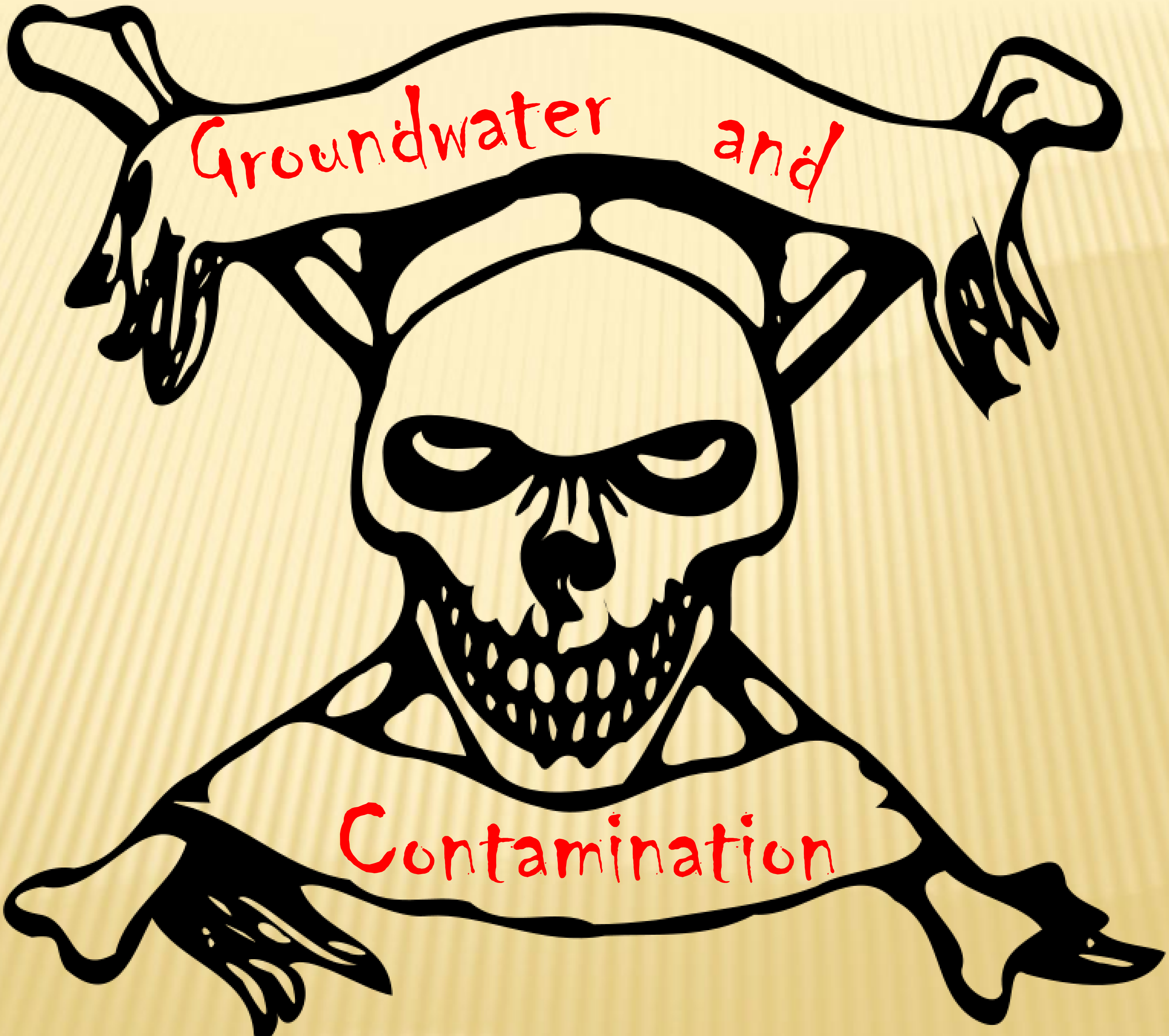
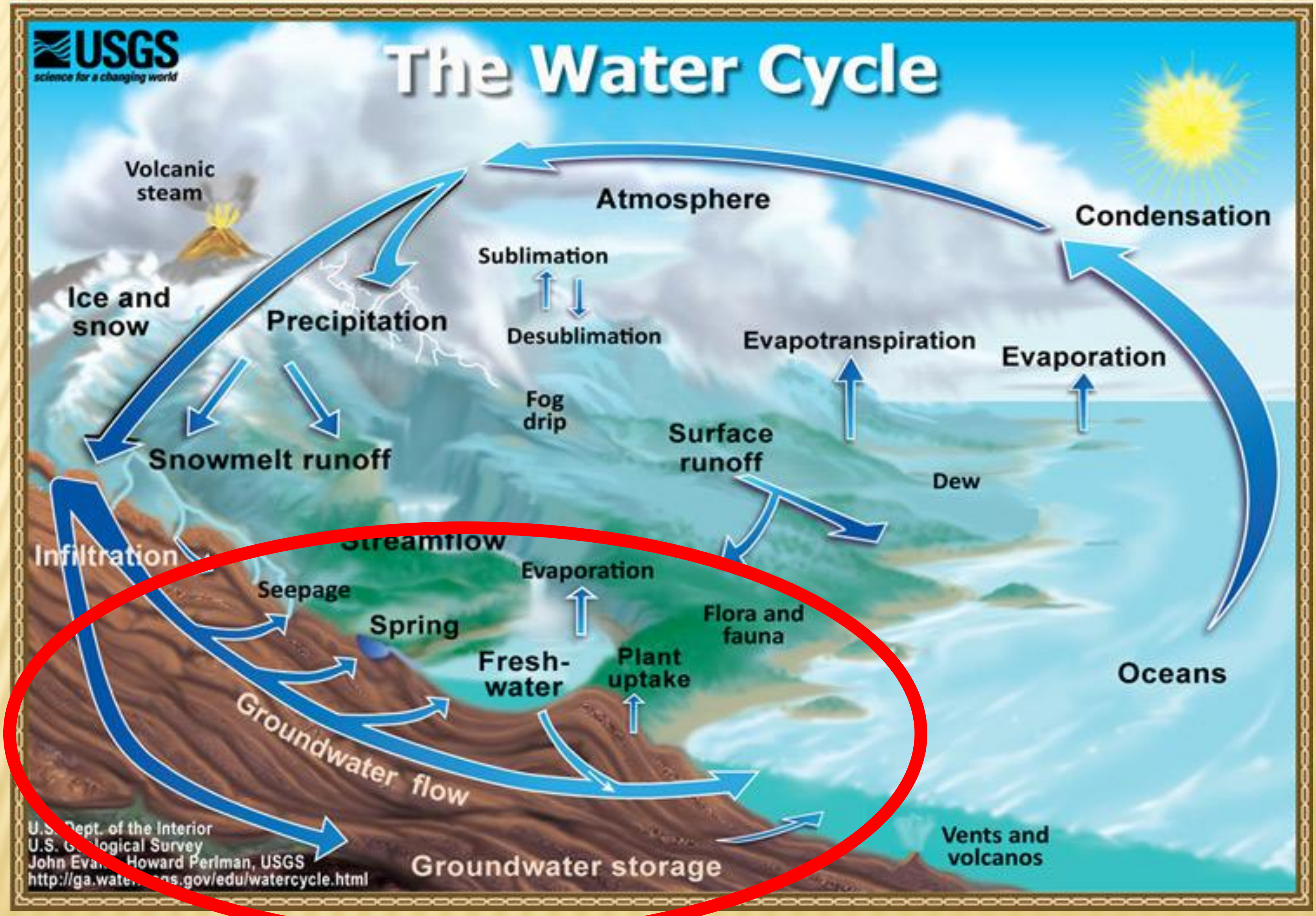
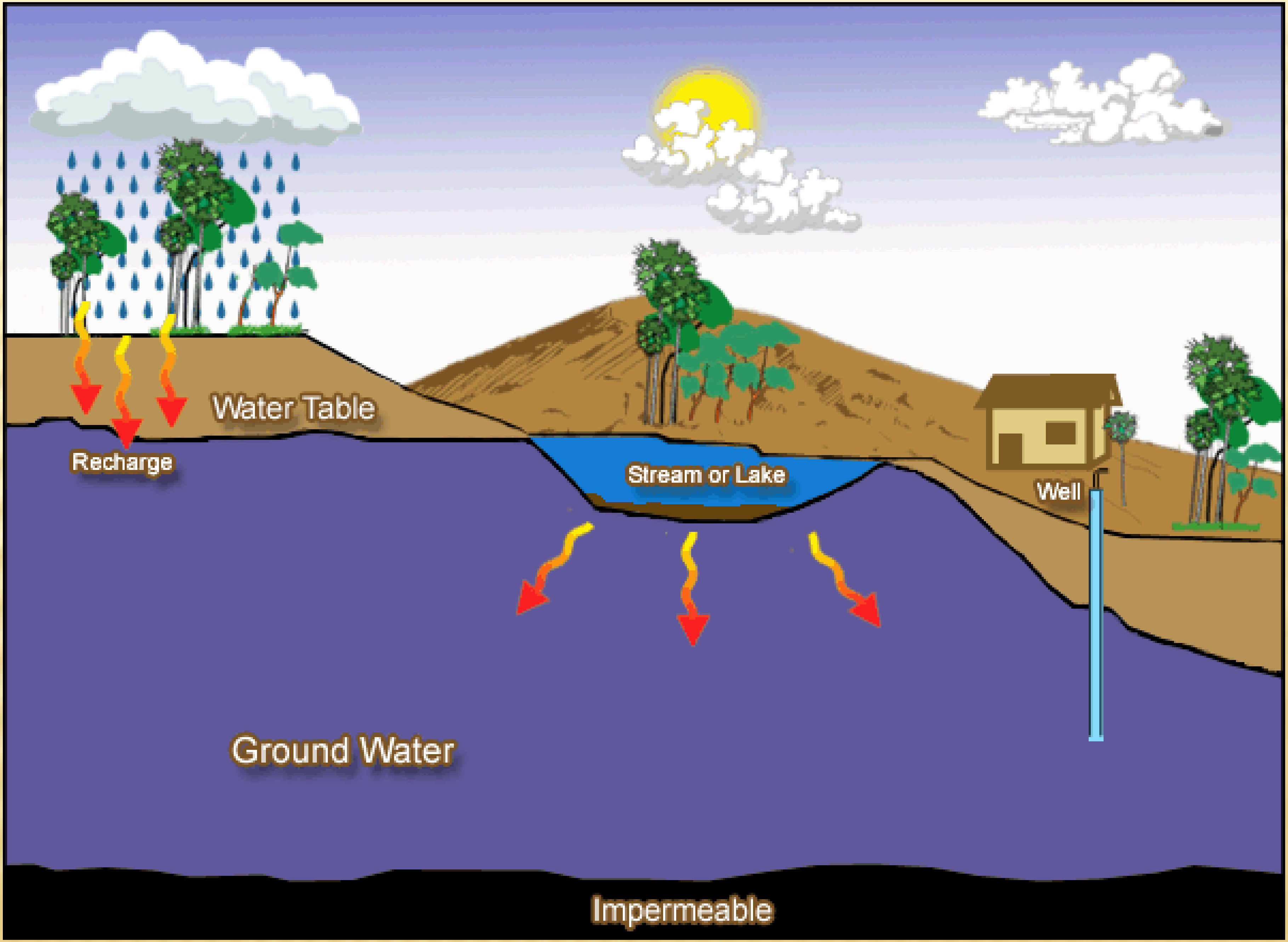
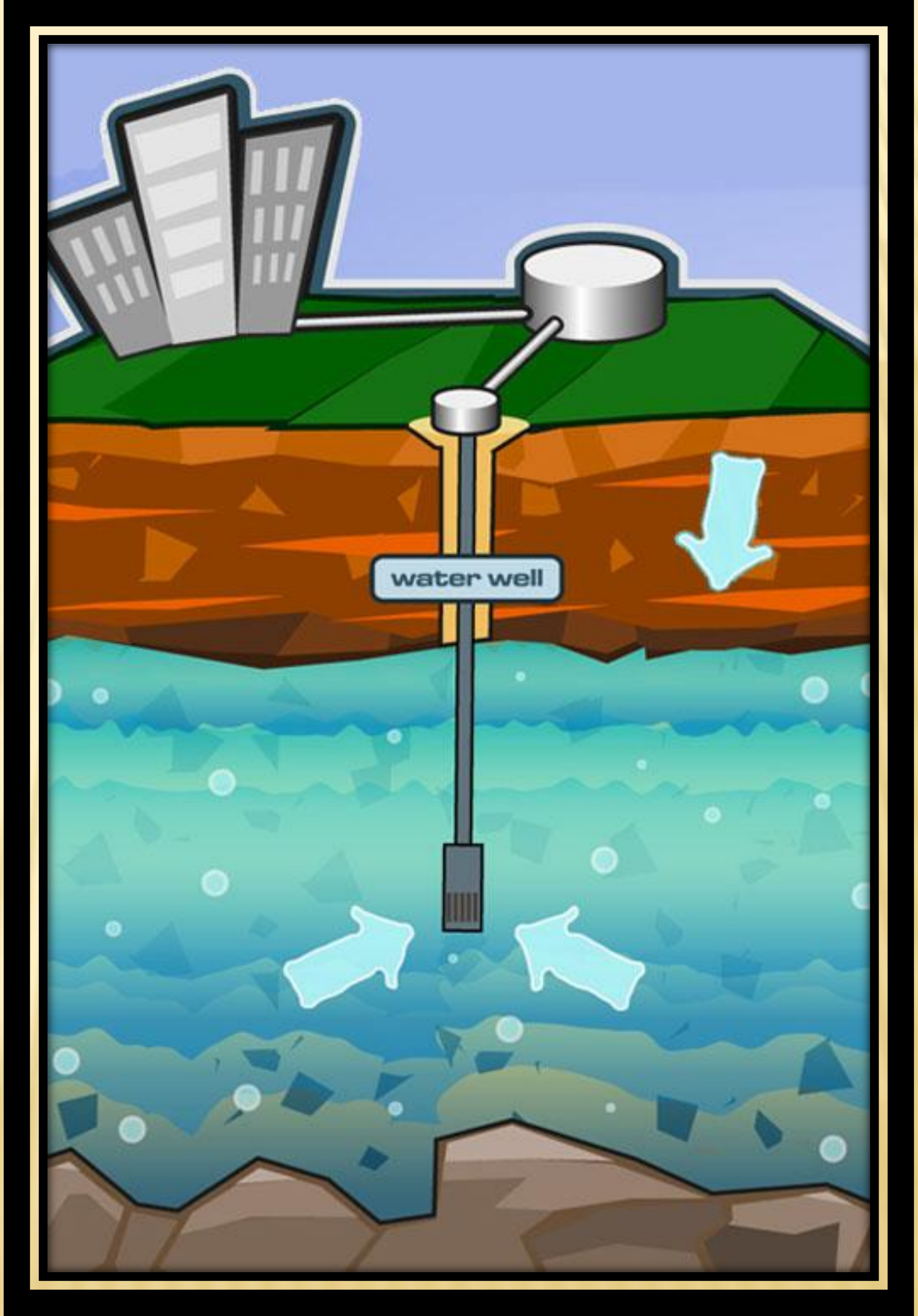

Groundwater and
Contamination


USGS
science for a changing world
The Water Cycle
Volcanic steam
Atmosphere
Condensation
Sublimation
Desublimation
Ice and snow
Precipitation
Evapotranspiration
Evaporation
Fog drip
Snowmelt runoff
Surface runoff
Dew
Streamflow
Infiltration
Evaporation
Seepage
Spring
Flora and fauna
Fresh-water
Plant uptake
Oceans
Groundwater flow
Vents and volcanos
Groundwater storage
U.S. Dept. of the Interior
U.S. Geological Survey
John Evans, Howard Perlman, USGS
http://ga.water.usgs.gov/edu/watercycle.html


Water Table
Recharge
Stream or Lake
Well
Ground Water
Impermeable


Water table
Saturated Zone
(Aquifer)


water well

Aquifer

An underground geological formation of sand, soil, gravel and rock able to store and yield water.

Confined Aquifer

An aquifer that exists where the groundwater is bounded between layers of impermeable substances like clay or dense rock. When tapped by a well, water in confined aquifers is forced up

Unconfined Aquifer

An aquifer in which the water table is at or near atmosphere pressure and is the upper boundary of the aquifer. Because the aquifer is not under pressure the water level in a well is the same as the water table outside the well.

Recharge

Water added to a groundwater aquifer. For example, when rainwater seeps into the ground.

Leachate

Liquids that have percolated through a soil and that carry substances in solution or suspension.

Leaching

The process by which soluble materials in the soil, such as salts, nutrients, pesticide chemicals, or contaminants, are washed into a lower layer of soil or are dissolved and carried away by water.

Infiltration

Flow of water from the land surface into the subsurface; also known as recharge.

Permeable/Permeability

Capable of transmitting water (porous rock, sediment, or soil); the rate at which water moves through rocks or soil.

Contamination

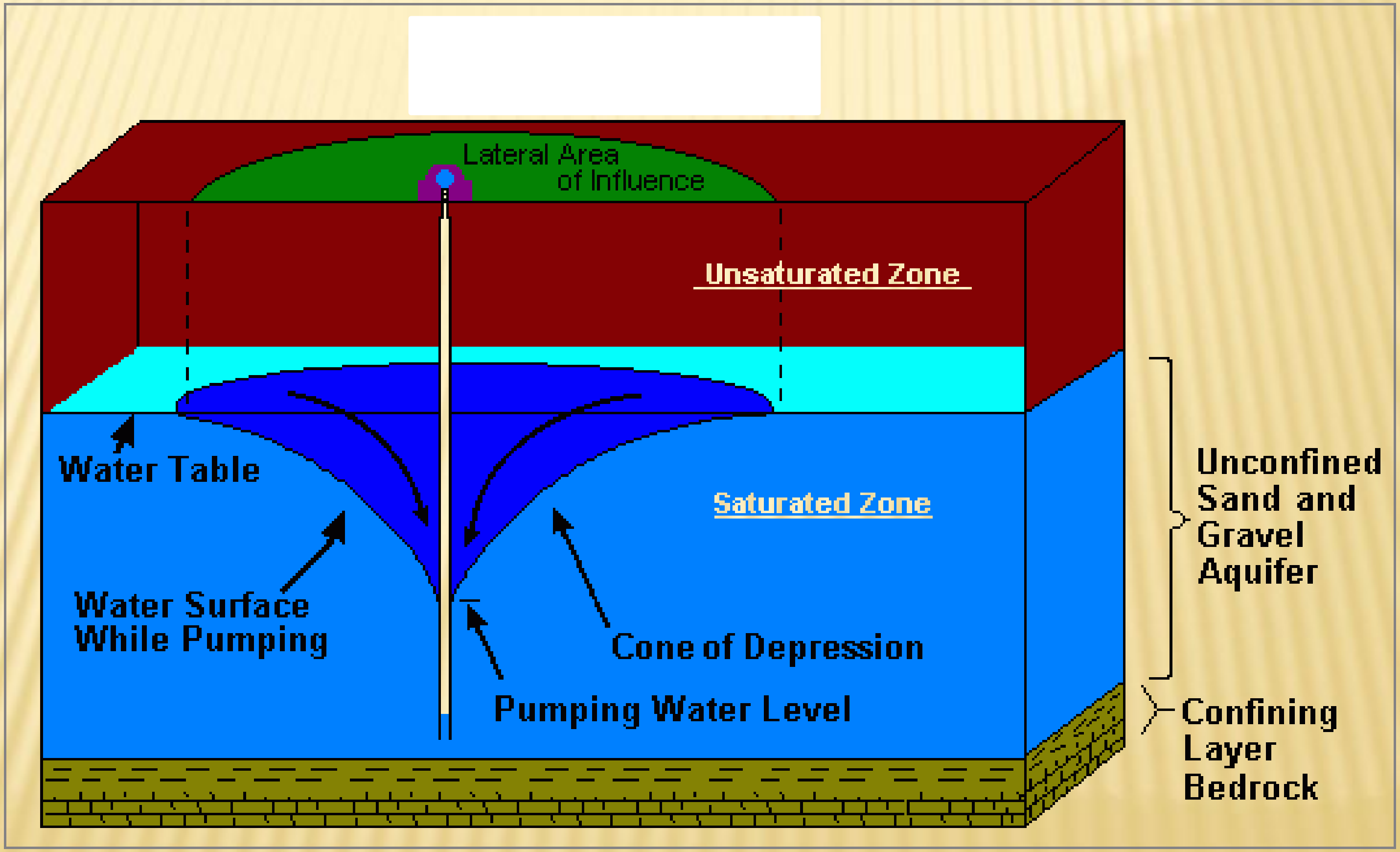
Substances in air, soil or water that makes it impure and unfit for consumption or an intended use, and can cause harm to human health or the environment. Contaminants can be naturally-occurring or caused by humans.

Water Table

The top of an unconfined aquifer; indicates the level below which soil and rock are saturated with water. The top of the saturation zone

Cone of Depression

The zone around a well in an aquifer that is normally saturated, but becomes unsaturated as a well is pumped,
leaving an area where the water table dips down to form a cone shape



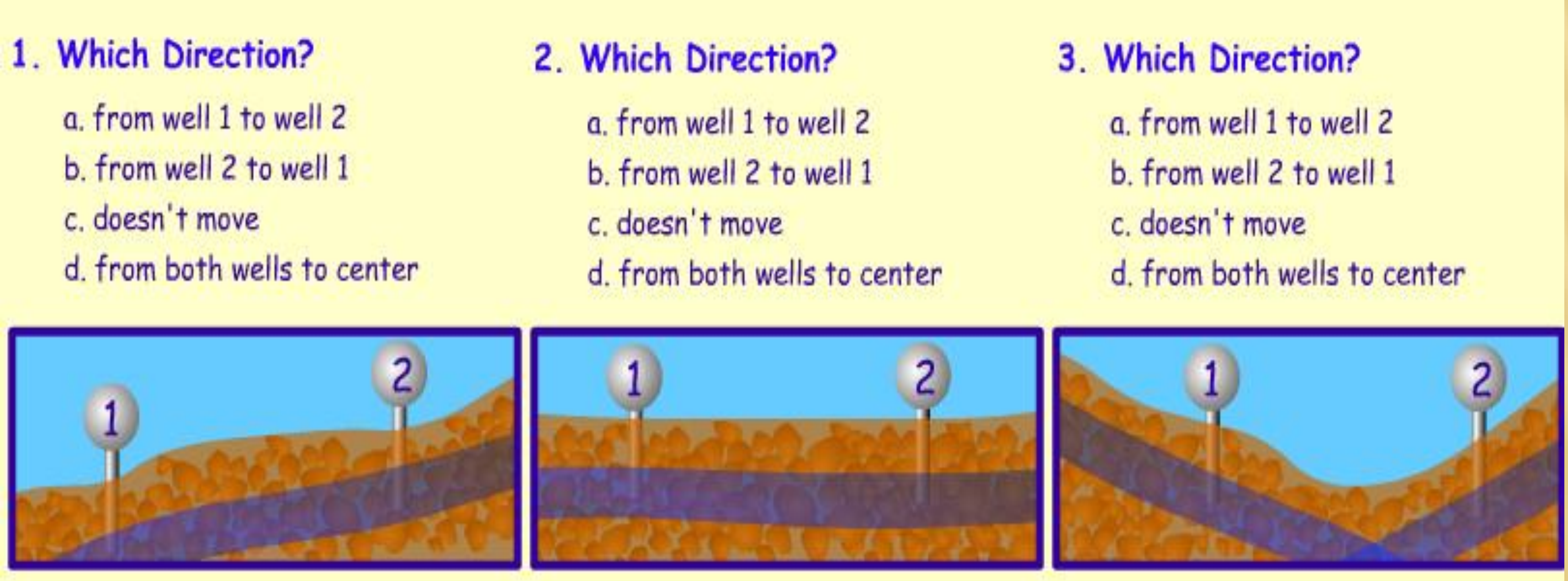
Taken from: Michigan Environmental Education Curriculum
Groundwater Contamination (http://techalive.mtu.edu/meec/module04/title.htm)

Groundwater is not held in one place underground- it flows through the aquifer.

Groundwater is transported through aquifers because of 2 main reasons:
•Gravity and
•Pressure.

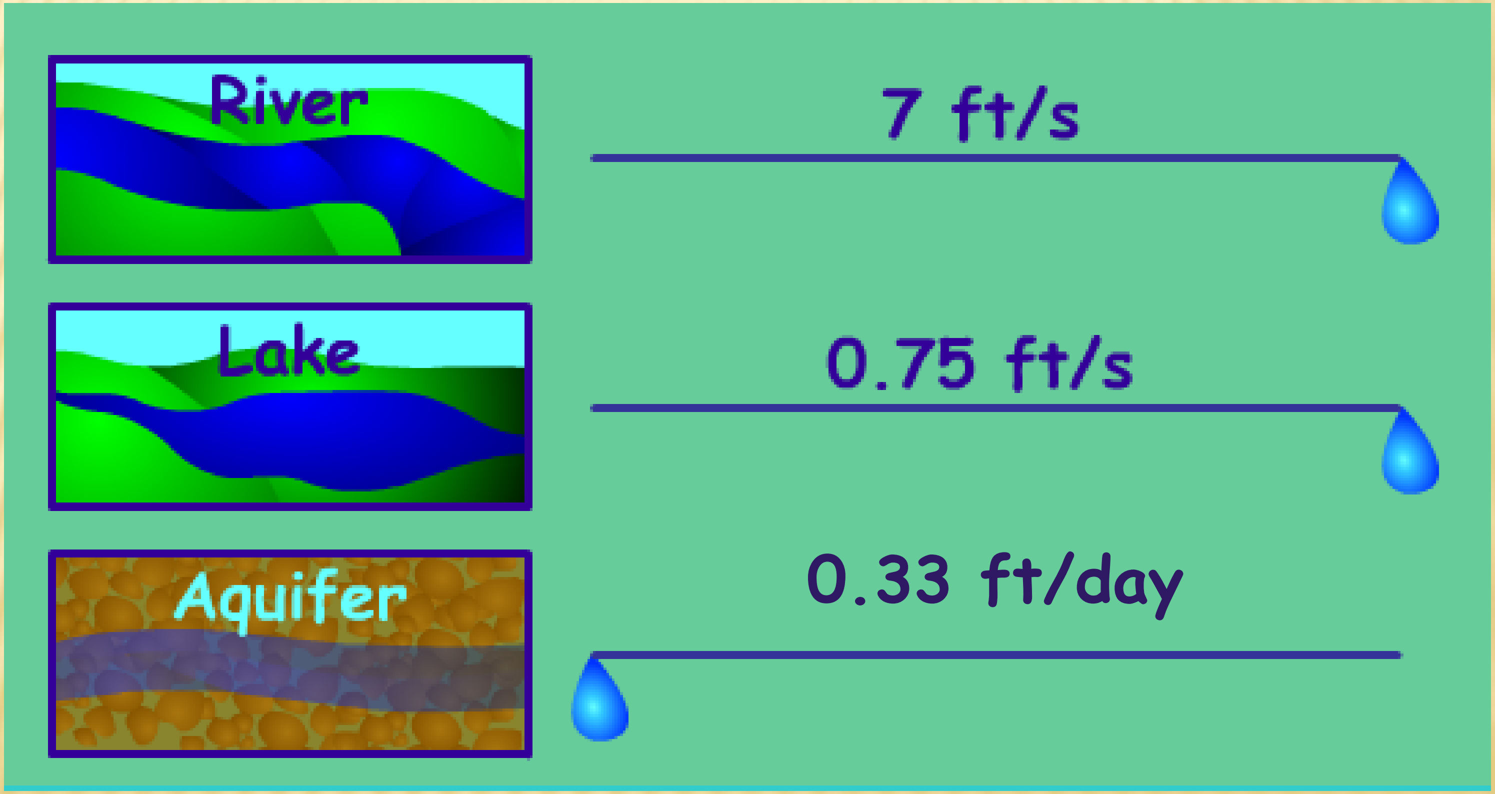
In confined aquifers, which are more likely to be contaminated, water always flows from high points to low points because of gravity.

Groundwater direction in an unconfined aquifer



Taken from: Michigan Environmental Education Curriculum
Groundwater Contamination (http://techalive.mtu.edu/meec/module04/title.htm

Groundwater flow is similar to water flowing in a sponge.



Taken from: Michigan Environmental Education Curriculum
Groundwater Contamination (http://techalive.mtu.edu/meec/module04/title.htm

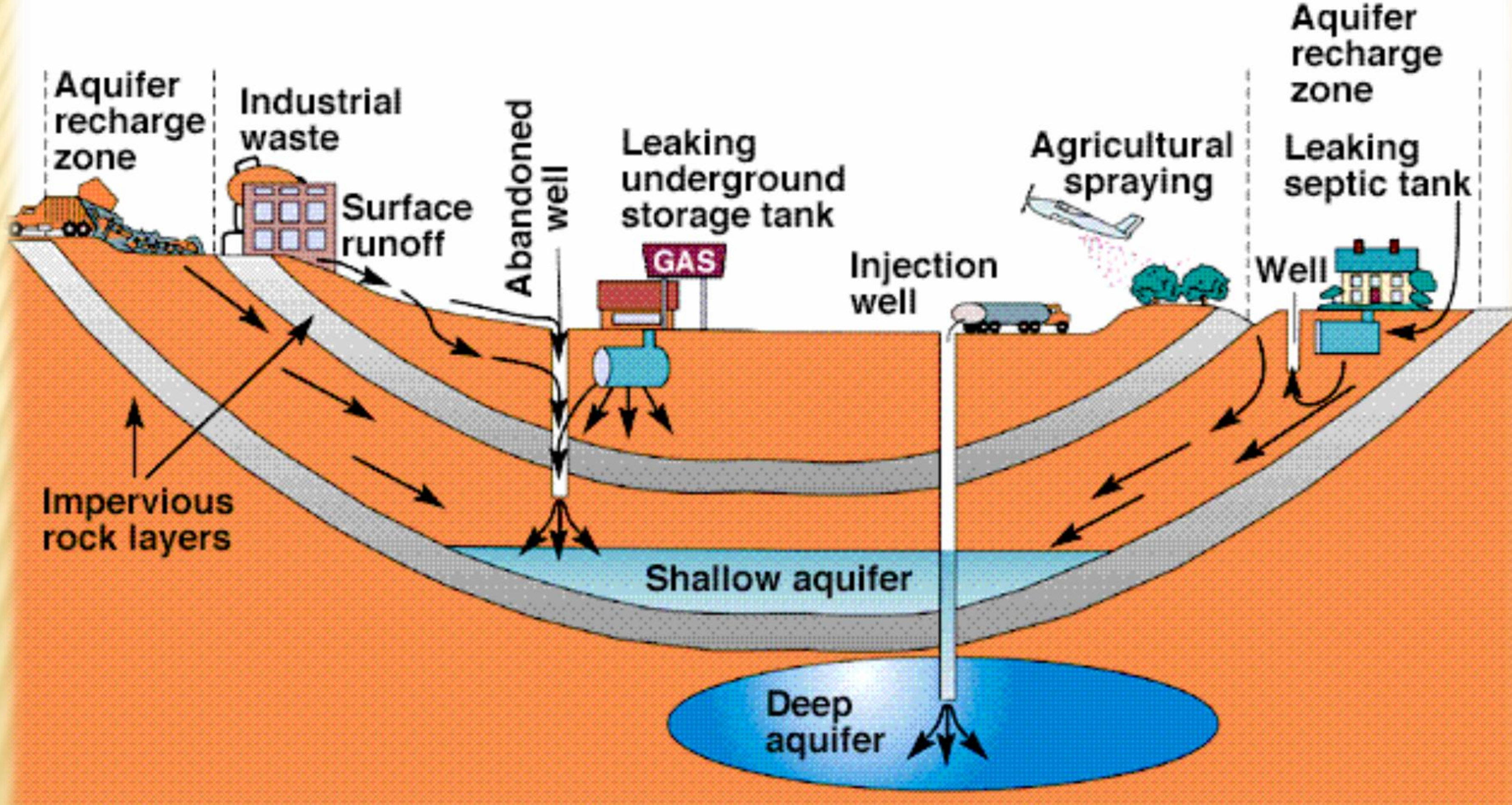
Groundwater Contamination

How?

• If rain water or surface water comes into contact with contaminated soil while seeping into the ground, it can become polluted and can carry the pollution from the soil to the groundwater. INFILTRATION

•Liquid hazardous substances themselves soak down through the soil or rock into the groundwater. Some liquid hazardous substances do not mix with the groundwater but remain pooled within the soil or bedrock. These pooled substances can act as long-term sources of groundwater contamination as the groundwater flows through the soil or rock and comes into contact with them.

Sources of groundwater pollution.



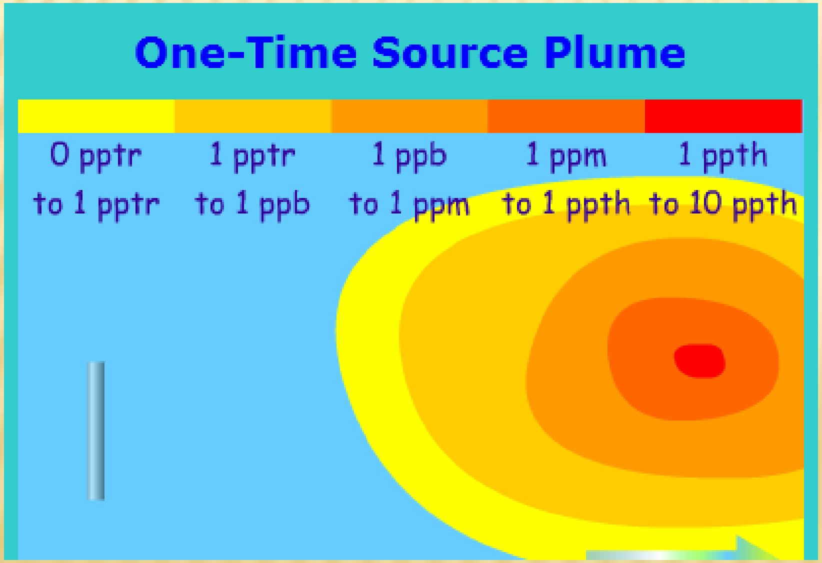
Contaminants can be grouped into 3 general types: sinking, floating and compatible/soluble

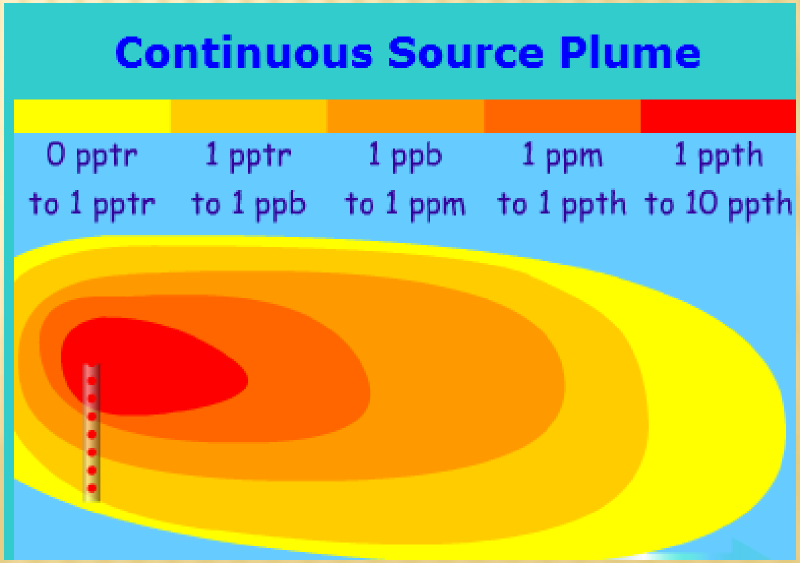
Contaminants move with groundwater flow once in an aquifer

As contamination moves it disperses. The concentration decreases as it moves farther away from the source of the pollution.

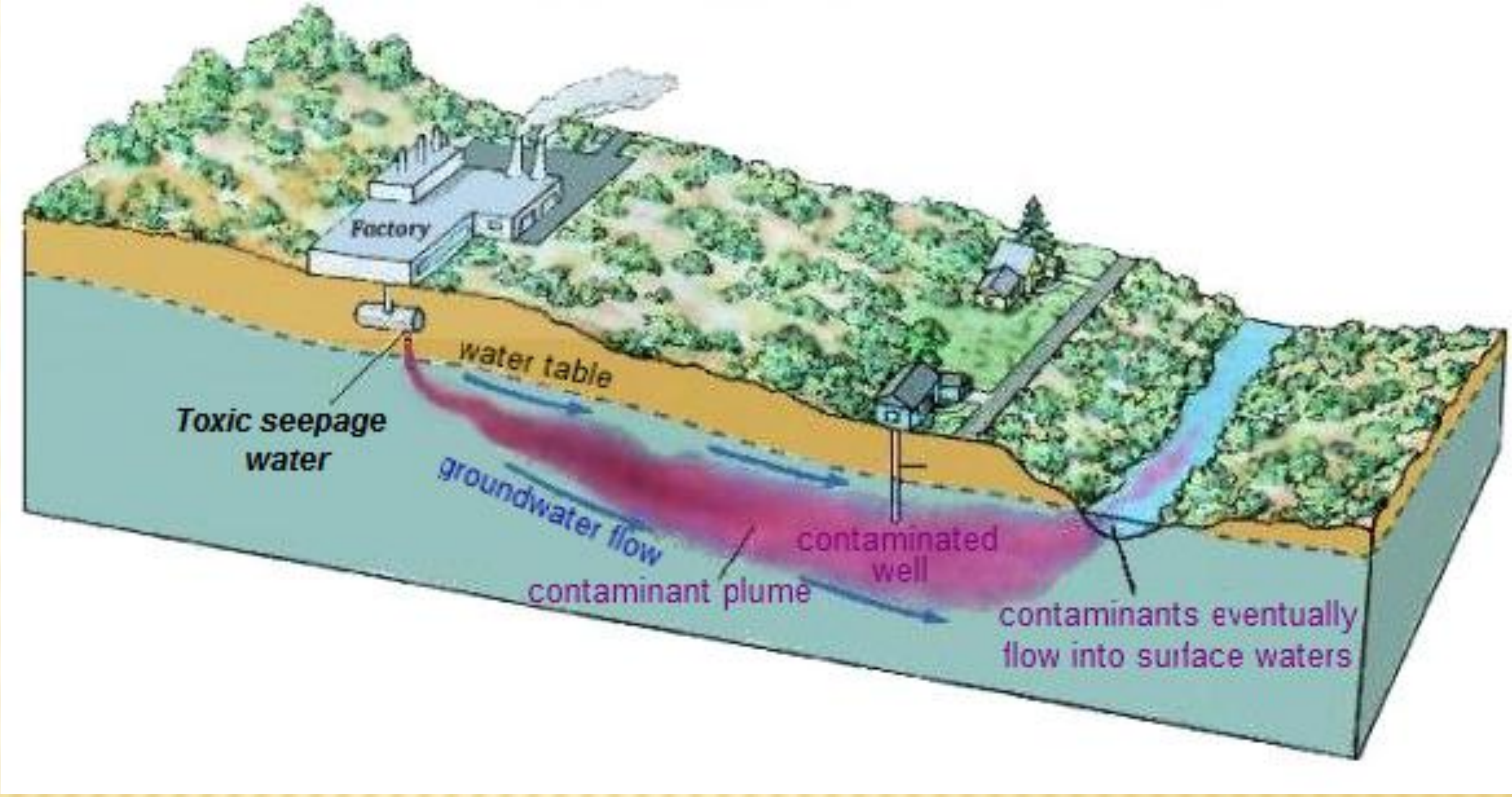
There are different concentrations of contaminants at different points in the aquifer.

The visual representation of the different concentrations is called a contamination plume. What the plume looks like depends on the type of contamination source, the specific contaminant(s), where the aquifer is, and different soils in the area.





Taken from: Michigan Environmental Education Curriculum
Groundwater Contamination (http://techalive.mtu.edu/meec/module04/title.htm


Factory
water table
Toxic seepage water
groundwater flow
contaminant plume
contaminated well
contaminants eventually flow into surface waters

To understand if groundwater contamination is a problem in an aquifer, it is necessary to know both the type and amount of contaminant in the groundwater system.

We measure amounts of contaminants in terms of concentration.

More specifically, we use the concepts of **ppm** and **ppb,** which are **parts per million** and **parts per billion**

1 drop in a half cup of water = 1 part per hundred	1 drop in a quart of water = 1 part per thousand	1 drop in two tubs of water = 1 part per million	1 drop in an Olympic size swimming pool = 1 part per billion	1 drop in a lake = 1 part per trillion
pph = 1 / 100	ppth = 1 / 1000	ppm = 1 / 1,000,000	ppb = 1 / 1,000,000,000	pptr = 1 / 1,000,000,000,000

Taken from: Michigan Environmental Education Curriculum
Groundwater Contamination (http://techalive.mtu.edu/meec/module04/title.htm

So if we want to find the contamination plume, we can just go and take a picture of the area, right?

NO...remember everything is underground! You can do some preliminary visual work at a contamination site, such as checking to see if a nearby river is contaminated or what possible above-surface sources exists. In order to find the contaminant plume, however, you need to drill test wells or use other technology to find concentrations at different points underground.

In reality the process is complex. There are no nicely drawn lines beneath the ground, but just water and soil that need to be taken out and sent to a laboratory for testing. The testing tells the scientist or engineer what the concentration is at that well point. After gathering many points the scientist can mathematically draw the plume.

$$ Each of these tests cost money $$

Activity Time ☺ Be a water detective

FACTS:

•You are a physician in a small community (about 1,000 residents). Yours is an old family in this area. Your great grandfather settled here in the 1800's and was a famous Officer in the Civil War.

•Over the past couple of years a few members of your community have described to you puzzling physical symptoms. Recently, a patient presented you with similar but more serious complaints: weakness, tingling and numbness in hands and feet, and dark warts on the palms of his hands and soles of his feet.

•Your patient responds to questions related to his medical history;

- •he works in the small, local factory (**Private Well #6** on the Community Map) that produces wood preservatives.
- •He has lived in the area for about 10 years
- •He and his wife of 10 months have a private well at heir home
- •His wife has not exhibited similar symptoms.
- •He quit smoking 3 years ago and does not drink alcoholic beverages
- •He takes no medications, only vitamins.

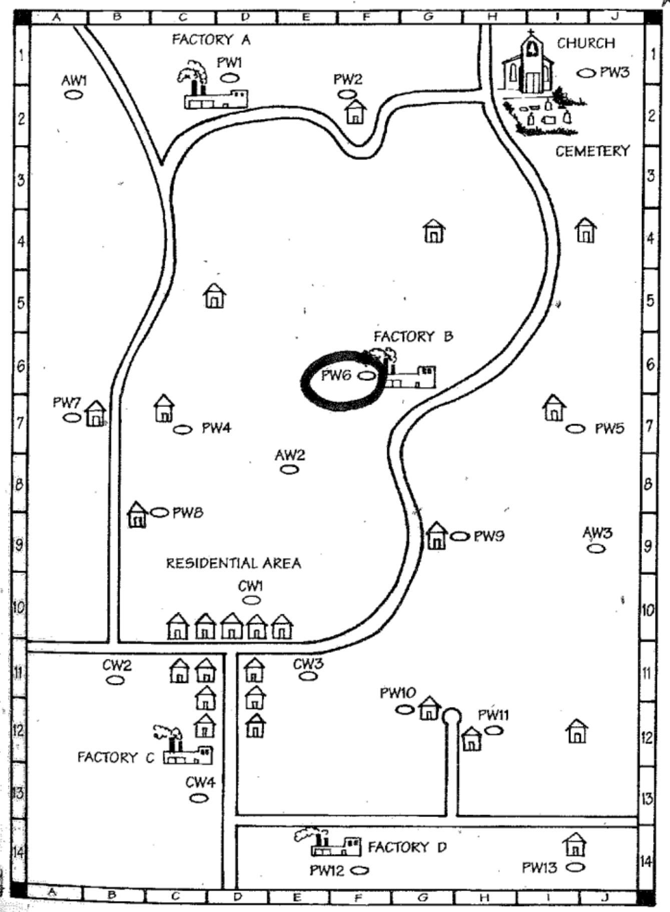
•You meet with members of your town council and express your suspicions- that the symptoms you have documented over the last few years are related to chronic arsenic poisoning from contaminated drinking water.

- •You advise them that the accepted level of arsenic in drinking water is 50 ppb.
- •The town council votes to budget money for ground water testing that will initially be limited to wells in existence.

Remember…..each test you do is going to cost you!

Community Map

Point of highest elevation ☆



Concentration of Contaminant (ppb)

DATA SET I
AW1 = 0
AW2 = 39
AW3 = 9
PW1 = 0
PW2 = 0
PW3 = 0
PW4 = 24
PW5 = 35
PW6 = 54
PW7 = 12
PW8 = 21
PW9 = 30
PW10 = 12
PW11 = 3
PW12 = 0
PW13 = 0
CW1 = 22.5
CW2 = 6
CW3 = 15
CW4 = 0

DATA SET II
(provided by teacher)

Point of lowest elevation ☆

KEY:
AW# = ABANDONED WELL
PW# = PRIVATE WELL
CW# = CITY WELL
= PRIVATE HOUSE
= SITE OF WELL
= FACTORY

COPY

What do we do about contamination of the groundwater supply?

Groundwater can sometimes be difficult to clean up due to its location.

Many times the water is pumped up a well, cleaned, and then sent back down the well into the aquifer.

Sometimes an additive is placed in the groundwater that either makes the contaminants less harmful or destroys them.

When there is contamination, not only does the water need to be cleaned, but often the soil as well.

If the soil wasn't cleaned, then the contaminants could just seep back into the water.

Thus, cleaning is a very, very expensive and time consuming process. Sometimes it might be impossible or too expensive to clean up the contamination at all!

A Few Examples of Common Cleaning Methods:
(There are many more and new ones always being developed as technology advances.)

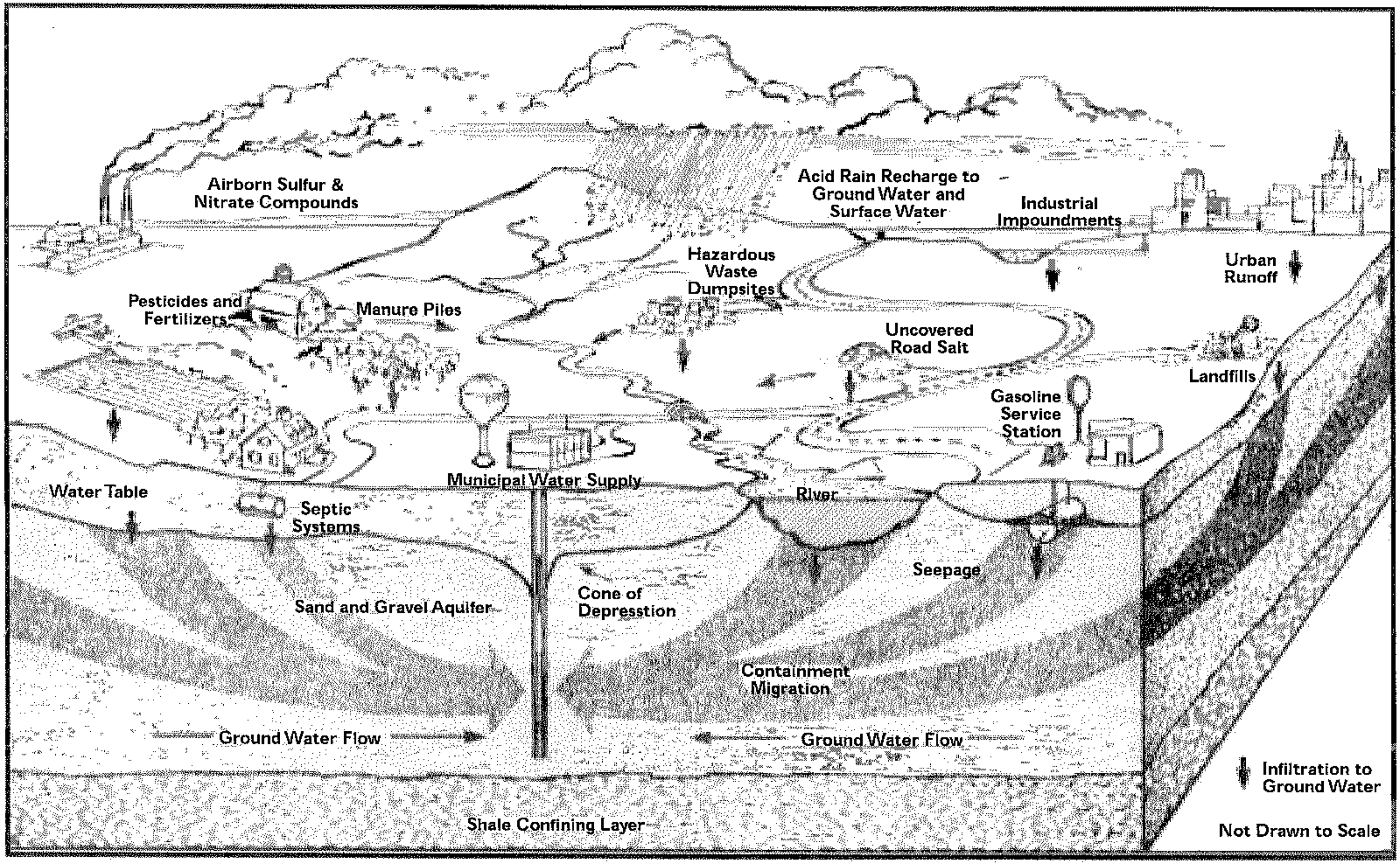
Bioremediation:
Bioremediation involves using bacteria to clean up the contamination by "eating" it. Usually nutrients are pumped down into the contaminated area. The nutrients help bacteria, which are already in the groundwater, to grow and destroy the contamination.

Soil Vapor Extraction:
In SVE, air is pulled through the ground in order to pull certain contaminants out of the groundwater. This method also increases air movement underground so that the helpful bacteria in the ground can "breath" better and destroy more contaminants. The air that is pulled out of the ground then needs to be treated also.

"Pump and Treat" Systems:
Sometimes groundwater is cleaned by pumping it to the surface and cleaning it above ground. The clean water is then pumped back into the ground. This is sometimes a problem, as there might not be anywhere to put it while it is being cleaned up. Another issue is that while the water is now clean, the contaminant still needs to be disposed of safely somewhere. This can take even more time and effort.

Phytoremediation (a fairly new technique):
Using plants and trees to soak up the pollutants from the groundwater on a continual basis. Once the contamination no longer exists, the trees are usually cut and disposed of.

Figure 2 **SOME POTENTIAL SOURCES OF GROUND WATER CONTAMINATION**



Source: Paly, Melissa and Lee Steppacher. *The Power to Protect: Three Stories about Ground Water*. U.S.E.P.A. Massachusetts Audubon Society and NEIWPCC.

Groundwater Contamination And Public Health

Case Study 1
Love Canal NY

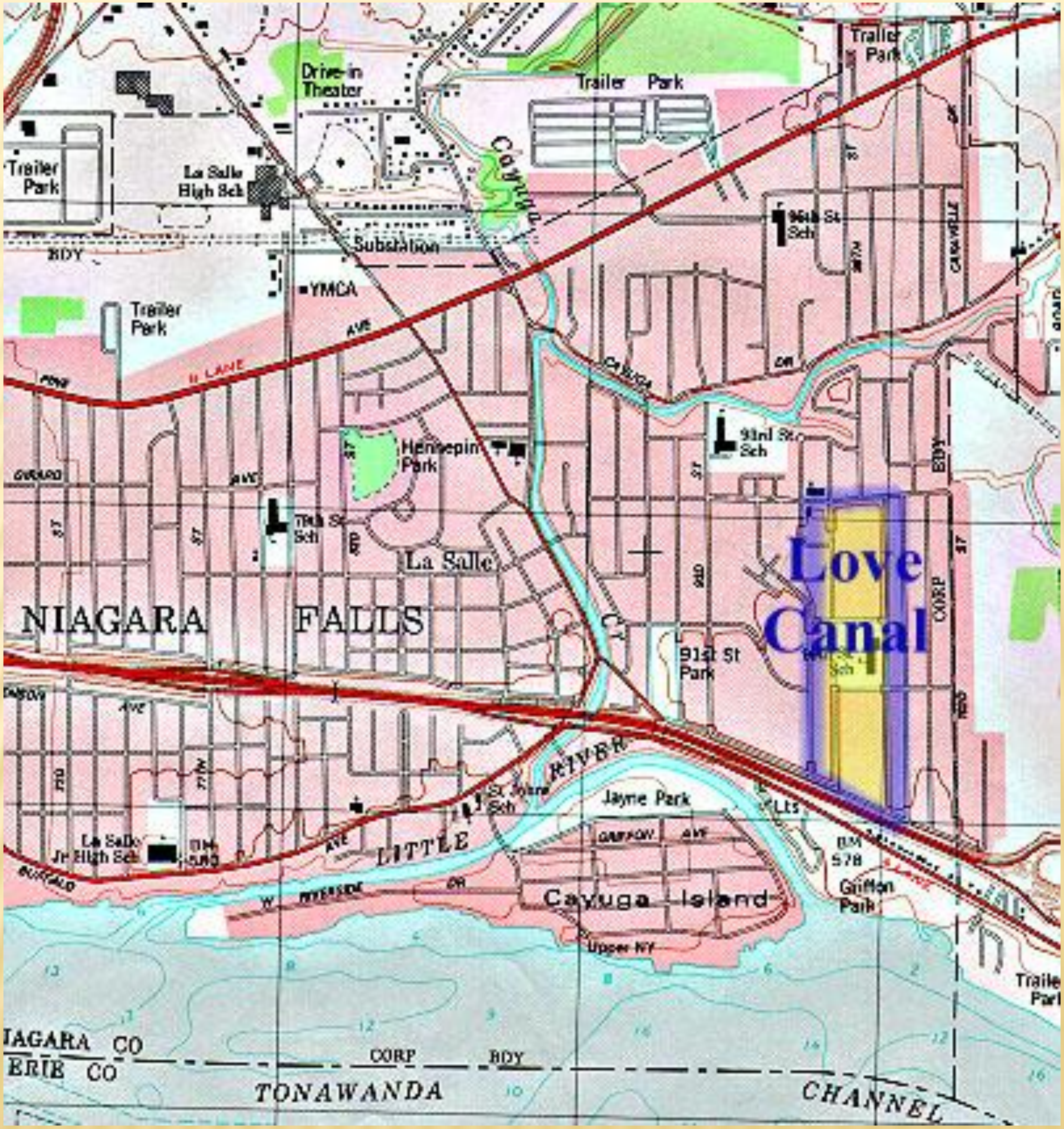
In the 1890’s, William T. Love began excavating a canal on a 70-acre site in a neighborhood in Niagara Falls, NY. His plan was to develop the canal and harness energy with a hydroelectric power plant. He hoped that the project would encourage development of the area.

The project became abandoned in 1910.

In the 1920s the seeds of a genuine nightmare were planted when the land was sold to Hooker Chemicals and Plastics.

In 1942 Hooker Chemicals and Plastics began using the excavated area as a landfill for chemical wastes.

Over a period of 10 years, over 21,000 tons of toxic wastes were disposed at the site. This stockpile of toxins – including halogenated organics, pesticides, chlorobenzenes and dioxin, covering nearly 16 acres – would eventually be capped and sold to the Niagara Falls Board of Education (NFBE) in 1953.


Love Canal
NIAGARA FALLS
La Salle
Drive-in Theater
Trailer Park
La Salle High Sch
Substation
YMCA
Hennepin Park
93rd St Sch
91st St Park
Jayne Park
Cayuga Island
LITTLE RIVER
Griffon Park
La Salle Jr High Sch
NIAGARA CO
ERIE CO
TONAWANDA CHANNEL
CORP BDY

Shortly after this transfer of ownership, the NFBE began development in Love Canal.

•200 homes and an elementary school were built in the area directly adjacent to the landfill.

•In the 1960's, residents began complaining of strange odors in their neighborhoods. These complaints escalated in the 1970's when the toxins from the landfill began leaching into surface- and groundwater bringing the substances into basements and backyards. (During construction, the cap was broken. allowing rainwater to seep through)

•A number of the leached chemicals were suspected carcinogens. It was later determined that the toxic wastes had contaminated much of the area surrounding the landfill and had also runoff into the sewer system and ultimately to surrounding creeks and the Niagara River, a source of drinking water for nearly 77,000 people.

•Residents suffered immediate effects such as lesions and burns as well as chronic effects such as leukemia and birth defects.

How do you prove that health effects are related to something someone else did?

At first, scientific studies did not conclusively prove that the chemicals were responsible for the residents' illnesses, and scientists were divided on the issue, even though eleven known or suspected carcinogens had been identified, one of the most prevalent being benzene.

There was also dioxin in the water. Dioxins are environmental pollutants which belong to the so-called “dirty dozen” - a group of dangerous chemicals known as persistent organic pollutants (POPs). Dioxins are of concern because of their highly toxic potential. Experiments have shown they affect a number of organs and systems.

Geologists were recruited to determine whether underground swales were responsible for carrying the chemicals to the surrounding residential areas.

:

When Eckhardt C. Beck (EPA Administrator for Region 2, 1977 – 1979) visited Love Canal in the late 1970s, he discerned the presence of toxic substances in the community:

"I visited the canal area at that time. Corroding waste-disposal drums could be seen breaking up through the grounds of backyards. Trees and gardens were turning black and dying. One entire swimming pool had been popped up from its foundation, afloat now on a small sea of chemicals. Puddles of noxious substances were pointed out to me by the residents. Some of these puddles were in their yards, some were in their basements, others yet were on the school grounds. ***Everywhere the air had a faint, choking smell. Children returned from play with burns on their hands and faces."***

Robert Whalen, New York's Health Commissioner, also visited Love Canal in 1978 and believed that the Canal constituted an emergency, stating:

"Love Canal Chemical Waste Landfill constitutes a public nuisance and an extremely serious threat and danger to the health, safety and welfare of those using it, living near it or exposed to the conditions emanating from it, consisting among other things, of chemical wastes lying exposed on the surface in numerous places pervasive, pernicious and obnoxious chemical vapors and fumes affecting both the ambient air and the homes of certain residents living near such sites."

Whalen also instructed people to avoid going into their basements as well as to avoid fruits and vegetables grown in their gardens.

People became worried because many had consumed produce from their gardens for several years.

Whalen declared a State of Emergency and urged that all pregnant women and children under the age of two be removed from Love Canal as soon as possible.

On August 7, 1978, United States President Jimmy Carter announced a federal health emergency, called for the allocation of federal funds and ordered the Federal Disaster Assistance Agency to assist the City of Niagara Falls to remedy the Love Canal site.

This was the first time in American history that emergency funds were used for a situation other than a natural disaster

Eventually, the government relocated more than 800 families and reimbursed them for their homes.

This was the beginning of the passage of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), also known as the Superfund Act. This was officially enacted on December 11, 1980 as a federal law.

In 1980, a 350-acre area surrounding the landfill was identified as an Emergency Declaration Area. Additionally, 10,000 and 70,000 people lived within one and three miles of Love Canal respectively.

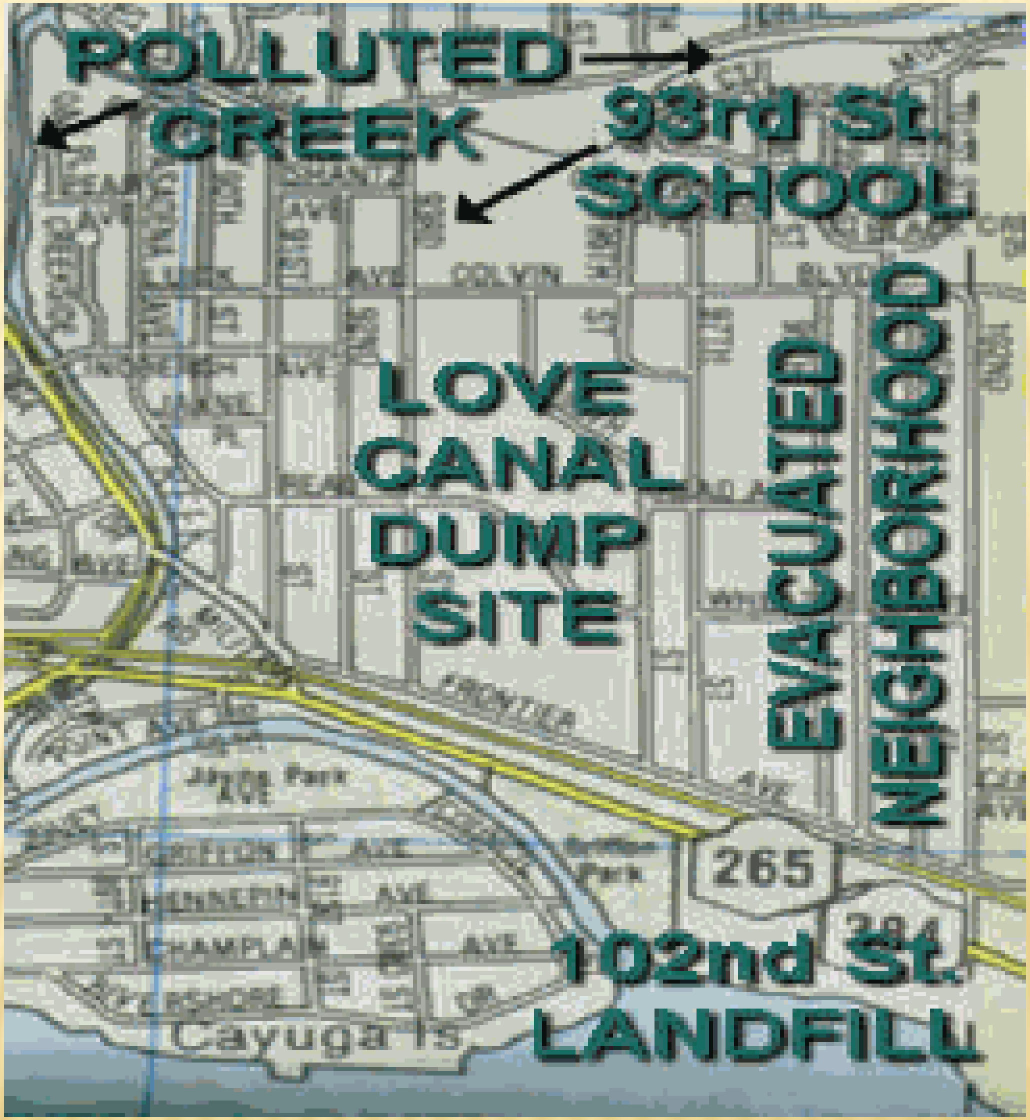
The contamination of the drinking water supply, which affected the majority of this surrounding population, significantly widened the scope of the impact.

Sign at closed school in Love Canal

The United States National Research Council (NRC) surveyed Love Canal health studies in 1991. The NRC noted that the major exposure of concern was the groundwater rather than drinking water; the groundwater "seeped into basements" and then led to exposure through air and soil.

On September 30, 2004, over two decades since the identification of the site as an Emergency Declaration Area and the forced evacuation of over 1,000 families, Love Canal was removed from Superfund's National Priorities List.

Although the site was declared safe for human habitation and has since been redeveloped, Love Canal will continue to be monitored on an annual basis.


POLLUTED CREEK
93rd St. SCHOOL
LOVE CANAL DUMP SITE
EVACUATED NEIGHBORHOOD
102nd St. LANDFILL
265
Cayuga Is

This figure shows the 93rd street school with surrounding housing developments around it.

This area was directly over the chemicals dumped by Hooker Chemical.


Love Canal site

Superfund or **Comprehensive Environmental Response, Compensation, and Liability Act** of 1980 (**CERCLA**)

is a United States federal law designed to clean up sites contaminated with hazardous substances as well as broadly defined "pollutants or contaminants". Superfund also gives authority to federal natural resource agencies, states and Indian tribes to recover natural resource damages caused by releases of hazardous substances

EPA may identify parties responsible for hazardous substances releases to the environment and compel those parties to clean up the sites, or it may cleanup itself using the Superfund (a trust fund) and cost recover from responsible parties by referring such matters to the U.S. Department of Justice.

The key difference between the authority to address hazardous substances and pollutants or contaminants is that the cleanup of pollutants or contaminants which are not hazardous substances cannot be compelled by unilateral administrative order.

CERCLA (or Superfund) authorizes two kinds of response actions:

Removal actions. These are typically short-term response actions, where actions may be taken to address releases or threatened releases requiring prompt response. Removal actions are classified as: (1) emergency; (2) time-critical; and (3) non-time critical. Removal responses are generally used to address localized risks such as abandoned drums containing hazardous substances, and contaminated surface soils posing acute risks to human health or the environment.

Remedial actions. These are usually long-term response actions. Remedial actions seek to permanently and significantly reduce the risks associated with releases or threats of releases of hazardous substances, and are generally larger more expensive actions which may include such measures as preventing the migration of pollutants with containment, or preferably removing and/or treating or neutralizing toxic substances. These actions can be conducted with federal funding only at sites listed on the EPA National Priorities List (NPL) in the United States and the territories.

Case Study 2
Pacific Gas & Electric

Case made famous by the movie *Erin Brockovich*

In the 1950's and 1960's, PG&E used cancer causing Hexavalent Chromium (Chromium 6) to kill algae and protect metal at its cooling towers and it's natural gas pumping station in Hinkley, California, located in the Mojave Desert.

Decades later, residents blamed their illnesses (including lupus, nosebleeds, brain tumors and leukemia) on a growing plume of contaminated groundwater and filed a class action lawsuit against Pacific Gas & Electric.

After many arguments, the case was referred to arbitration with maximum damages of $400 million.

After the arbitration for the first 40 people resulted in roughly $110 million, PG&E reassessed its position and decided to end arbitration and settle the entire case.

The case was settled in 1996 for $333 million, the largest settlement ever paid in a direct-action lawsuit in U.S. history, to just over 600 residents.

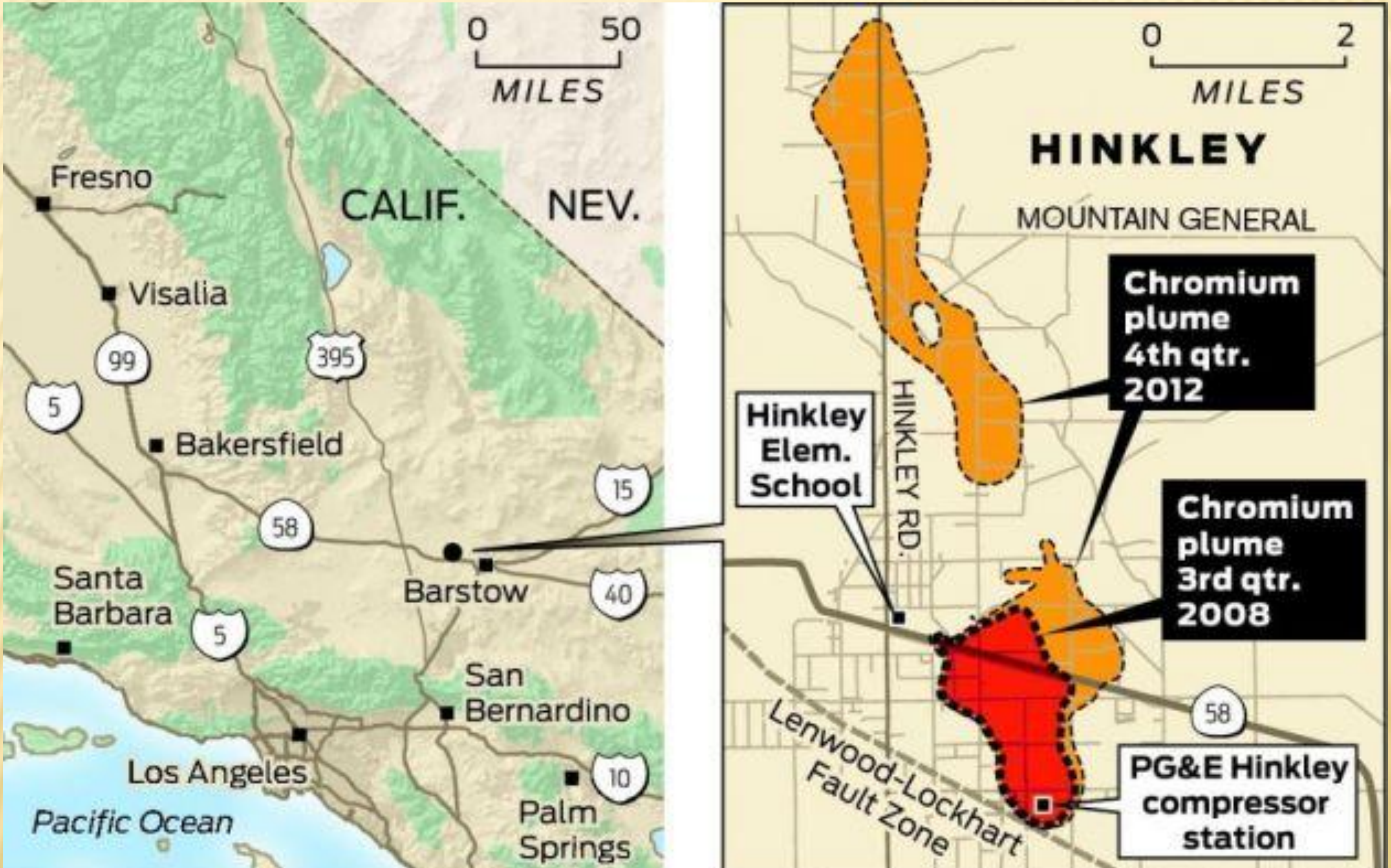
In 2006, PG&E agreed to pay $295 million to settle cases involving another 1,100 people statewide for hexavalent chromium-related claims.

In 2008, PG&E settled the “last” of the cases involved with the Hinkley claims for $20 million.

As part of the settlements, PG&E promised to contain the plume of contaminated groundwater.

They also had to supply bottled water to the residents and provide expensive filtration to homes in Hinkley.

In July 2013, tests had confirmed that the contaminated plume was heading North.

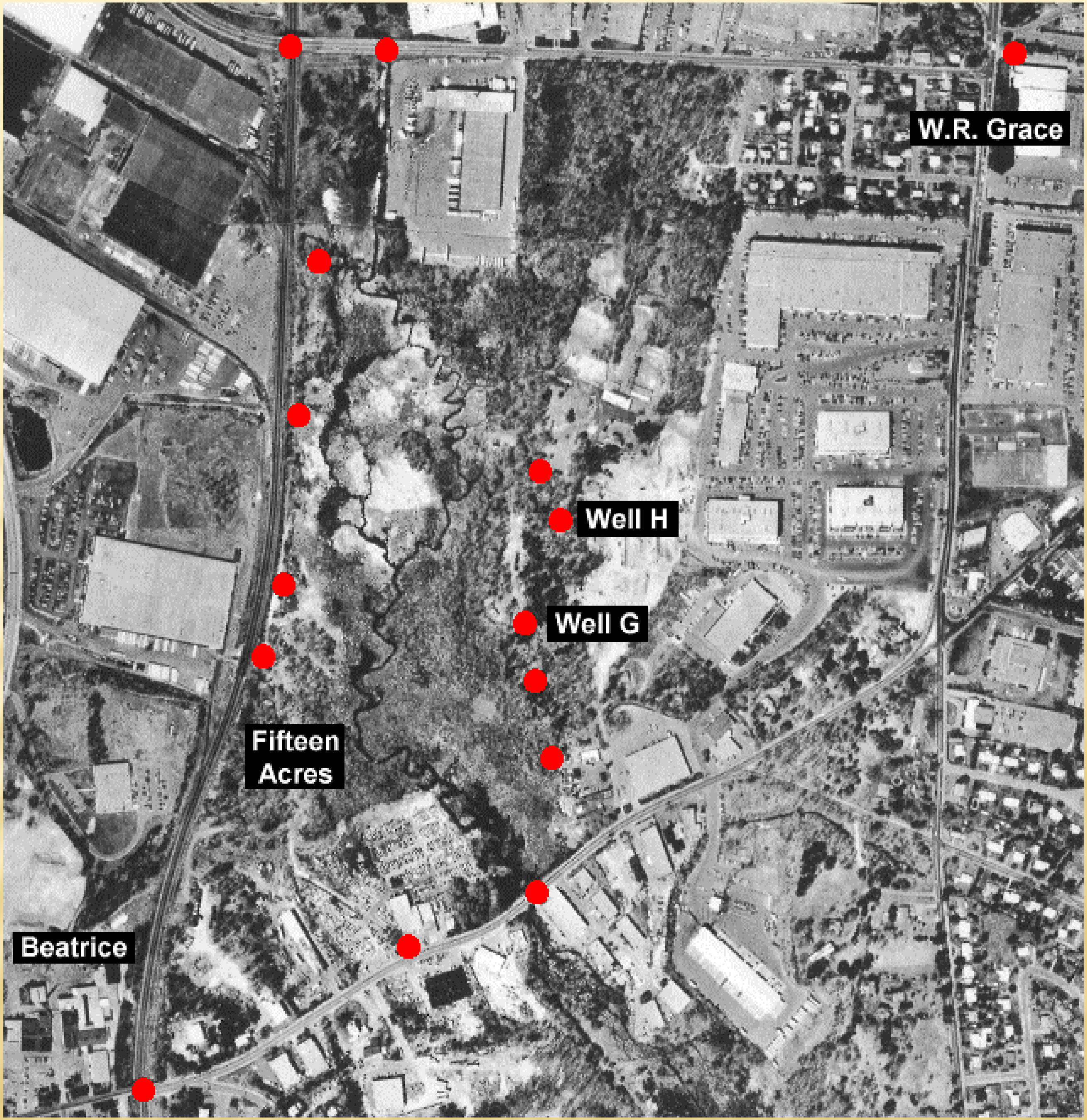


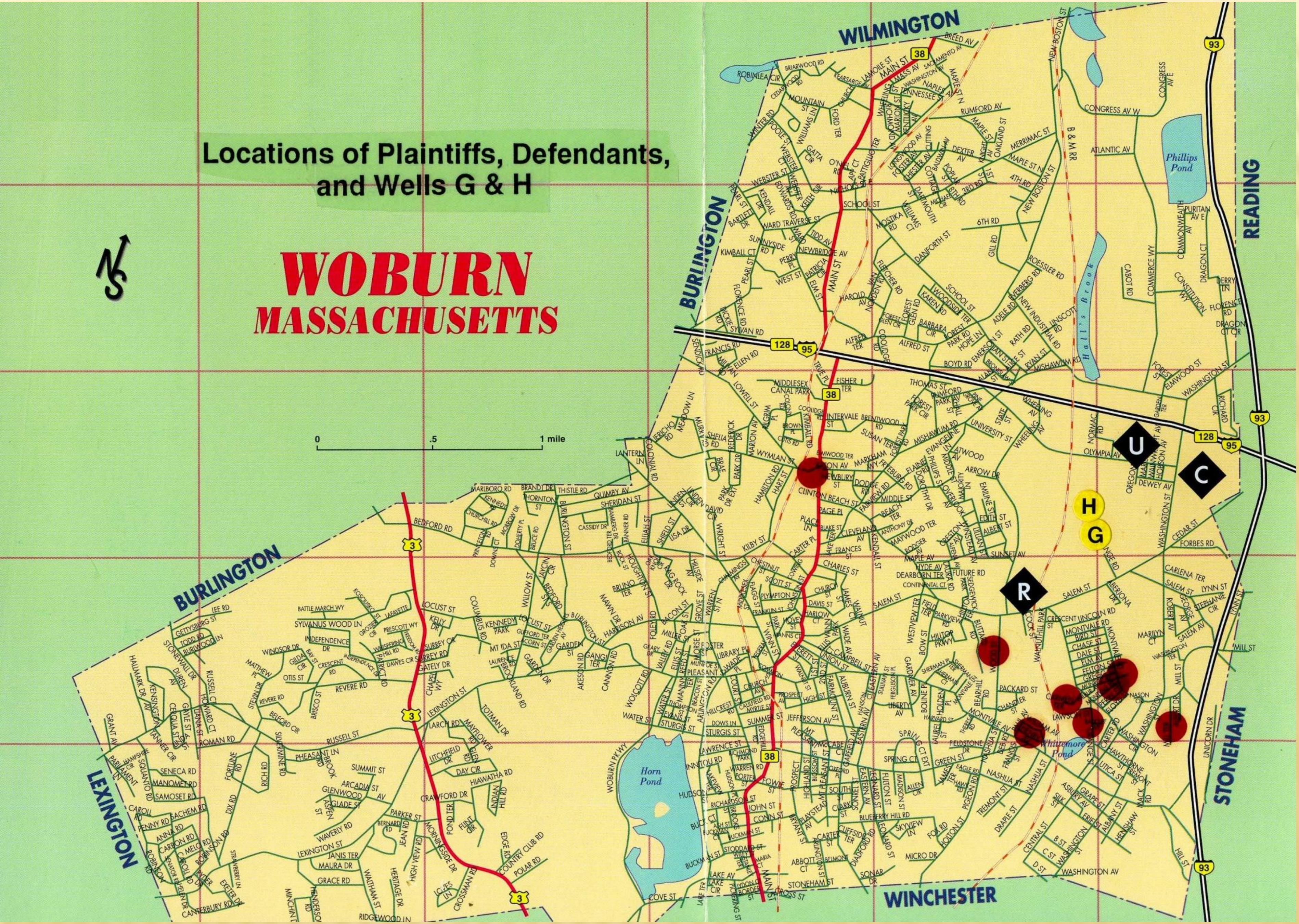
Source: Lahontan Regional Water Quality Control Board John Blanchard / The Chronicle http://www.youtube.com/watch?v=n7Knz8MHsTU

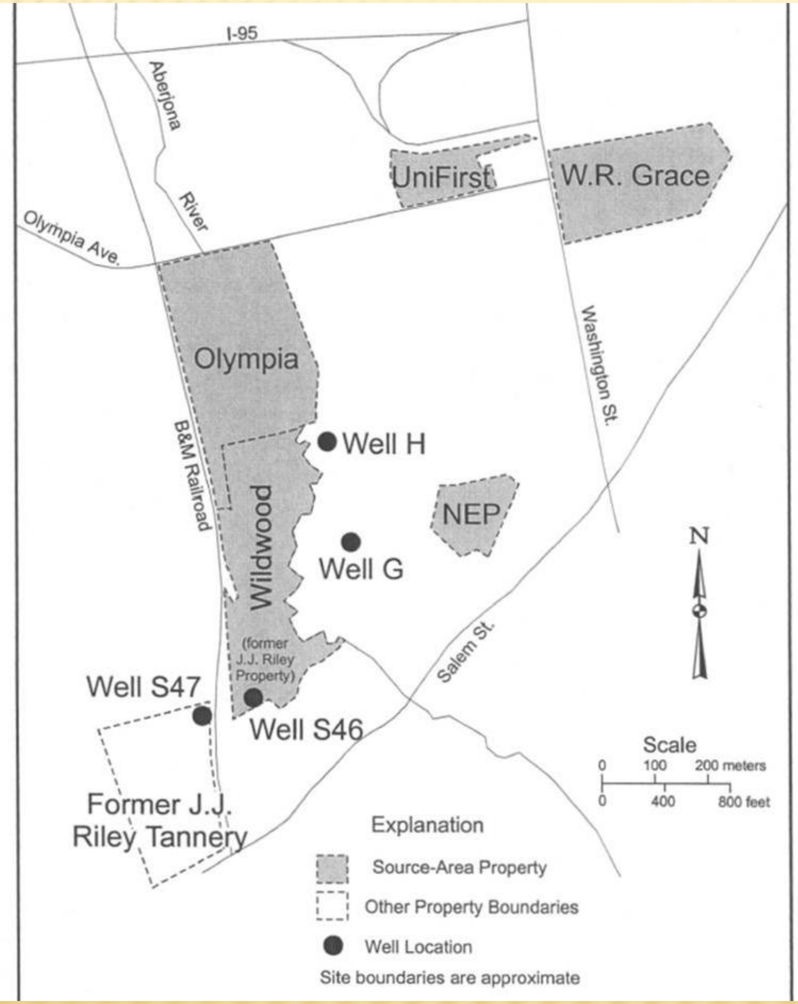
~5 minutes

Case Study 3
"Closer to home"
Anderson et al. vs.
W.R Grace and Beatrice Foods
Woburn Mass.


JOHN TRAVOLTA
A CIVIL ACTION
DVD


W.R. Grace
Well H
Well G
Fifteen Acres
Beatrice


Locations of Plaintiffs, Defendants, and Wells G & H
WOBURN
MASSACHUSETTS
WILMINGTON
BURLINGTON
READING
LEXINGTON
STONEHAM
WINCHESTER
Horn Pond
Phillips Pond
0
.5
1 mile
U
C
H
G
R



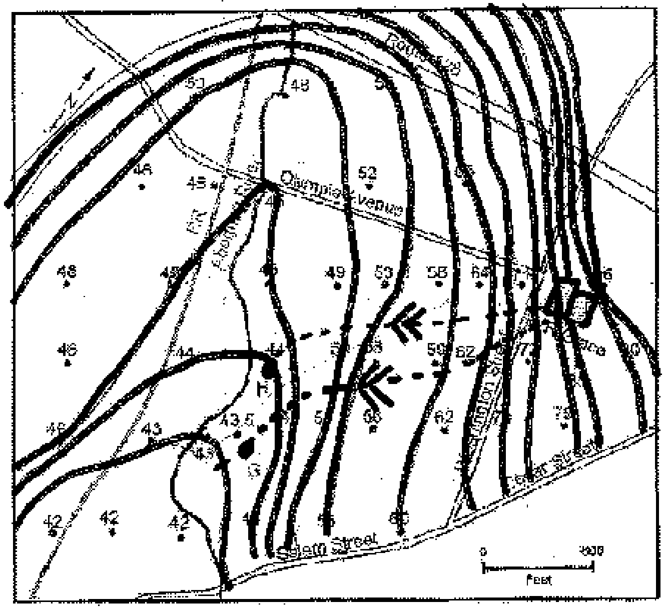


Figure 5. Elevation of the water table in December 1985, prior to the pump test.

groundwater flow
W.R. Grace
wells G & H
aberjona River

6

Summary

This landmark case centered on the alleged contamination of two municipal supply wells (G and H) in Woburn, Massachusetts, by three local industries.

The plaintiffs were a group of eight families that lived in a part of town served by the two municipal wells.
The defendants were W.R. Grace & Co., owner of the Cryovac Plant, UniFirst Corporation, owner of Interstate Uniform Services, and Beatrice Foods, Inc., owner of the John Riley Tannery.

The plaintiffs alleged that ingestion of toxic chemicals used at these industries, which were measured in water samples from the municipal wells, were responsible for severe health effects. Children of seven of the plaintiffs contracted leukemia. Five of the children died from leukemia or complications of having leukemia. The spouse of one plaintiff contracted acute myelocytic leukemia and died.

- The CDC and Mass. Dept. of Public Health confirmed that the children in Woburn were coming down with leukemia at a rate significantly higher than would be expected based on national statistics (what is termed a “cluster”) and the incidences were ultimately linked to the contaminated water in wells G & H.

The court case, in simple terms, had to determine who, if anyone, was at fault.

Consumption of contaminated water over a long period of time can cause physical infirmities ranging from digestive dysfunction to nervous system disorders, cancer, and even death.

Dangerous contamination in drinking water is not always readily detected or treated, and its effects are not critically acknowledged.

One problem in treating pollution and stopping the spread of contaminants within a water supply is identification of the contaminating agent.

This can also be an issue in assigning legal responsibility for the negative health effects of public water contamination; this was the case in Woburn, Massachusetts when volatile organic compounds (VOCs) as well as polycyclic aromatic hydrocarbons and heavy metals were detected in the groundwater supply for two municipal wells.

Taken from:
Woburn, Massachusetts: A Water Quality Case Study
Mandy Spence and Amanda Stephenson

Contamination (changes in average stream water caused by humans) of the Aberjona River began as early as 1648 when Woburn’s first tannery opened.

As the industry expanded, Woburn became home to 21 active tanning and currying shops.

From 1863-1929, Woburn Chemical Works operated on one of the country’s largest industrial sites, which is now known as the Industriplex waste site.

Pollution was detected as early as 1927, when the city decided to construct a sewer system to alleviate the problem.

In 1958 the city’s public water consultant warned that the groundwaters of the Aberjona River Valley were too polluted to be used for a public drinking water supply.

W.R. Grace & Co. opened a machine shop in Woburn around 1960 and in 1964 and 1967 the city Installed two wells, G & H to meet public water demands.

In 1975, Mass. Dept of Health recommended that Woburn not rely on Wells G & H due to chemical contamination and then ordered the removal of iron and manganese from these wells.

Wells were closed in 1979 when the Mass. DEQE (now DEP) found them contaminated with several VOC's, including trichloroethylene (TCE) and tetrachloroethylene.

During their peak, Wells G & H supplied the City of Woburn with 30% of it's public drinking water.

Outcome:

UniFirst agreed to pay the families $1.05 million before Anne Anderson et al. v. W.R. Grace et al. went to court in 1986.

Following a seven-month trial, W.R. Grace was found liable for polluting the wells. A second phase of the trial was to consider whether the pollution caused the leukemia cases, but W.R. Grace settled with the families for a reported $8 million.

Beatrice Foods was found not responsible for any contamination by the presiding judge.

Riley Tannery

Well H

Excavation of drums -W.R. Grace