POINT SOURCE WATER CONTAMINATION

From the *Technology and Environmental Decision-Making* Series

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Cover image: Ground water monitoring wells, Cape Cod, MA. Credit: U.S. Geological Survey.

Point Source Water Contamination

Corroded pipes from Flint's water distribution system. Credit: Min Tang and Kelsey Pieper

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Introduction

"When the well's dry, we know the worth of water." –Benjamin Franklin

"Water that is filthy cannot be washed." –African proverb

In its best form, freshwater is tasteless, colorless, and odorless. It is then no surprise that it can fall beneath our notice in daily life. We turn our tap on, and water comes out in a seemingly endless supply until we turn it off. Technology allows us to take water for granted. Water supply, shortages, and contamination are things we read about in the news, not things most of us experience firsthand.

While technology does tend to create barriers between human beings and the natural world, these same scientific advances can ensure the quality and availability of the resources so necessary to our survival. But the possibility that human activity might be compromising crucial natural resources has been a major catalyst in bringing environmental concerns to our attention. Unfortunately, the public is often bombarded with seemingly contradictory analyses, assertions, and opinions, making it difficult to assess and address environmental concerns rationally. The way to combat this uncertainty is to ensure that environmental decision-making is grounded in the best available scientific data.

Decisions must be made to ensure the healthfulness of our drinking water, but few people understand exactly where drinking water comes from and the potential for chemical contamination of that water. Ground water accounts for over 50 percent of the world's drinking water and 43 percent of the water used for agriculture.[1] Current environmental concerns about ground water are focused in two main areas: quality and quantity of ground water resources.

This instructional module deals mainly with ground water quality and how it can be affected by industrial point source chemical contamination.

This module will also examine a current topic involving ground water: and the water contamination in Flint, Michigan.

The purpose of each section in the module is to provide the instructor with a brief summary of the different issues of the module topic, with links throughout to the case study. Located at the end of each section is a link to Aids to Understanding, which provides in-depth resources on that section's topic.

Contaminant Formation and Environmental Impact

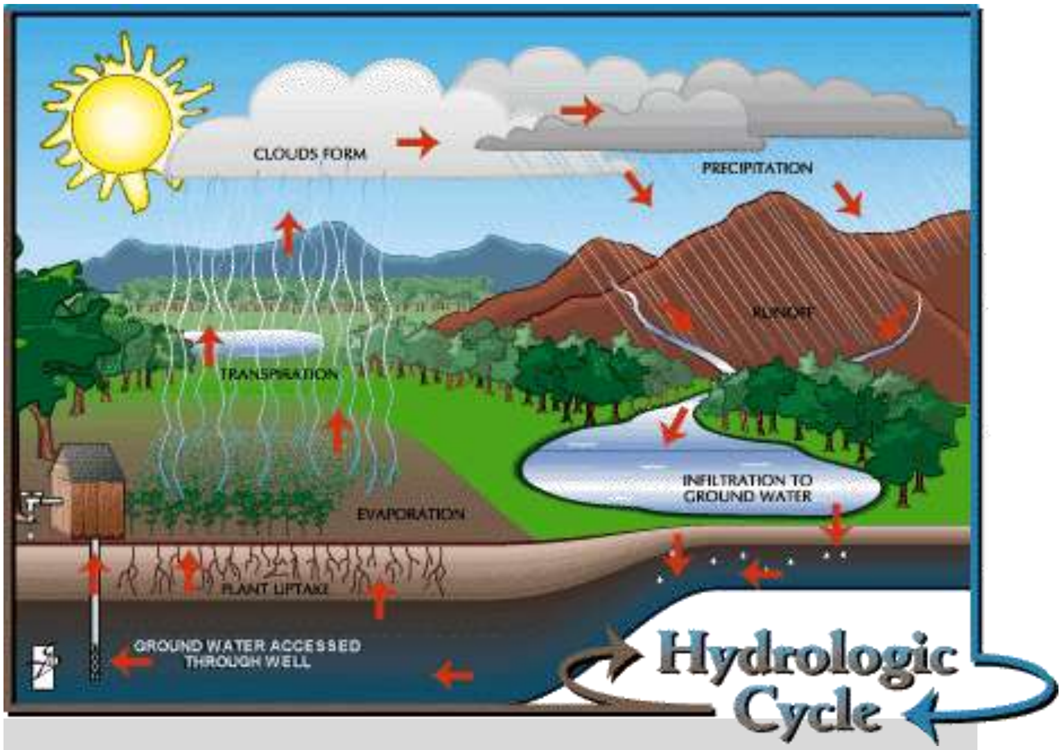
This section provides the instructor with a brief review of the facts—the basic science—involved in industrial point source contamination of ground water.

Hydrologic Cycle

Water constantly moves within and above the earth in the hydrologic cycle. This cycle operates continuously and receives energy from the sun. The hydrologic cycle consists of inflows, outflows, and storage. Inflows add water to the different parts, or processes, of the hydrologic system, while outflows remove water. Storage is the retention of water by parts of the system. Because water movement is cyclical, an inflow for one part of the system is an outflow for another. The six major parts of the cycle[2] include:

- Evapotranspiration
- Condensation
- Precipitation
- Infiltration
- Percolation
- Runoff

Figure 1. The Hydrologic Cycle



Credit: U.S. EPA

As an example, percolation of water into the ground is an inflow to an aquifer. Discharge of ground water from the aquifer to a stream is an outflow from the aquifer, as well as an inflow for the stream. Over time, if inflows to the aquifer are greater than its outflows, the amount of water stored in the aquifer will increase. Conversely, if the inflows to the aquifer are less than the outflows, the amount of water stored decreases. Inflows and outflows occur naturally and also result from human activity.[3]

Human Impact on Hydrologic Cycle

The earth's water supply remains constant, but humans can and do alter the cycle of that fixed supply. Population increases, rising standards of living, and industrial and economic growth have placed greater demands on natural resources. Human activities can create an imbalance in the hydrologic equation and affect the quantity and quality of natural water resources available to current and future generations.[4]

> "The cycling of water and our global interconnections mean that all of us are 'living downstream'—everyone on this planet. Thus, we need to step back and take a clear, dispassionate look at the world's supply of water, using all available tools, from the nanoscale to the global scale."
>
> Dr. Rita R. Colwell, Director of the National Science Foundation, in the 2002 Abel Wolman Distinguished Lecture

Water use by households, industries, and farms has increased steadily. People demand clean water at a reasonable cost, yet the amount of freshwater is limited and the easily accessible sources have been developed. As the population increases, so will the need to withdraw more water from rivers, lakes, and aquifers, threatening local resources and future water supplies. A larger population will not only use more water, but will discharge more wastewater.[5]

Domestic, agricultural, and industrial wastes (including the intensive use of pesticides, herbicides, and fertilizers) often overload water supplies with hazardous chemicals and bacteria. Also, poor irrigation practices raise soil salinity and evaporation rates. These factors contribute to a reduction in the availability of potable water, putting even greater pressure on existing water resources.[6]

Large cities and urban sprawl particularly affect local climate and hydrology. Urbanization is accompanied by accelerated drainage of water through road drains and city sewer systems, which increases further the magnitude of urban flood events. This process alters the rates of infiltration, evaporation, and transpiration that would otherwise occur in a natural setting. The replenishing of ground water aquifers occurs at a slower rate or does not occur at all.[7]

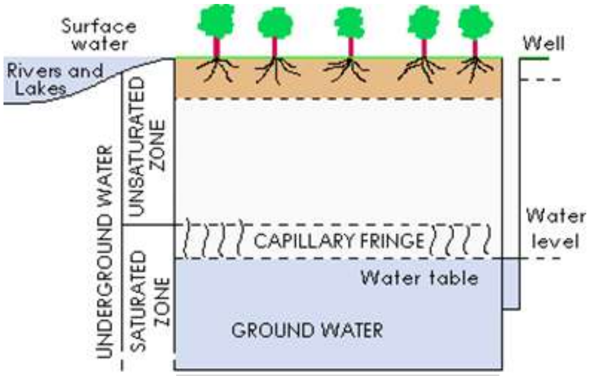
Together, these various effects determine the amount of water in the system and can result in extremely negative consequences for river watersheds, lake levels, aquifers, and the environment as a whole. Therefore, it is vital to learn about and protect existing water resources.[8]

For further details on the human impact on the hydrologic cycle, refer to *The Ground Water Primer* and *The Citizen's Guide To Ground-Water Protection*.

Hydrogeology

Hydrology is the science of water occurrence, movement, and transport. Hydrogeology is the part of hydrology that deals with the occurrence, movement, and quality of water beneath the earth's surface. Because hydrogeology deals with water in a complex subsurface environment, it is a complex science. On the other hand, much of its basic terminology and principles can be understood readily by non-hydrogeologists.[9]

Figure 2. Saturated/Unsaturated Zones



Credit: U.S. EPA

As shown through the hydrologic cycle, when rain falls to the ground, water flows along the land surface to streams or lakes, evaporates into the atmosphere, is taken up by plants, and seeps into the ground. As water begins to seep into the ground, it enters the unsaturated or vadose zone that contains both water and air. The upper part of this zone, known as the root zone or soil zone, supports plant growth and is crisscrossed by living roots, holes left by decayed roots, and animal and worm burrows. Below lies an intermediate zone, followed by a saturated capillary fringe, which results from the attraction between water and rocks. As a result of this attraction, water clings as a film on the surface of rock particles.[10]

Porosity is the ratio of the volume of voids to the volume of aquifer material. It refers to the degree to which the aquifer material possesses pores or cavities, which contain air or water.

Permeability is the capacity of a porous rock, sediment, or soil to transmit ground water. It is a measure of the inter-connectedness of a material's pore spaces and the relative ease of fluid flow under unequal pressure.

Water moves through the unsaturated zone into the saturated zone, where all the interconnected openings between rock particles are filled with water. It is within this saturated zone that the term “ground water” is correctly applied.[11]

An aquifer is a subsurface formation that will yield water in usable quantities to wells or springs. An aquifer can be visualized as a giant underground sponge that holds water and which, under certain conditions, will allow water to move through it. Depending on the type, the aquifer may contain both the saturated and unsaturated zones, or just the saturated zone.[12]

For water to move freely through a deposit, the pores and/or fractures must be large enough and connected enough to allow the free flow of the water moving past the particles. The key to the movement of ground water through an aquifer is the degree of its porosity and permeability.[13]

Ground water is withdrawn from wells to provide water for everything from drinking water for homes and businesses, to irrigate crops, to industrial processing water. When water is pumped from the ground, the dynamics of ground water flow change in response to this withdrawal.[14]

For further details on the basic terms and principles of hydrogeology, with graphics to aid in explanation, refer to *The Ground Water Primer*.

Another good explanation of ground water basics is available from the Groundwater Foundation.

Common Chemical Contaminants

According to the U.S. Environmental Protection Agency (EPA), at least 65,000 synthetic chemicals are commonly used in the U.S. today, and this number grows each year. Even when used properly, many chemicals still have the potential to harm human health and the environment. When these hazardous substances are thrown away, they can become hazardous waste. Hazardous wastes are often a byproduct of a manufacturing process, but they can also come from many other sources, including people's homes.[15]

Regardless of the source, unless disposed of properly, hazardous waste can create health risks for people and damage the environment. When hazardous waste is released into the air, water, or on the land, it can spread, contaminating a broad area and exposing more people to health risks. Proper management and control can greatly reduce the dangers of hazardous waste. In the past, improper management and disposal of hazardous waste created sites so badly contaminated that the U.S. government created a National Priority List to clean them up in an EPA program called Superfund.[16]

Hazardous wastes from a variety of sources have contaminated the ground water at many of these Superfund sites. This contamination can be caused in different ways. Typically rainfall seeps through the ground, comes in contact with buried waste or another source of contamination, picks up chemicals, and carries them into the ground water. Some pollutants spread quickly, while others spread over a period of years.[17]

Polluted ground water may affect drinking water; surface waters; and the people, plants, and animals near the site. Often the first clue that ground water is contaminated is when pollutants from a nearby site are found in local drinking water or monitoring wells. If left unchecked, ground water contamination can continue to spread, increasing the cost of future cleanup, reducing useful water resources, and potentially affecting more people.[18]

Read about various contaminants in drinking water: "What's in Your Drinking Water?"

Currently, the ground water contaminants of greatest concern are synthetic compounds. These contaminants are usually divided into organic substances and inorganic substances. Also of concern are various naturally occurring elements such as arsenic, radionuclides, and microbiological contaminants.[19] This module is concerned only with chemicals that result from industrial processes.

Organic chemicals have become a more frequently detected contaminant in ground water supplies. Solvents, pesticides, paints, inks, dyes, varnishes, and gasoline are just a few of the products that contain organic chemicals. Inorganic chemicals that are of most concern for ground water contamination include arsenic, silver, cadmium, mercury, and chromium.[20]

For a detailed listing of hazardous substances (both organic and inorganic), refer to the Centers for Disease Control and Prevention's (CDC) Agency for Toxic Substances Portal.

For contaminant charts with further details of drinking water standards levels, health risks, and water treatment methods, refer to *The Ground Water Primer*.

For further details on hazardous materials contamination, refer to the National Contaminant Occurrence Database (NCOD).

For further details on environmental impacts on water quality in the U.S., refer to the "National Water Quality Inventory Report."

Aids to Understanding provides resources and activities.

Fate and Transport

Definition

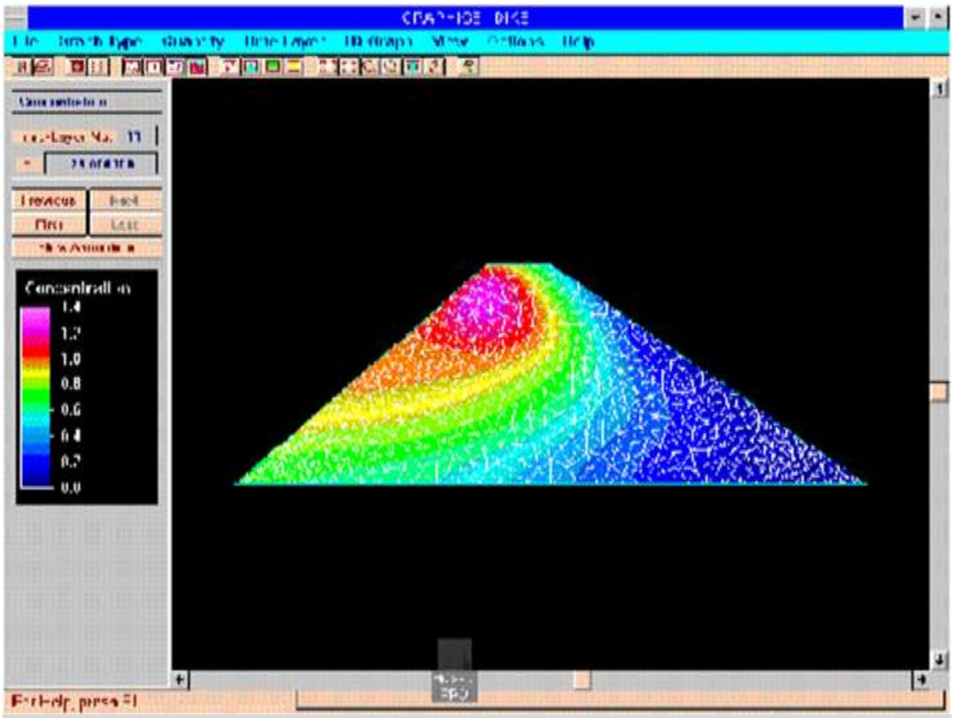
The phrase “fate and transport” is often used in the multidisciplinary fields of earth and environmental science. The study of fate and transport involves math (usually calculus), geology, hydrology, chemistry, engineering, and biology. The phrase usually refers to chemicals in the environment and, in particular, to contaminants or pollutants. The properties of the chemical and the media (air, water, and/or soil) in which the chemical exists affect the advection, dispersion, sorption, accumulation, and transformation of the contaminant.

In conjunction with fate and transport studies, scientists may also consider some aspects of hazard assessment—what the contaminant may encounter in terms of using water and what happens to a person if the contaminant is ingested, inhaled, or absorbed through the skin (exposure pathways).

Fate and transport is always a part of risk assessment for environmental cleanup. Often, if contamination will not adversely impact the environment in which it exists, it will simply be left to naturally attenuate. (In some cases, even if the contamination is harmful, it may be too expensive to clean up and is simply left to naturally attenuate.) The study of fate and transport is part of the evaluation process to determine the extent and effects of contamination and how to lower the risk.

Fate and transport is usually incorporated as part of a model of what will happen to a chemical if it is released. The model is usually developed as a computer program that evaluates a situation based on data collected or assumed about a site's parameters. The principal purpose of fate and transport modeling is to predict and quantify migration of contaminants in the environment that are subject to transport. Models are used to predict the migration of contaminants through soil, water, and air (or a combination of these) over time, with most models focusing on the following fate and transport processes.[21]

Figure 3. Chemical Dispersion Model



Credit: U.S. Department of Agriculture

- Advection, the movement of dissolved contaminants caused by the bulk movement of fluid (liquids and gasses).
- Dispersion, the three-dimensional spreading of dissolved constituents as fluid migrates through environmental media.
- Sorption, taking up and holding a particle, as by absorption and adsorption.
- Diffusion, the spreading of a mass of contamination.
- Equilibrium, the partitioning of a contaminant mass between solid and fluid (liquid and gas) portions of the environmental medium as a result of sorption chemical reactions.
- Biodegradation, the disintegration of contaminants by indigenous microorganisms along the migration pathway.
- Phase separation, the conversion of a solution into immiscible liquids.[22]

Simply put, fate and transport refers to scientific attempts to predict what will happen to chemicals in surface and subsurface environments.

For further details on the fate and transport of chemicals in the environment, refer to the Environmental Fate Data Base.

"Sources, Transport and Fate of Arsenic in Groundwater" provides a good example of a fate and transport study.

Sources of Ground Water Contaminants

Overview

A variety of human activities (stemming from agricultural, industrial, community, and residential needs), as well as natural processes, can contaminate ground water. Sources of contamination are referred to as point or nonpoint sources. Point sources are generally considered as localized sources of pollution, whereas nonpoint source pollution is dispersed from a very broad area or combination of areas. (To learn more about nonpoint source water contamination, refer to the *Nonpoint Source Water Contamination* module.)

This map shows locations of arsenic in U.S. ground water.

Agricultural (nonpoint) sources of contaminants include the use and storage of fertilizers and pesticides, and the disposal of animal and agricultural waste. Contaminants enter ground water from improper industrial processes for the storage, handling, and transporting of materials, and from the improper use of surface impoundments to store, treat, and dispose of wastewater and liquid wastes. Mining operations, leaking underground storage tanks (LUSTs), and improperly managed hazardous waste sites are also significant sources of water contamination.[23]

Community and residential waste disposal, including septic systems and improper storage and disposal of chemicals in our homes, also contributes to water contamination. A major cause of ground water contamination comes from residential effluent, or outflow, from septic tanks and cesspools. Finally, natural substances found in rocks or soils (such as arsenic, iron, manganese, chloride, fluoride, and sulfate) can dissolve and contaminate water.[24]

For further details on the different sources of residential ground water contamination and the different sources of chemical contaminants of ground water, refer to *The Ground Water Primer*.

For further details on watershed and water quality-based assessment and integrated analysis of point and nonpoint sources, refer to "Better Assessment Science Integrating Point and Nonpoint Sources (BASINS)."

Industrial Sources

This module concentrates on industrial point sources of ground water contamination. Modern economic activity requires the transportation and storage of materials used in manufacturing, processing, and construction. Along the way, some of this material can be lost through spills, leaks, or improper handling. Even the cleanup of spills can pose a threat to ground water, when the spills are flushed with water rather than cleaned up with absorbent substances.[25]

The disposal of wastes associated with industrial and commercial activities contributes another source of ground water contamination. Some businesses, usually without access to sewer systems, rely on shallow underground disposal. They use cesspools, dry holes, or send the wastewater into septic tanks. Any of these forms of disposal can lead to contamination of underground sources of drinking water. Dry holes and cesspools introduce wastes directly into the ground. Septic systems cannot treat industrial wastes.[26]

Wastewater disposal practices of certain types of businesses, such as automobile service stations, dry cleaners, electrical component or machine manufacturers, photo processors, and metal platers or fabricators are of particular concern because the waste they generate is likely to contain toxic chemicals. Other industrial sources of contamination include cleaning holding tanks or spray equipment on the open ground, disposing waste in septic systems or dry wells, and storing hazardous materials in uncovered areas or areas that do not have pads with drains or catchment basins.[27]

Although most businesses have proper disposal procedures in place, small amounts of waste fluids can end up on the shop floor and be washed down floor drains. These drains may be connected to shallow-injection well systems, which are not designed to handle the industrial chemicals typically used by businesses such as those listed above. Even low concentrations of certain contaminants can accumulate through time.[28]

Underground and aboveground storage tanks that hold petroleum products, acids, solvents, and chemicals can develop leaks from corrosion, defects, improper installation, or mechanical failure of the pipes and fittings.[29]

Mining of fuel and nonfuel minerals can create many opportunities for ground water contamination. These types of problems stem from the mining process itself, disposal of wastes, and processing of the ores and the wastes created.[30]

For further details on the different sources of industrial ground water contamination, refer to *The Ground Water Primer*.

Aids to Understanding provides resources and activities.

Measuring and Monitoring

Environmental Measurements

Ground water monitoring wells. Credit: U.S. Geological Survey (USGS)

When discussing environmental contamination, the words "measuring" and "monitoring" tend to bring to mind high-tech processes. But the effectiveness of the equipment (especially simulation models and qualitative judgments for measuring, monitoring, and remediation techniques) is limited by the scientist's ability to make efficient and accurate field and laboratory measurements. This limitation holds true for properties as fundamental as stream flow and as complex as the concentrations of a trace contaminant in different media (water, sediment, and tissue). Techniques include:

- aquifer and tracer tests to determine flow and transport properties in unconsolidated and fractured-rock aquifers.
- stream tracers to determine contaminant sources and dispersal, and surface and borehole geophysics that indicate subsurface properties.
- measurement of chemical tracers, such as bromide, CFCs (chlorofluorocarbons), or isotopes that indicate relative age and source.
- measurement of the concentration of pesticides and their environmental breakdown components.[31]

For further details on environmental measurements, refer to "Methods" from the U.S. Geological Survey (USGS).

Water Contamination Measurement Techniques—Field Methods

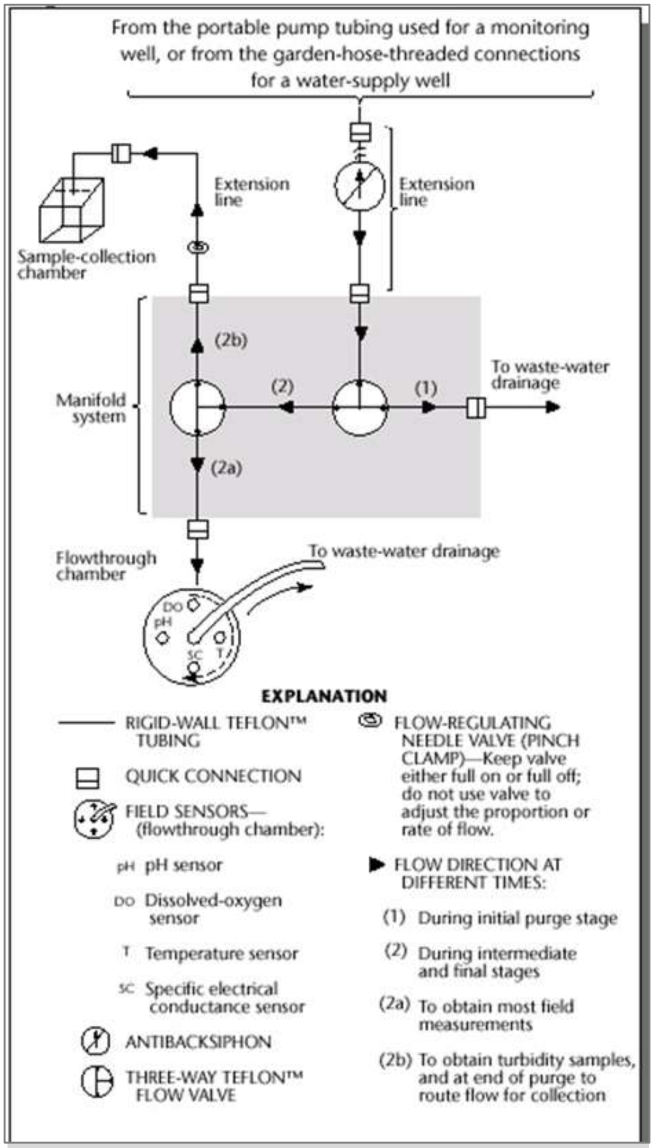
The "National Field Manual for the Collection of Water-Quality Data" describes protocols and provides guidelines for personnel who collect data used to assess the quality of surface water and ground water resources. These personnel must perform field trip preparations (including selection of sample collection sites) and site reconnaissance and well selection for studies of water quality, and establish electronic files and field files for a sampling site.[32] Generally, the process of measuring water contamination includes:

- collection of water data by direct measurement.
- collection of environmental data.
- application of hydraulics.
- hydrologic analysis and interpretation.
- laboratory analysis.
- data processing and computations.
- modeling.[33]

For further details on water quality data collection/analysis, refer to:

- "National Field Manual for the Collection of Water-Quality Data."
- EPA's CLU-IN
- Field Sampling and Analysis Technologies Matrix
- *Investigating Groundwater Systems on Regional and National Scales*
- "Flexible Approaches to Environmental Measurements"
- "Techniques of Water-Resources Investigations of the USGS"

Figure 4. Sample Page from Field Manual



Credit: USGS

For further details on environmental monitoring and assessment, refer to the National Aquatic Resource Surveys (NARS).

Computer Modeling

Ground water computer models attempt to represent an actual ground water system with a mathematical counterpart. The conceptualization of how and where water originates in the ground water flow system, and how and where it leaves the system, is critical to the development of an accurate model. The mathematical representation of these boundaries in the model is important because many hydrologic boundary conditions can be mathematically represented in more than one way. The determination of the most appropriate mathematical representation of a boundary condition usually depends on the objectives of a particular study.[34]

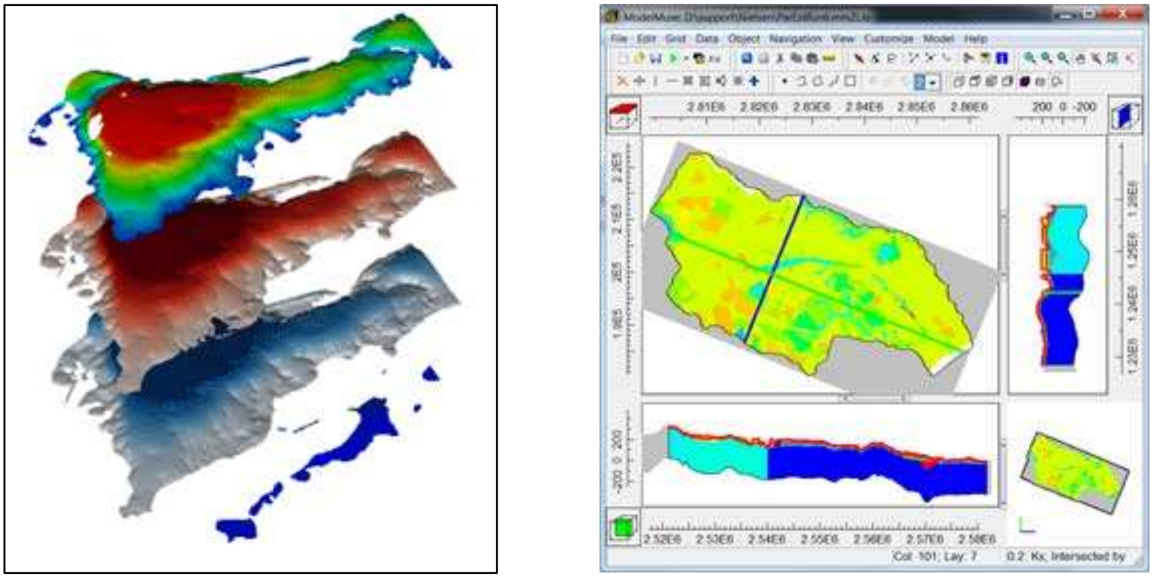
Darcy's Law of Thermodynamics– The flow rate of water is equal to the hydraulic conductivity times the driving force (typically gravity and pressure differences).

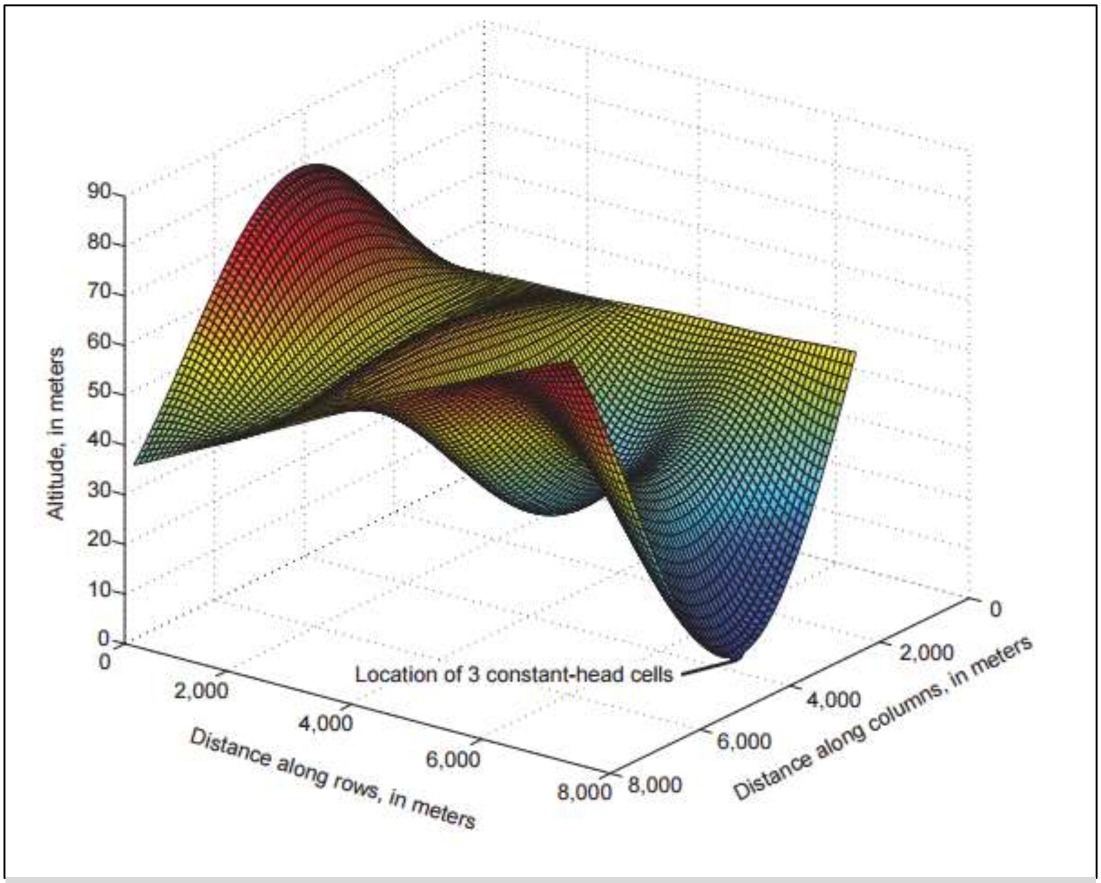
USGS

One of the most widely used, basic ground water flow modeling software programs is the Modular Finite-Difference Ground-Water Flow model (MODFLOW) developed by the USGS. MODFLOW is a computer program for simulating ground water flow and common features in ground water systems. The program is designed to simulate aquifer systems in which the following common aquifer conditions exist:

- Saturated-flow
- Darcy's Law applies
- Constant density of ground water
- Unvaried principal directions within the system of horizontal hydraulic conductivity or transmissivity[35]

Figure 5. Three Examples of MODFLOW Applications





Credit: USGS

For these systems, MODFLOW can simulate a wide variety of hydrologic features and processes. Steady-state and transient flow can be simulated in unconfined aquifers, confined aquifers, and confining units. A variety of features and processes such as rivers, streams, drains, springs, reservoirs, wells, evapotranspiration, and recharge from precipitation and irrigation can be simulated also. At least four different solution methods have been implemented for solving the finite-difference equations that MODFLOW constructs. The availability of different solution approaches allows scientists to select the most efficient method for their individual applications.[36] (See Figure 5 for examples of MODFLOW applications.)

For further details on modeling, refer to "Water Resources Groundwater Software" and "Modeling Software."

Aids to Understanding provides resources and activities.

Health Effects

Human Health Effects of Contaminants in Drinking Water

Credit: U.S. EPA

Ground water is the source of much of the drinking water in the U.S. The EPA sets standards for contaminants that may occur in drinking water and pose a risk to human health (especially vulnerable groups, such as children). These contaminants fall into two groups, acute and chronic, according to the health effects that they cause. Local water suppliers alert customers through the media, mail, internet forums, or other means if there is a potential adverse health effect from compounds in the drinking water.[37]

For details on drinking water standards, refer to "Drinking Water Contaminants – Standards and Regulations."

Acute effects are those that occur within hours or days of consuming a contaminant. People can suffer acute health effects from almost any contaminant, especially if exposed to extraordinarily high levels (as in the case of a spill). In drinking water, microbes—such as bacteria and viruses—are the contaminants with the greatest chance of reaching levels high enough to cause acute health effects. Most people's bodies can fight off these microbial contaminants the way they fight off germs, avoiding permanent effects. Nonetheless, high enough contaminant levels can make a person ill, especially if the immune system is already weak due to HIV/AIDS, chemotherapy, steroid use, or other reasons.[38]

Chronic effects are those that occur for many years after consuming a contaminant at levels over the EPA's safety standards. The drinking water contaminants that can produce chronic effects are chemicals (such as disinfection byproducts, solvents, and pesticides), radionuclides (such as radium), and elements (such as arsenic). Examples of the chronic effects of drinking water contaminants are cancer, liver or kidney problems, or reproductive difficulties.[39]

Refer to "Toxic Substances Hydrology Program" for more information on the toxicity of a variety of chemicals.

Human Health Risk Assessment

Scientists generally study the effects of chemicals on humans through epidemiological and toxicological studies. Epidemiology focuses on the frequency and distribution of diseases in human populations. Toxicology focuses on the actions and detection of toxic chemicals, usually through animal studies.

In the simplest sense, human health risks from toxic contaminants are a function of two measurable factors: **hazard** and **exposure**. To cause a risk, a chemical has to present a hazard and has to be present in the human environment at some significant level. Risk assessment, therefore, is an interpretation of the evidence of hazard and exposure. It provides a judgment on whether or not adverse effects will occur and, if appropriate, provides the calculations necessary to estimate the extent of such effects.[40]

The framework for risk assessment helps to organize information gathering and scientific interpretation of facts that help formulate regulatory decisions and environmental management strategies. For each part of the risk assessment process—hazard identification, dose-response assessment, exposure assessment, and risk characterization—data is gathered and interpreted, and inferences are made about risk factors. Often, the interpretation of the information is expressed as the best scientific judgment on the part of the risk assessor or the investigating group of scientists.[41]

Hazard identification, the first step in the process of health risk assessment, involves weighing the available evidence and deciding whether a particular substance causes an adverse health effect. It may also involve characterization of the behavior of a chemical within the body and its interaction with organs, cells, or even parts of cells.[42]

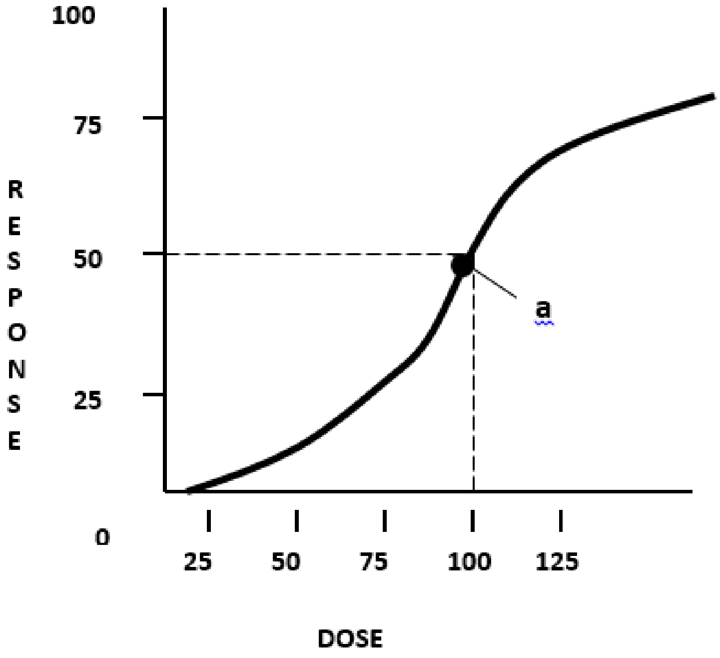
Adequate epidemiological studies can provide the most important data in an assessment. Unfortunately, such data is not often available, and assessments often depend on animal tests. Such tests allow rigorous control over many factors that contribute to uncertainty. However, since animal biological systems differ from those of humans, some species will appear more sensitive than humans to certain substances and less sensitive to others.[43]

Dose-response assessment is the process of characterizing the relationship of the dose of the toxicant received and the incidence of adverse effects in the exposed population. While the hazard identification process helps determine whether a chemical is likely to cause a particular effect in humans or animals, dose-response studies help quantify the effect: how strongly a substance elicits that response at various levels of exposure (dose). Chemical potency varies widely; for instance, chemical A and chemical B might both cause cancer in animals, but it might take millions of times more of chemical A than of chemical B to produce tumors in test animals.[44]

For specific dose-response data, refer to the *Integrated Risk Information System (IRIS)* and enter the name of a specific chemical.

When animal dose-response is extrapolated to humans, adjustments must be made to correct human/animal differences in sensitivity and pharmacokinetics. Usually, effects at low dosages are inferred from high dose results of laboratory or epidemiologic studies. While some differences can be adjusted for, many more are not understood well and thus pose uncertainties. (For instance, animals and humans may differ in susceptibility based on age, sex, genetic diversity, state of health, lifestyle, or other heterogeneous factors.)[45]

Figure 6. Typical Dose-Response Curve



Exposure assessment is the process by which exposure and dose to humans are estimated. Exposure occurs when humans come into contact with a toxic contaminant. The dose, on the other hand, is the actual amount of the substance taken into the body. Environmental exposure can occur through ingestion, inhalation, or dermal absorption. The route of exposure generally affects the extent of absorption and therefore the dose. Exposure and dose are considered when assessing risk because:

- a toxic substance must reach biologic receptors (e.g., organs or cells) to elicit a response.
- the production and degree of a response are related to the dose of the toxicant at the receptor.
- the exposure concentration and the route of exposure significantly affect the dose of the toxicant at the receptor.[46]

Exposure assessment is based on ambient monitoring, modeling, or some combination of these. Human data and monitoring typically are quite limited, usually because of limited resources.[47]

Exposure modeling provides useful support when scientists are faced with inadequate research or a lack of epidemiologic data. In these instances, data on contaminant releases, release characteristics, meteorology, hydrology, terrain, and other factors are considered and used to estimate the distribution of contaminants. Census data and routes of exposure are also considered when making final exposure estimates.[48]

Risk characterization is the combination of hazard identification, dose-response information, and exposure information. While the final calculations for risk are straightforward, the way in which the information is presented is important. The final assessment should display all relevant information pertaining to the decision at hand, including such factors as the nature and weight of evidence for each step of the process, the estimated uncertainty of the component parts, and the distribution of risk across various sectors of the population.[49]

For further details on the assessment of hazardous waste and toxic substance risks to human health, refer to the "Public Health Assessment Guidance Manual."

For further details on health data standards, scientific data, surveillance, health statistics reports, and laboratory information, refer to the Centers for Disease Control and Prevention (CDC).

For further information on teaching epidemiology, refer to "EXcellence in Curriculum Integration through Teaching Epidemiology" (EXCITE).

Additional online data related to human health risk assessment is available from the National Library of Medicine's "TOXNET Toxicology Data Network."

Aids to Understanding provides resources and activities.

Decision-Making

The Role of Science in Decision-Making

Personal Decision-Making about Chemical Risks

Recent information about the amounts of chemicals released to the environment has heightened public concern about the health effects of chemicals in food, air, water, and households. Citizens in today's highly technical society are faced with vast amounts of information about the risks and benefits of chemicals.

Most people feel it is their responsibility to base the personal decision-making process on a basic understanding of the science involved, the capabilities as well as the limitations of science, and an appreciation of the risks and benefits afforded by chemicals.

Personal decisions about chemical exposures involve:

- evaluating the situation's risk.
- applying this evaluation to discriminate between serious and less serious risks.
- accepting a certain degree of risk.

This decision-making process can help citizens determine their support or opposition to actions that contribute to public exposure to chemicals.

Chemicals comprise each and every thing in our world—animals, plants, minerals, water, and air. Many natural processes are simply chemical changes, such as the growth of plants and animals, fire, and the corrosion of metal. Similarly, many manufacturing processes involve chemicals, such as those for pharmaceuticals, steel, cleaning products, paints, synthetic fibers, and food products.

Every day, people are exposed to the many chemicals present in the environment. Some exposures entail risks to health. The risk may be low, since the concentrations of most potentially toxic chemicals in the environment are low. Sometimes, however, the risk is high, since certain chemicals are harmful to health, even at relatively low concentrations. These chemicals may be natural or synthetic and may occur in the form of liquids, solids, or gases. The chemicals may be substances in foods and common household products; or contaminants in air, water, and soil.

Many exposures to chemicals in the environment are involuntary. For example, people have no direct, personal control over exposure to a number of common air pollutants emitted by others, such as the carbon monoxide emitted by automobiles. Other exposures are mainly or entirely voluntary, such as the use of household cleaners and pesticides, or activities such as smoking or pumping gasoline. For example, exposure to toxic chemicals in household products can be reduced by carefully following the directions for use or by switching to products with less harmful ingredients.

Personal decisions about exposure to toxic chemicals need to be based on the answers to several questions.

- Why should a certain chemical be of concern?
- What risk does it pose?
- How can exposure be avoided or minimized?
- What will such action cost, in terms of money or changes in behavior?
- What will be gained in return?

Sometimes these questions are easy to answer, but just as often they are not. Little thought is needed to decide to keep household chemicals out of the reach of small children. On the other hand, imagine experiencing a recurring symptom, such as a rash or a headache, with no obvious cause. Is the symptom caused by a chemical and, if so, which one? Or suppose a local newspaper reports that the air in the region contains a potentially hazardous contaminant. How does one assess the significance of such a report? Questions like these can be difficult to answer without some research.

Even with 21st century advances in technology, scientists are not always able to provide clear-cut answers. Still, basic knowledge and a logical approach can help supply information to make decisions. Data on chemical exposure provides a framework for making decisions and is organized by addressing these issues in the decision-making process:

- Basic safeguards that protect us from exposure
- Process of regulating chemicals
- Sources and exposures to chemicals
- Bases for decisions, including a discussion of short-term and delayed effects
- Examples of personal decisions about radon, lead in drinking water, and pesticides
- Decision guidelines that can be applied when assessing the information

Aids to Understanding provides resources and activities.

Issue in Focus—The Flint Water Crisis

Introduction

In 2015, problems with the water supply in Flint, Michigan came to national attention. Reports surfaced of high levels of lead in the drinking water. Since then, details have emerged that revealed a series of decisions that resulted in one of the worst municipal emergencies in the history of the U.S.

Typically, a discussion on polluted surface water sources would be more appropriate for nonpoint source water contamination. However, the Flint water crisis was not just about polluted water. It was about how polluted water interacted with an outdated water system to create a series of point source contaminations that caused irreparable harm to the health of many Flint residents.

At the heart of the Flint water crisis were a series of decisions that placed economic concerns above environmental and health concerns. These decisions were made at multiple levels of government. Investigations are ongoing that have produced criminal charges and prompted civil suits.

Background

When the city of Flint's water system was built, it was designed for a population of 250,000 with room for expansion. In the 1960s, the population peaked at nearly 200,000. However, Michigan's well-documented manufacturing and overall economic decline led to unemployed residents leaving the area to find work. Thriving communities were reduced to shells of their former selves. Flint's population dwindled to approximately 100,000 by 2014. This meant that fewer people had to bear the cost burden of a water system designed for a much larger population.[50]

As often happens when times are tough, proactive infrastructure improvements and preventative maintenance came to a halt for several public entities. Unfortunately, this included the water distribution system. Over time, parts of the water distribution system broke. By then, the cost to repair the damage was several times higher than the cost of the preventative maintenance would have been.[51] This type of scenario is known as an "infrastructure death spiral." The high water rates caused residents to leave Flint, which increased the rates for the remaining residents. By 2014, residents of Flint were paying a water rate of $3.84 per cubic meter while the average U.S. citizen only paid $0.51.[52]

Figure 7. Water Cost Comparison

Country	Dollars per cubic meter
Flint MI	$3.84*
Germany	$1.91
Denmark	$1.64
Belgium	$1.54
Netherlands	$1.25
USA	$0.51
Australia	$0.50
South Africa	$0.47
Canada	$0.40

Credit: MLive Media Group

Until the 1960s, Flint's water treatment plant used the Flint River as its source. The city then switched the water treatment plant to receive water from the Detroit Water and Sewage Department (DWSD), which is sourced from Lake Huron and the Detroit River. Because the cost of water had risen so high, city and state officials began looking for alternative water suppliers. In April of 2013, these officials notified the DWSD that they were going to transition city water services to the Karegnondi Water Authority (KWA). They planned to build a new pipeline to the KWA, saving an estimated $200 million over 25 years.[53] The DWSD terminated its agreement with city of Flint, effective one year later, in April of 2014.

Building this new pipeline was scheduled to take approximately three years. The city needed a water source for the period of time between the end of its agreement with DWSD and the new KWA system becoming operational. On April 25, 2014, the Flint water treatment plant began using water from the Flint River.[54] Press releases at the time of the switch characterized Flint River water as safe and drinkable. Michael Prysby, of the Michigan Department of Environmental Quality's (MDEQ) Office of Drinking Water, verified that "the quality of the water being put out meets all of our drinking water standards and Flint water is safe to drink." Mayor (Dayne) Walling said, "It's regular, good, pure drinking water, and it's right in our backyard. This is the first step in the right direction for Flint, and we take this monumental step forward in controlling the future of our community's most precious resource."[55]

As soon as May 2014, residents started to complain about the quality of the water. In January 2015, the city was found in violation of the Safe Drinking Water Act by MDEQ for levels of total trihalomethanes (TTHM) that exceeded the federal allowance. TTHM is a chemical compound that is produced when organic matter in water reacts to chlorine disinfectants, and can cause a variety of illnesses or death.

In February 2015, a water test at the home of Flint resident Lee Anne Walters showed lead content of 104 parts per billion (ppb). The EPA has a legal limit of 15 ppb. By September 2015, tests began to show more and more homes had elevated lead levels. Most notably, a team from Virginia Tech tested hundreds of homes and found that 90 percent had lead levels averaging 25 ppb. The Virginia Tech team recommended that residents install filters certified for removing lead, or flush the water lines for five minutes before collecting water to be used for cooking or drinking.[56]

On September 24, doctors from Hurley Medical Center (located in Flint) shared the results of a study that tested lead levels in children five years old and younger. They found that 2.1 percent of these children had elevated lead levels before the city switched to the Flint River as their water source, and 4.0 percent after the switch. The next day, Flint city officials issued a lead advisory to city residents.[57]

Measures were implemented to stem the lead problem with free water testing and water filters for residents. On October 16, 2015, a new agreement was made with the DWSD (renamed the Great Lakes Water Authority) to provide water services to the city of Flint. Unfortunately, this was too little, too late. On December 14, 2015, Mayor Karen Weaver declared a state of emergency due to the elevated lead levels.[58]

The Contamination

So what exactly was in the Flint River water, and how did it get there? The Flint River has a long, troubled history of numerous pollution events.

- Starting as far back as the 1830s, lumber mills introduced industrial waste into the river. Paper mills later brought in chemical processing waste.
- A population explosion in the early 1900s meant that 150,000 people were using water from the Flint River for drinking and industrial use, all while discharging untreated waste back into the river.
- By the 1930s, residents began to notice that fish were disappearing. Pollution had lowered the oxygen levels in the water, causing the fish to suffocate.[59]
- By the 1960s, the Flint River was being polluted by factories, landfills, and the city's wastewater treatment plant. No significant improvements to the Flint River were made until the passage of the Clean Water Act in 1972.
- A 1974 study of the Flint River showed that standards created by the Act improved the quality of the river upstream. Downstream, however, the river still contained raw sewage that produced fecal coliform bacteria. Phenol and ammonia discharged from industrial and municipal plants caused skin rashes, cardiovascular and gastrointestinal disorders, as well as other health problems.[60]

- Also in 1974, heavy fertilizer use resulted in higher levels of phosphates in the water. These phosphates stimulated algae growth, eventually shrinking the water's oxygen levels. Landfills also polluted the grounds and ground water that interacted with the river.
- By the 1980s, as the automotive industry faced serious decline, land along the river that was sold back to the city of Flint contained contaminants including arsenic, mercury, lead, toxic solvents, volatile organic compounds, and polynuclear aromatics.
- Various point source pollution events continued throughout the 1990s. Notably, a 1990 illegal dumping of methylene chloride, toluene, xylene, and lead produced 65 gallons of toxic sludge. This necessitated the removal of 527,000 cubic yards of contaminated soil on the banks of the Flint River.
- In 1999, the river was polluted by a massive construction accident. While digging a ditch to lay fiber optic cable, a subcontractor accidentally opened a 360 square-inch hole in a wastewater pipe. Over two days, 22 million gallons of raw waste emptied into the river. This caused city officials to ban swimming, fishing, or coming directly into contact with the water for 14 months.[61]

As part of an effort to clean the state's water sources, Michigan passed a law in 2000 requiring the municipal and county authorities to report sewage spills to the Department of Environmental Quality. Reports flowed in under an amnesty program that revealed 90 illegal sewage overflows into the Flint River had occurred in the five years before the law was passed. Even after the passage of the state law, the city itself continued to dump untreated or partially treated sewage into the river.[62]

This continued pollution of the Flint River laid the groundwork for a contaminated water supply that required massive amounts of treatment.

Science Behind the Crisis

Water tests conducted in August 2014 were positive for total coliforms. Total coliforms are used to measure the effectiveness of water treatment and the integrity of the water distribution system. If total coliforms are detected, it does not necessarily imply contamination, but it does indicate that further testing is required. Two tests confirmed the presence of total coliforms, prompting Flint city officials to issue a water boiling notice.[63]

For more information on coliform bacteria, see the New Hampshire Department of Environmental Sciences' fact sheet entitled "Interpreting the Presence of Coliform Bacteria in Drinking Water."

Many states provide information about testing water for coliform bacteria. Maine provides this informational sheet for proper sample collection.

Total coliforms can indicate fecal coliform or Escherichia coli (E. coli) contamination, bacteria associated with human or animal feces. These microbes can cause a variety of health problems including diarrhea, nausea, and headaches. They can also present significant health risks for infants, young children, the elderly, or those with compromised immune systems.[64] In response to the confirmation of total coliforms in the water, city officials increased the amount of chlorine used to treat the water. However, they did not implement Corrosion Control Treatment (CCT).

CCT is a tool used for keeping elements of a water supply from interacting in a negative way with the water's means of transport to the public. Corrosion is one of the leading causes of copper and lead contamination in drinking water.

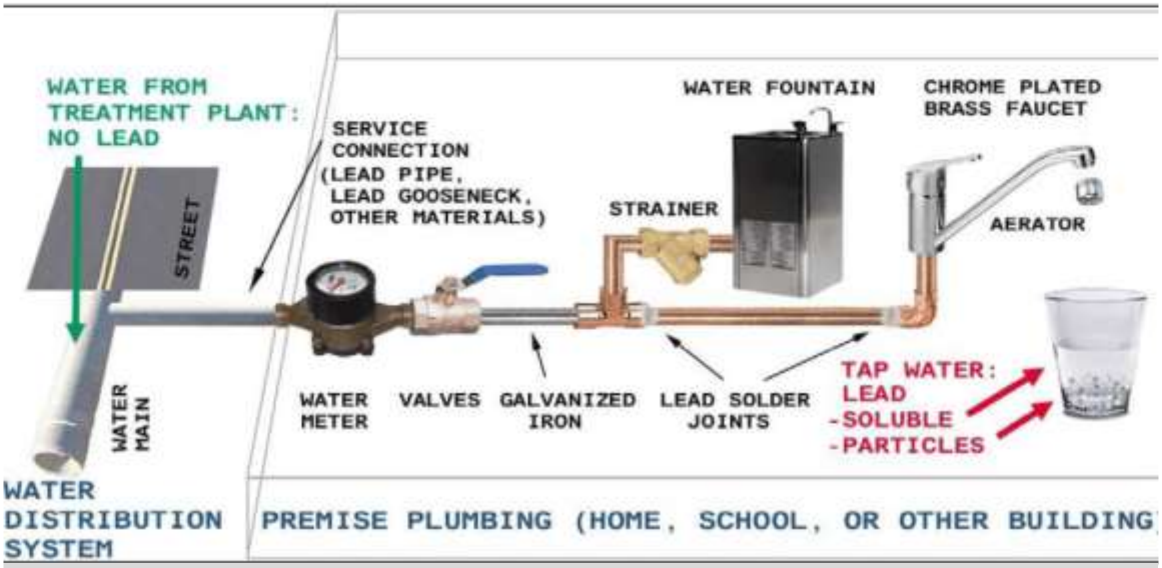
Corroded pipes from Flint's water distribution system. Credit: Min Tang and Kelsey Pieper

River and inland water sources typically have higher levels of chloride than other sources of water, in part due to the salt used to deice roads during the winter. (Runoff carries chloride ions to streams, rivers, and other waterways.)[65] Flint River water contained eight times more chloride than the water provided by the DWSD. Because city and state officials had decided not to implement CCT, the iron and lead pipes, valves, soldered joints, and other distribution components of the water system were exposed to highly-corrosive chloride levels. The water corroded lead out of the water distribution system and introduced it straight into the water itself. The corrosion was exacerbated by the fact that the water flowed more slowly through the system due to the smaller population drawing water.[66]

It can be easy to confuse "chlorine" and "chloride." For an explanation of the differences, please see "Chloride – Chlorine… What's the Difference?" by Alexander G. Schauss, Ph.D.

The corrosion of the iron pipes also consumed the chlorine that was meant to limit the growth of microorganisms, leaving the water filled with contaminants like coliform bacteria and TTHM.[67]

Figure 8. Potential Sources of Lead Contamination



Credit: Simoni Triantafyllidou & Marc Edwards

Health Effects of Flint Water Crisis

Lead is not safe for anyone, but it is especially harmful to young children. According to the World Health Organization, “lead affects children's brain development, resulting in a reduced intelligence quotient, behavioral changes such as a shortened attention span and increased antisocial behavior, and reduced educational attainment. Lead exposure also causes anemia, hypertension, renal impairment, immunotoxicity, and toxicity to the reproductive organs."[68]

For example, Lee Anne Walters, whose early water test confirmed high levels of lead, has been affected forever. Her five-year-old twin sons suffer from memory loss, physical growth problems, and hand-eye coordination issues.[69]

The unfortunate reality facing Flint residents is that there are no medicines to treat the effects of the developmental damage caused by lead. At best, blood tests allow scientists to track children who have been affected in order to study the short- and long-term harm of the lead poisoning.[70]

In addition to lead poisoning, it is suspected that Flint’s water may have played a role in an outbreak of Legionnaire’s disease. During 2014 and 2015, 78 people in Genesee County contracted Legionnaire’s disease; 12 people died. As of February 2017, there is an ongoing investigation into whether the outbreak was localized to McLaren-Flint Hospital, or if it is indeed systemic to the Flint water system.[71]

Environmental Decision-Making

For the city of Flint, what began as a financial problem turned into a health crisis. Flint's lower population and aging infrastructure contributed to high water costs, forcing city officials to seek an alternate source of water.[72]

From here, officials made three significant choices. First, they decided to use the Flint River as a temporary water source while switching their water supply from the DWSD to the KWA. Second, while officials added chlorine to the river to fight bacteria, they did not implement corrosion control treatment to keep the water from damaging the water distribution system and contaminating the water. Third, a state-appointed emergency manager overrode a Flint city council vote to return to using DSWD's water system in March of 2015.

This speaks to the larger problem of financial concerns taking priority over environmental damage. Difficult economic times in Flint focused public attention on cutting costs wherever possible. City officials were planning to save approximately $140 per day by not implementing corrosion controls.[73] However, the cost of cleaning up the water, fixing the infrastructure, and dealing with the health fallout from the water crisis is almost inestimable.

How did Flint get to this point? Who made the decisions that created this municipal public health emergency? On March 21, 2016, the Flint Water Advisory Task Force (FWATF) published the results of an independent investigation into the Flint water crisis. According to the FWATF, MDEQ is primarily at fault for the Flint water crisis, although other organizations failed in their roles in environmental protection.

In all, the FWATF published 36 findings in their investigation. These findings are summarized below.

MDEQ bears the primary responsibility for the water contamination in Flint. MDEQ misinterpreted the EPA's Lead and Copper Rule, leading to high levels of lead exposure. MDEQ also waited months before accepting an offer from the EPA to engage its lead experts in the problem. MDEQ failed to quickly investigate reports of problems with the water supply. Finally, they dismissed reports that could have led to corrective action, had they followed through properly.

The Michigan Department of Health and Human Services (MDHHS) was found to have a lack of timely analysis and understanding of the data on childhood blood lead levels and failed to share data with the necessary parties. Additionally, the MDHHS screened too few children for lead. They also bear responsibility for coordinating leadership and follow-up efforts across the state for lead poisoning issues. Communication with MDEQ was found to be inadequate; when it existed, it was primarily to conclude that health problems were not related to switching water supplies.

The Michigan governor's office was found to have relied on incorrect information provided by MDEQ and MDHHS despite the fact that the governor's executive staff recommended switching back to the Detroit water supply as early as October 2014. The governor's office bears responsibility for relying exclusively on one or two departments for information. Statements issued to the public were often inappropriate and unacceptable.

State-appointed emergency m**anagers** helped make the decision to switch to using the Flint River as a water source, and later rejected switching back to the DWSD (as Flint city officials and the public demanded). Emergency managers were meant to deal with financial reform and did not have the necessary expertise to make these kinds of environmental decisions. Combined with the MDEQ's failures, this places primary accountability for the Flint water crisis at the state government level.

The city of Flint was not prepared to adequately run the local water treatment plant or distribution system. The city's lack of investment in infrastructure contributed to the crisis. Flint city officials also failed to use corrosion control treatment and lead monitoring, over-relying on flawed MDEQ information and policies.

The Genesee County Health Department was found to have inadequate communication, coordination, and cooperation with the city of Flint and the MDHHS. Follow-up medical investigation on children with elevated blood levels was unacceptable.

The United States Environmental Protection Agency (EPA) failed to promptly exercise its authority in enforcing environmental regulations in Flint. The EPA failed to hold MDEQ accountable for sufficiently complying with the Lead and Copper Rule.[74]

Investigations into the events surrounding the Flint water crisis are ongoing, and new developments arise seemingly on a monthly basis. Several civil lawsuits have been filed. Criminal investigations are also resulting in charges being brought up against several officials. As of February 2017, charges have been filed against 13 people: Michael Prysby, Stephen Busch, Liane Shekter-Smith, Adam Rosenthal, Adam Cook, Nancy Peeler, Robert Scott, Darnell Earley, Jerry Ambrose, Daugherty Johnson, and Howard Croft. Michael Glasgow and Corinne Miller were also charged, and elected to enter plea deals to provide more information to prosecutors.[75] More people may be charged with crimes as the investigation continues.

The Future

The Flint water crisis is a story of financial hardship, environmental decisions, criminal behavior, and dire health consequences. Cleanup efforts are ongoing, and the health effects will need to be studied for years to come. The only surefire way to prevent future lead poisoning would be to replace the current water distribution system in Flint, which is projected to cost up to $1.5 billion.[76]

If there is any positive outcome to be gained, it is that other cities across the country are seeing the real costs of taking environmental decision-making lightly. Flint's economic and infrastructure challenges are not unique. For example, lead pipes in East Chicago are leaching dangerous levels of lead into the water due to a lack of corrosion control. In contrast to its performance in Flint, the EPA is taking a leadership role to expose and address the problem, in part by creating public awareness and providing lead filters at a much earlier stage than it did in Flint.[77]

The top nail was exposed to DWSD water for one month. The bottom nail was exposed to Flint River water for one month. Credit: FlintWaterStudy.org

Aids to Understanding

Contaminant Formation and Environmental Impact

Resources

Several sites provide good background information about ground water.

- "Groundwater Basics" at the Groundwater Foundation
- "Ground Water Fundamentals" at the National Ground Water Information Center
- Universities Council on Water Resources (UCOWR)

For a detailed listing of hazardous substances (both organic and inorganic), refer to the CDC's Agency for Toxic Substances Portal.

The U.S. EPA has several good Web pages related to ground water contaminants and their impact on the environment.

- "The Citizen's Guide to Ground-Water Protection"
- "How EPA Regulates Drinking Water Contaminants"
- "National Contaminant Occurrence Database"
- "National Water Quality Inventory Report"

Activities

The websites below are excellent sources for activities related to ground water contaminant formation and environmental impact.

From the U.S. EPA:

- Classroom Activities for Understanding Hazardous Waste
- "Home Drinking Water Testing Fact Sheet"
- Locate Your Watershed
- Magnificent Ground Water Connection

From the U.S. Department of Energy:

- Soda Bottle Hydrology

From the U.S. Geological Survey:

- Real-Time Water Data
- National Water Quality Assessment Program (NAWQA)
- Water Maps and GIS Data

Fate and Transport

Resources

The Ralph M. Parsons Laboratory at the Massachusetts Institute of Technology conducts an extensive research program in environmental chemistry and biology, hydrology, and fluid mechanics. -For a summary of the Environmental Systems Group's research, visit the Parsons Laboratory website.

The U.S. EPA website has several informative links related to fate and transport of ground water contaminants.

- "Fate, Transport and Transformation Test Guidelines"
- BASINS Program (Better Assessment Science Integrating Point and Nonpoint Sources)
- "RBCA Fate and Transport Models: Compendium and Selection Guidance"

The U.S. EPA and Purdue University's Agricultural and Biological Engineering Department collaborated on *The Ground Water Primer*, an excellent source of basic information.

Measuring and Monitoring

Resources

The U.S. Geological Survey conducts extensive water research programs. These websites provide additional information.

- USGS National Research Program
- Toxic Substances Hydrology Program
- "Water Resources Investigations Reports"

The U.S. Department of Agriculture hosts the Water Quality Information Center, an online database of information about water and agriculture.

Many computer modeling programs are available to help simulate ground water behavior.

- MODFLOW ground water modeling software from Aardton Software
- Groundwater Solute Transport Simulator for MODFLOW: MT3DMS
- U.S. Geological Survey resources Modeling Software page
- "Water Quality Criteria" from the U.S. EPA
- Methods, Models, Tools, and Databases for Water Research from the U.S. EPA

ASTM International, formerly known as the American Society for Testing and Materials, has published consensus standards for materials, products, systems, and services in 130 industry areas. These ASTM publications relevant to ground water may be ordered via the ASTM International website.

- *STP1288, Subsurface Fluid Flow (Ground-Water and Vadose Zone) Modeling.* 1996.
- *STP1053, Ground Water and Vadose Zone Monitoring*. 1999.
- *STP963, Ground-Water Contamination: Field Methods.* 1988.

The Federal Remediation Technologies Roundtable's Field Sampling and Analysis Technologies Matrix is an online encyclopedia that provides information about technologies used in the field to characterize contaminated soil and ground water and to monitor remediation progress.

The National Research Council published a study on ground water issues and the increasing complexity of ground water management. It covers ground water's importance to society, as well as scientific issues. Investigating Groundwater Systems on Regional and National Scales is available online.

Many tools and technologies are available for measuring and monitoring ground water quality. The websites below provide a sampling.

U.S. EPA Region 1 has developed a list of EPA test methods available online.

Several useful resources are available on the U.S. EPA website.

- Flexible Approaches to Environmental Measurements
- Approved Drinking Water Analytical Methods

The U.S. Geological Survey website also has some good resources on measuring and monitoring.

- Environmental Measurements
- Techniques of Water-Resources Investigations of the U.S. Geological Survey
- National Field Manual for the Collection of Water-Quality Data

Activities

The websites below are good sources for measuring and monitoring ground water quality activities.

- How Safe is My Ground Water? from the Advanced Technology Environmental and Energy Center (ATEEC)
- Toxic Substances Hydrology Program Investigations from the USGS

Human Health

Resources

The Agency for Toxic Substances and Disease Registry (ATSDR), an agency of the U.S. Department of Health and Human Services (DHHS), was created by the Superfund Law in 1980. It is the principal federal public health agency involved with hazardous waste issues. A wealth of information is available on the agency's website.

The Centers for Disease Control and Prevention, another division of the U.S. DHHS, has an excellent website. One particularly useful CDC resource is the "EXcellence in Curriculum Integration through Teaching Epidemiology (EXCITE)" program.

Another U.S. DHHS division, the National Institutes of Health, is host to the National Library of Medicine, which includes "Toxicology Data Network Fact Sheets" and "TOXNET," a cluster of databases on toxicology, hazardous chemicals, and related areas.

The U.S. EPA website includes:

- Integrated Risk Information System (IRIS)

The Integrated Risk Information System (IRIS) contains summaries of chronic human health risk information that represents EPA consensus opinion on the potential adverse health effects for approximately 500 chemicals and other agents. IRIS risk information includes summary sections on potential non-cancer effects resulting from oral and inhalation exposure (oral reference dose and inhalation reference concentration, respectively) and summaries of carcinogenicity risk information. IRIS is a useful initial resource for hazard identification and dose-response information, and for directing the user to the underlying data on which the information is based. Other information in IRIS includes summaries of drinking water health advisories and regulations. Refer to the online version of IRIS.

The U.S. Geological Survey Web page includes a "Toxicity of Chemicals" resource.

Activities

The CDC's "EXcellence in Curriculum Integration through Teaching Epidemiology (EXCITE)" website is an excellent resource for activities.

The ATEEC website includes a multidisciplinary Environmental Risk Assessment activity.

Decision-Making

Resources

The U.S. EPA's Office of Enforcement and Compliance Assurance offers "Emerging Tools for Local Problem-Solving."

Activities

Two pages on the U.S. EPA's Superfund website allow you to:
- Find the superfund site nearest you
- Find laws on hazardous wastes

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