic

Arsenic is a metalloid element, having properties of both metals and nonmetals. It is ubiquitous in the environment and is presentnaturally in soil, water, air, plants, and animals (Tamaki and Frankenberger, 1989). The average arsenic concentration in the earth's crust has been estimated to be approximately 2 parts per million (ppm) (Yan-Chu, 1994). Arsenic concentrations in soil (0.1 to 40 ppm) and in sedimentary rocks (13 ppm) are generally higher than the average in the earth's crust due to movement and accumulation of arsenic through weathering processes.

Sources

Naturally occurring arsenic commonly is found in a variety of solid phases: as a component of volcanic glass in volcanic rocks, adsorbed to and co-precipitated with metal oxides (especially iron oxides), adsorbed to surfaces of clays, and associated with sulfide minerals and organic carbon.

Weathering of arsenic-containing rocks is considered to be the main natural source of arsenic in the environment (Tamaki and Frankenberger, 1989). Additionally, volcanic activity and forest fires can release arsenic into the atmosphere, from which the arsenic later falls to earth. However, precipitation in unpolluted areas usually contains less than 1 ppb arsenic. Naturally occurring arsenic can be mobilized chemically and subsequently can migrate into groundwater at landfills and other sites, where contaminants, such as volatile organics and petroleum products, are present (Welch, 2000).

Regulations

In 1942, the U.S. Public Health Service established an arsenic drinking water standard for interstate water carriers. The level was set at 50 parts per billion (ppb). In 1974, Congress specified that EPA was to set an arsenic drinking water standard. EPA issued an Interim Primary Drinking Water Regulation for arsenic in 1975 at the same level used previously, 50 ppb. In 1986, Congress directed EPA to revise the arsenic standard. In 1996, Congress, through the reauthorization of the Safe Drinking Water Act, gave EPA new deadlines to propose and issue a final arsenic drinking water regulation.

EPA's proposed health-based, non-enforceable goal, or Maximum Contaminant Level Goal (MCLG), for arsenic is zero, and the proposed enforceable standard, or maximum contaminant level (MCL), for arsenic is 5 ppb. EPA is also requesting comment on 3 ppb, 10 ppb and 20 ppb for the MCL (EPA, 2).

known that particulate chromium VI can be carcinogenic when inhaled. A number of drinking water suppliers in California rely on water sources that have total chromium concentration greater than the reporting detection limit of 10 micrograms per liter. Most of those suppliers get their water from groundwater wells.

Originally, hydrologists and geologists assumed that chromium VI results mainly from industrial contamination. It was also thought that where chromium exists naturally (reported as total chromium), the chromium VI portion is relatively small. These ideas are being re-evaluated in light of new evidence, and because chromium in water has become a high-profile issue, thanks in part to the highly popular movie *Erin Brockovich*. That movie is based on a 1996 court case in which residents of the California town of Hinkley won $333 million in compensation from Pacific Gas & Electric Company after the company's tanks leaked chromium VI into their groundwater.

Arsenic

Arsenic in drinking water has become a subject of debate. Some factions propose requiring tighter standards for this known carcinogen. Others, especially those with ties to mining and industry, cite the high costs of removing arsenic from drinking water.

Anthropogenic Contaminants

Threats to water quality are divided among agriculture, spills, leaking underground storage tanks and septic systems, urban runoff, mining, and industrial operations.

California leads the nation in agriculture, farming and ranching, accounting for around $20 billion in revenues per year. So it's not surprirising that agriculture has emerged as one of the biggest sources of groundwater pollution in California. Of all the states, California uses the most pesticides and fertilizers (Figure 2), resulting in widespread problems due to pesticide-laden seepage and millions of acre-feet per year of irrigation drain water containing high concentrations of contaminants.

Pesticides

According to a national survey conducted by the EPA, the pesticides detected most often in groundwater are dacthal, atrazine, simazine, prometon, hexachlorobenzene, dibromo-chloropropane (DBCP) and dinoseb.

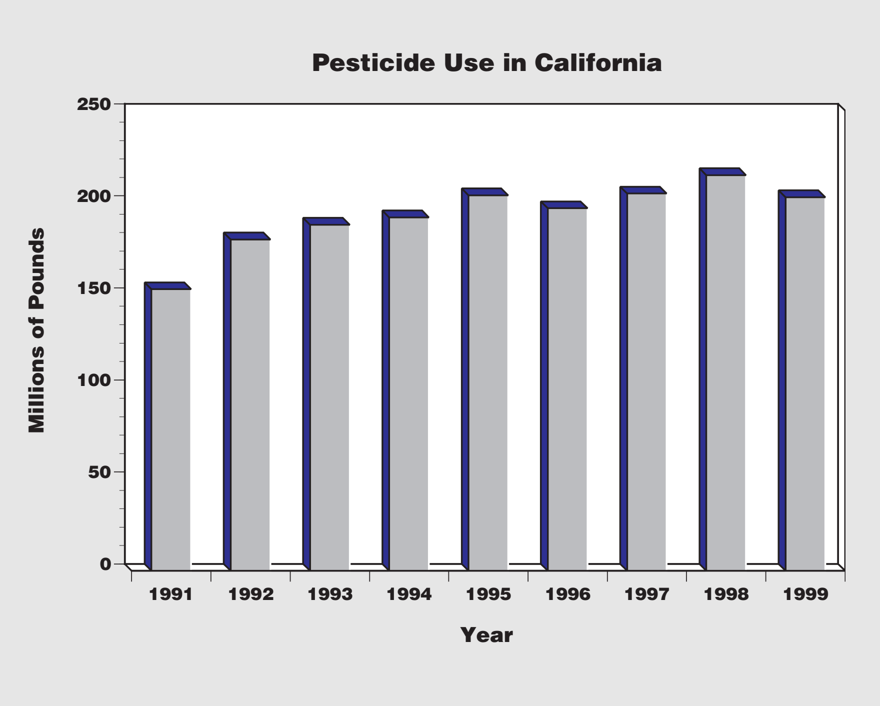

Figure 2: The use of pesticides in California has risen by about one-third during the past decade. (Adapted from illustration accompanying newspaper article by Leavenworth (2000). Original source of data: California Department of Pesticide Regulation.)

DBCP is the most widely detected pesticide in the San Joaquin Valley. Fresno County reported recently that 41 percent of its wells have detectable levels of DBCP. The city of Fresno so far has had to shut down over 37 wells, because water from those wells exceeded the DBCP drinking water standard.

Nitrate

Many groundwater contaminants cause harm only after relatively long exposure (chronic toxicity). Not so, for nitrate (NO$_3$). Consuming water containing high concentrations of nitrate can have almost immediate effects on a person (acute toxicity). In addition, nitrate in water used for drinking can lead to methemoglobinemia, or "blue baby syndrome."

California has established a drinking water Maximum Contaminant Level (MCL) for nitrate of 45 milligrams per liter (mg/l) NO$_3$. EPA's Safe Drinking Water Interim Health Standard is 10 mg/l of nitrate as nitrogen (NO$_3$–N). These two standards express the same quantity of nitrate present, differing only in the molecular form of nitrogen. Over 800 wells in southern California and 130 wells in the San Joaquin Valley have been closed because nitrate levels exceeded the 45 mg/l NO$_3$ threshold.

The Department of Health Services (DHS) and the State Water Resources Control Board (SWRCB) report that more public water supply wells have been closed due to nitrates than any other contaminant. Nitrates most often enter the groundwater from fertilizers, manure, septic systems, or nitrate-laden wastewater percolating downward from holding ponds.

Nitrate is very soluble in water and not readily adsorbed by soil, so it is typically very mobile in the subsurface environment. When transported by water into a geologic medium that lacks oxygen—certain types of soil, for example—nitrate is subject to *denitrification*, whereby some if it can be converted into gas and released to the atmosphere. However, denitrification is not enough to solve the problem of high nitrates. The increased use of chemical fertilizers, as well as an

DBCP

Dibromochloropropane, also known as 1,2-dibromo-3-chloropropane, or DBCP, is a dense yellow or amber organic liquid with a pungent odor at high concentrations. It was used primarily as an unclassified soil fumigant to control nematodes on cucumbers, summer squash, cabbage, cauliflower, carrots, snap beans, okra, aster, Shasta daisy, lawn grasses, and ornamental shrubs. The pesticide was banned in 1979, except for the use as a soil fumigant against nematodes on pineapples in Hawaii. Even that use was canceled in 1985 (EPA, 2).

Historically, DBCP entered the environment principally from its use as a fumigant. According to U.S. EPA, 831,000 pounds of DBCP was used in California in 1977, mainly on grapes and tomatoes. In 1974, 9.8 million pounds of DBCP were applied to commercial crops in the USA.

DBCP was first detected in drinking water in California in 1979. In 1983, a statewide drinking water monitoring program was initiated, and researchers soon found DBCP to be the most commonly detected pesticide in ground water. Even though its use was suspended over 20 years ago, DBCP is still found in California drinking water sources today, primarily in the Central Valley.

increase in the production of animals—and animal wastes—has resulted in greater quantities of nitrate leaching into and degrading groundwater.

Salt and Salinity

Salts occur naturally in soils, and in various kinds of sediments and rocks. Many such salt compounds can be dissolved by water as the water flows through the geologic material. Usually, the net result is that the salinity of the groundwater increases.

Discharges of wastes, such as treated sewage, into rivers can also increase the amount of salt in a groundwater aquifer. Typically, this occurs indirectly: the river contributes water to groundwater beneath the river's drainage basin.

Many groundwater basins have natural outlets, such as:

- subsurface flow to an adjacent basin
- flow to the ocean, or
- flow to surface water bodies such as rivers and lakes.

In such cases, salinity is kept in check because salts are discharged through natural mechanisms.

In basins that have no natural outlet, or in which pumping of groundwater has reduced groundwater levels below the natural outlet, salts will accumulate and the salinity of the basin will tend to increase.

Irrigation practices also can result in increased salt concentrations. This happens all the time during irrigation, actually, because evaporation and transpiration by plants removes pure water, leaving salt behind in the soil. *Salt loading* (long-term accumulation of salt) occurs in many basins in California. This occurs commonly in inland valleys that have only interior drainage, or in coastal basins where pumping has eliminated natural outflows.

Seawater Intrusion

In most coastal areas, the groundwater flow gradient pushes fresh water toward the ocean. Thus, water typically exits the land (and enters seawater) at subsea outcrops of the aquifer. If the original groundwater gradient changes—for example, as a result of pumping—then seawater can intrude into the coastal aquifer. Intrusion of seawater is particularly prevalent in areas where the coastal shelf is narrow, or where submarine canyons breach the shelf.

Intrusion of sea water into groundwater can make an aquifer too salty for drinking. It can also make the aquifer's water too saline to be used for irrigation. Usually, the contaminated parts of an aquifer can be reclaimed, by stopping the intrusion and then promoting natural flushing of the groundwater by fresh sources of water.

Nitrates

Nitrates have caused the shutdown of more public supply wells than any other contaminant. They come from the following sources:

- Fertilizers applied to crops
- Dairy, cattle and poultry feed lots
- Agricultural chemical dealerships
- Septic systems and leach fields

The California Department of Food and Agriculture has a committee that meets with growers and publishes information about fertilizer application. The committee is educating growers, fertilizer salespeople, and agricultural extension agents on the amounts of fertilizer that are best for crops.

Where groundwater is used for irrigation, fertilizer tanks are often connected to the irrigation pipeline to take advantage of the pressure in the system provided by the well pump. If there is no backflow prevention valve and no form of air gap, the fertilizer can be accidentally siphoned back into the well when the well is turned off. Some counties are considering requiring backflow prevention on every well, as required by California well standards.

The Central Valley Water Quality Control Board is conducting a pilot study at a dairy feed lot in the San Joaquin Valley to find the best ways to reduce discharge of dairy waste nitrates to groundwater. One method to reduce discharge is to run wash water into a settling pond and re-circulate it for later washing.

Education of chemical dealerships, together with the desire to avoid liability for contamination, is helping to diminish nitrate contamination from feedlots.

Septic tanks and leach fields will continue to be a source of contamination by nitrates, as long as most rural areas are not required to provide off-site secondary or tertiary sewage treatment for human wastes (GRA, 1997).

Lateral Migration

Extensive pumping of groundwater can create local “troughs” in the groundwater table (for unconfined aquifers) or the potentiometric surface (confined aquifers). These troughs can cause saline water in adjacent bedrock or salt-rich clays to migrate into the aquifer. If heavy pumping of groundwater occurs in costal aquifers, lateral influx of saline water from bedrock or clays can occur at the same time as seawater intrusion.

Vertical Seepage

Sometimes, saline groundwater exists above or below a relatively fresh aquifer. The saline water may occur in “perched” groundwater zones near the surface. Or it may occur in a full-size aquifer that overlies or underlies the high-quality aquifer. Vertical seepage of salt into the “good” aquifer can occur in several ways:

- In some areas the mechanism is natural, as when confining layers in the aquifer system are deposited in discontinuous lenses.
- The primary manmade pathways are wells and boreholes that provide conduits for contaminants.
- Another, less natural mechanism involves downward seepage of leachate from sewage, agricultural waste, or industrial waste disposed of indiscriminately above the aquifer. Technically, by law, such discharges of waste are prohibited, or at least regulated, by the regional water quality control boards via the waste-discharge permit program. However, older (legacy) waste dumps or small, ephemeral dumpsites may escape detection, and their leachates continue to seep downward.

Landfills and Hazardous Waste Disposal Sites

California has more than 2,300 active and inactive landfills, most of which are simply large holes in the ground filled with a variety of hazardous and non-hazardous wastes and covered with dirt. Although landfills built after 1984 must comply with design requirements established by the California State Water Resources Control Board (SWRCB) and other agencies, most of California’s landfills were built before 1984 and are leaking contaminants into the groundwater. Some of the more common contaminants from Class 3 landfills (those that accept only municipal solid wastes) are heavy metals, nitrate, and organic compounds, such as petroleum products, solvents, and pesticides. Class 1 landfills are said to be designed to receive and contain hazardous wastes, but some of the older Class 1 landfills, such as Stringfellow in Riverside County and Casmalia in Santa Barbara County, have caused groundwater contamination because minimum standards for liners were not in effect when they were designed. Even landfills built with liners eventually will leak, necessitating some kind of active leachate control system.

After hazardous materials were found to be leaking from solid waste disposal sites, the California Legislature enacted a one-time evaluation of all known sites, to determine to what extent wastes are migrating into surface water and groundwater. This evaluation, known as the Solid Waste Assessment Test (SWAT) program, is administered by the SWRCB. The program does not provide for cleanup or source control. The main responsibility for solid waste management and planning rests with local government. This includes permitting, inspections to verify compliance, and enforcement of permit conditions. The California Integrated Waste Management Board establishes statewide policy and reviews local solid waste management plans and permit decisions pursuant to the Solid Waste Management Resource Recovery Act.

The California Department of Toxic Substances Control (DTSC) issues permits that impose specific conditions on the way hazardous wastes can be handled, treated, stored or disposed. These permits include conditions requiring waste analysis, recordkeeping, site monitoring, contaminant procedures, site improvements, closure procedures, and financial responsibility. DTSC also has set up a regulatory program to phase out land disposal of certain hazardous waste. DTSC annually conducts inspections of land disposal facilities as part of the EPA’s Resource Conservation and Recovery Act program.

In addition to having authority over municipal landfills, the SWRCB and associated regional water quality boards regulate hazardous waste disposal sites to protect water quality. The federal Toxic Substances Control Act (TSCA) also regulates the production and handling of toxic chemicals. With TSCA, EPA has the authority to identify and control chemical products that pose an unreasonable risk to human health or the environment through manufacture, distribution, processing, use, or disposal. EPA can take a variety of steps to protect health and the environment from the introduction or unrestricted use of new chemicals. These steps include: publishing a chemical inventory, gathering information, and examining manufacturing data.

All landfills leak, eventually. A well-managed groundwater basin is one that is monitored to detect leaks, so that any harmful leakage can be attended to quickly by the responsible agencies.

Underground Storage Tanks

Many underground storage tanks (USTs) are associated with gas stations. Most of the extensive groundwater contamination that has occurred over the years has come from these tanks and from other subsurface impoundments used by industry and the government.

Solvent leakage from underground storage tanks used by the computer industry in Silicon Valley near San Jose has resulted in the largest concentration of federal groundwater cleanup sites (Superfund sites) in the country.

In addition, more than 100 *state* Superfund sites exist within California. Many of them are dry-cleaning businesses or other solvent users who have caused perchlorethane (PCE) and trichloroethylene (TCE) to enter groundwater from leaking tanks or from past disposal practices, which included in some cases the pouring of used solvent into sewer systems or dry wells. Also on the list are several present or former U.S. miliary bases. The military has proven to be one of the largest generators of hazardous wastes in California, and chemical leaks or spills have been discovered at military sites throughout the state.

Congress included the regulation of USTs in the 1984 amendments to the Resource Conservation and Recovery Act. Similarly, the California Legislature enacted an underground tank inventory and an underground tank permit program. Responsibility for implementing the inventory and permit program rests with local agencies designated by the county or city in which the tank is located.

In October 1995, the Lawrence Livermore National Laboratory (LLNL) presented to the SWRCB a report, *Recommendations to Improve the Cleanup Process for California's Leaking Underground Fuel Tanks*. The LLNL team found that the impacts to the environment from leaking USTs may not be as severe as once thought. The SWRCB is currently evaluating the conclusions of the LLNL report, as well as those contained in the Senate Bill 1764 Advisory Committee's Recommendations Report, to develop new policy regarding the cleanup of leakage from underground tanks.

The recent large-scale introduction of an oxygenate, methyl tertiary butyl ether (MTBE), into gasoline fuel has made the cleanup of leaking USTs even more urgent. MTBE is miscible in water and extremely mobile. Consequently, already it is being found widely in surface water and groundwater. Its effects on humans are unknown, and studies are underway.

Urban Stormwater Runoff

Urban stormwater runoff has been identified by EPA as a significant impairment to the nation's waters. Urban stormwater runoff contains a variety of contaminants, including household pesticides, animal wastes, heavy metals, and volatile organic compounds. The runoff containing these contaminants can be discharged to streams or surface impoundments, from which they can get into groundwater. The 1987 amendments to the Clean Water Act require EPA to develop NPDES (National Pollution Discharge Elimination System) permits for specific classes of stormwater discharges, including cities with populations greater than 100,000 and selected industrial sources.

Mine Drainage

The construction and byproducts of mining operations can pose serious threats to groundwater. Subsurface excavation and drilling at mines often result in disrupted groundwater flow. Furthermore, the minerals associated with mine tailings, waste, and drainage can produce acid effluent. Mining wastes are broadly defined as solid, semi-solid, or liquid waste materials from the extraction

MTBE

The federal Clean Air Act requires the use of oxygenates in gasoline. Oxygenates are designed to reduce emissions from gasoline-powered engines. By 1992, petroleum refiners wee heavily favoring the oxygenate MTBE (methyl tertiary butyl ether) for gasolines they sell in California. Widespread use of MTBE in California has resulted in MTBE contamination of soil and groundwater at locations where gasoline is stored or transported.

MTBE has a disagreeable taste and odor at extremely low concentrations. A turpentine-like taste and odor can be detected in water that contains MTBE at concentrations as low as 2.5 parts per billion (ppb).

MTBE is highly soluble in water, and groundwater plumes of MTBE are more mobile than plumes of other gasoline products.

MTBE may be regarded as recalcitrant in that it is not significantly degrading as contaminated groundwater plumes migrate. The primary mechanism for attenuation of MTBE appears to be dispersion.

Contamination in California may be widespread in shallow groundwater since there are at present over 32,000 leaking underground fuel tanks within the state.

MTBE is considered a possible human carcinogen (EPA, 3).

and processing of ores and minerals. These wastes include soil, waste rock, and overburden, as well as tailings, slag, and other processed materials.

Inactive and abandoned mines are also sources of contamination. For example, Iron Mountain Mine in northern California released up to four tons of heavy metals a day into the Sacramento River watershed, resulting in the largest discharge of hazardous materials into a U.S. river. Millions of fish were killed in the river each year. The Western Governors Association Mine Waste Task Force estimated that California has approximately 2,500 inactive and abandoned mine sites.

The SWRCB regulates mining wastes by issuing waste discharge permits (via the regional boards). The SWRCB also has established siting and construction standards for mining-waste management units. These standards generally cover flood protection, containment structures, liners, leachate collection, removal systems, and precipitation and drainage control.

Oil-field Brines

During the process of producing oil and gas, substantial quantities of wastewater are produced that must be disposed of in some manner. Prior to 1970, oil-field wastes were disposed of by discharging to streams or unlined evaporation ponds, which resulted in groundwater and surface water pollution. In some older wells, the volume of highly saline water pumped to the surface can exceed the volume of crude oil produced from the well (Hammer & MacKichan, 1981).

Currently, oil and gas wastes are disposed of through injection wells that convey the wastes to deep geologic formations isolated from freshwater aquifers. This has eliminated the widespread groundwater pollution historically associated with oil and gas production; however, production and disposal wells can serve as vertical pathways through which contamination may migrate (Todd, 1980).

Contamination Caused by Wells

Improperly built wells can result in contaminated groundwater, by establishing a pathway or a conduit for pollutants entering a well from surface drainage or by allowing communication between aquifers of varying quality.

Unused wells sometimes are simply abandoned, or truncated just below the ground surface and plowed over, or otherwise destroyed improperly. Such wells can contaminate groundwater in several ways:

- Contaminants enter the well from the surface.
- The well casing can corrode, allowing poor-quality water or contaminants to move vertically from one aquifer to another.
- The well might be used for direct (and illegal) disposal of waste.

Some basins in California have been shown to have 1,000 or more abandoned wells and significant cross-contamination of aquifers.

At a minimum, any work conducted on wells should be completed in accordance with Bulletin 74-90 by the California Department of Water Resources (California DWR, 1991). Some local enforcement agencies have adopted ordinances that contain more stringent standards than Bulletin 74-90. An appropriate local enforcement agency should be consulted prior to any work on wells.

Another type of well that often causes groundwater contamination is the “dry well”: a cased or uncased hole in the ground that does not penetrate the groundwater table. Such wells sometimes are used to dispose of a variety of potential contaminants, including household and septic wastes, rinsate from commercial and industrial operations, waste oil, solvents, and storm water runoff. The exact number of dry wells in California is not known. It may be true that, collectively, dry wells are a substantial source of groundwater contamination.

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