Pramod sir
7th sem Civil CTM

SMH

RURAL WATER SUPPLY AND SANITATION

Subject Code	: 06CV666	IA Marks	: 25
No. of Lecture Hours/Week	: 04	Exam Hours	: 03
Total No. of Lecture Hours	: 52	Exam Marks	: 100.

Text Books :

1. Environmental Sanitation - Joseph. A. Solveto.

2. Water Supply and Sanitary Engineering - E.W. Steel.

PART – A

UNIT –1

RURAL WATER SUPPLY Introduction : Need for a protected water supply, investigation and selection of water sources, water borne diseases, protection of well waters, drinking water quality standards.

Need for a Protected Water Supply :

The use of water by man, plants and animals is universal. Without it, there can be no life. Every living thing requires water. Man and animals not only consume water, but they also consume vegetation for their food. Vegetation, in turn, cannot grow without water. Growth of vegetation also depends upon bacterial action, while bacteria need water in order to thrive. Following are some basic requirement of water for various beneficial uses :

- Water is required for various purposes in community life, viz., cooking, drinking, bathing, washing, gardens, etc.,
- Water bodies such as rivers, oceans, ponds, lakes etc., are the cheapest and easily available sites for disposal of treated, partially treated, untreated waste waters or sewage.
- Water is required for the irrigation, fish culturing, transportation, navigation, recreation etc.,

In India, the first public water supply system was provided for Kolkata in 1870 and was followed by other cities. The National Water Supply and Sanitation Committee of 1960 reported that only 6.5% of the population was supplied with potable drinking water and that too mostly catering to the urban population. India has thus a long way to go in the matter of providing safe drinking water to urban and rural areas. Further, it is necessary that the water required for town and village people needs must be good and it should not contain unwanted impurities or harmful chemical compounds or bacteria in it. This envisages protected water supply to all people residing in towns and villages.

Water supplied to the community should be treated to make it fit for drinking purposes for the following reasons:

- The water in the rivers is often polluted by the people inhabiting the watershed. This water carries bacteria, some of which are pathogenic, and can cause water-borne diseases such as typhoid, dysentery (amoebic and bacillary), cholera, etc., when such water is consumed by human beings, there may be epidemic outbreak of the diseases mentioned.
- Wastes from some of the industries are let off into rivers and pollute the water rendering it unsafe for human consumption.
- Surface run-off due to rainfall partly percolate into the ground dissolving the salts and minerals present in the soil. As a result, sometimes the ground water cause diseases such as fluorosis due to the presence of fluorides in the water. For example, in some districts of Andhra

Pradesh many people suffer from the effects of fluorosis contracted from water consumed. First there may be the mottling teeth and later deformation of the bones.

- In order to ensure the availability of sufficient quantity of good quality water, it becomes almost imperative in a modern society, to plan, and build suitable water supply schemes, which may provide potable water to the community in accordance with their demands and requirements.
- The provision of such a scheme shall ensure a constant and a reliable water supply to that section of the people for which it has been designed.
- Protected water supply scheme is needed to promote overall hygiene by keeping the diseases away and to ensure safety against fire by supplying sufficient quantity of water to extinguish it.
- Such a scheme thus helps in maintaining better sanitation and beautification of surroundings, thereby reducing environmental pollution.

Investigation and Selection of water sources :

The various sources of water available on the earth can be classified into following categories :

(i) Rain Water
(ii) Surface Sources
(iii) Sub-surface sources or Underground sources.
(iv) Water obtained from reclamation.

i. Rain Water :

(a) From roofs of houses and dwellings : Water is stored in small underground tank or cistern for small individual supplies.

(b) From prepared catchments : The surface of catchments is made impervious by suitable lining material, and suitable slope is given so that water is stored in moderate size reservoirs. This water is used for communal supplies, mostly for drinking purposes.

ii. Surface Sources :

Surface water is the one which is available as run-off from a catchment area, during rainfall or precipitation. This run-off flows either into streams or into undrained lakes. The run-off water flowing into streams can either be stored in a reservoir by constructing a dam across it, or be diverted into water supply channel. We get surface water from the following sources :

(a) Ponds and Lakes
(b) Streams and Rivers
(c) Storage Reservoirs ; and
(d) Oceans, generally not used for water supplies, at present.

iii. Sub –surface Sources or Underground Sources :

The largest available source of fresh water lies underground. The total under-ground water potential is estimated to be one-third the capacity of oceans. The main source of ground water is precipitation. A portion of rain falling on the earth's surface infiltrates into ground, travels down and when checked by impervious layer to travel further down, forms ground water. The ground water can be tapped from the following sources:

(a) From natural Springs.
(b) From Wells and Bore holes.
(c) From infiltration galleries, Basins or Cribs.
(d) From Infiltration Wells.

R-2

SMH

iv. Water obtained by Reclamation :

(a) Desalination : Saline or brackish water may be rendered useful for drinking purposes by installing desalination plants. The common methods used for desalination are : distillation, reverse osmosis, electrodialysis, freezing, and solar evaporation.

(b) Re-use of treated Waste Water : Effluent or waste water can be treated suitably so that it may be re-used. An example of the controlled indirect re-use is the intentional artificial recharge of ground water aquifers by adequately treated waste water.

Factors Governing the Selection of a Particular Source of Water :

The following important factors are generally considered in selecting a particular sources for supplying water to a community;

(i) The Quantity of Available Water : The quantity of water available at the sources must be sufficient to meet the various demands during the entire design period of the scheme. If sufficient quantity of water is not available in the vicinity of the area, we may have to think of bringing water from distant sources.

(ii) The Quality of Available Water : The water available at the source must not be toxic, poisonous or in any other way injurious to health. The impurities present in the water should be as less as possible, and should be such as to be removed easily and economically by normal treatment methods.

(iii) Distance of the Source of Supply : The location of the source must as near as possible. Because the more the distance, the more lengths of pipe conduits are required to be laid. Hence the cost of laying pipes along with the costs for pipes and associated appurtenances will be more.

(iv) General topography of the Intervening area : The area or land between the source and the supply area should not be highly uneven. In other words, it should not contain deep valleys or high mountains and ridges. In such uneven topographies, the cost of trestles for carrying water pipes in valleys and that of constructing tunnels in mountains, shall be enormous.

(v) Elevation of the source of supply : The source of water must be on a high contour, laying sufficiently higher than the distribution area, so as to make the gravity flow possible. When the water is available at lower levels than the average village level, pumping has to be resorted to, which involves huge operational cost and frequent possible breakdowns.

WATER BORNE DISEASES :

About 1.1 billion people in the world still lack access to safe water for drinking and 2.4 billion people have no basic sanitation. The large majority of people are seriously affected by or die from preventable water and sanitation related diseases are rural dwelling and the urban poor in the developing countries. Current international estimate of deaths are due to water related diseases which range from 2.2 million to 5 million annually.

Description of Selected Water Borne Diseases :

Water borne diseases are caused by *pathogenic organisms* carried by water containing faecal or sewage contamination. These diseases may be grouped in four heads: (a) Bacterial diseases, (b) Protozoal diseases, (c) Virus diseases, and (d) Helminthic (worm) diseases. Following table gives details about some important water borne diseases.

DISEASE TYPE	CAUSATIVE ORGANISM	SOURCE	REMARKS
(A) BACTERIAL DISEASES :			
1. Typhoid fever	Salmonella Typhi	Contaminated water supply/food source by human faeces or urine.	Results in high fever accompanied with diarrhea or vomiting.
2. Paratyphiod fever	Salmnonella paratyphi A,B or C.	Contaminated food, milk, dry or frozen eggs.	Less infectivity and smaller than typhoid fever .
3. Cholera	Vibrio cholerae.	Contaminated water (faecal origin), dirty hand/flies	Highly contagious diarrhea. Rapid loss of body fluids leads to dehydration and shock.
4. Bacillary Dysentery	Shigella bacteria	Contaminated food by flies and contaminated water	Results in problem of dehydrations and malnutrition.
(B) PROTOZOAL DISEASES:			
5. Amoebiasis	Entamoeba hystolytica	Contaminated water flies or even human fingers.	The person's feces will frequently contain blood and mucus. It spreads from person to person..
6. Amoebic dysentery	Entamoeba hystolytica	Contaminated water/ flies/dirty hands	Cysts are found in human large intestine.
(C) VIRAL DISEASES:			
7. Infectious hepatitis	Adeno viruses Reo viruses	Contaminated water/ flies/dirty hands	Multiply in intestinal wall and discharged through faeces.
8. Poliomyelitis	Polio viruses, coxsakie viruses, ECHO viruses	Poor sanitation, poor food hygiene	Multiply in intestinal wall and discharged through faeces.
(D) WORM DISEASES: (Helminthic)			
9. Schistosomiasis	Blood Flukes or trematode worms	Urine or faeces	Inhibit the veins of bladder, or large intestine. Fever, pain in lower abdomen, over time results in liver damage.
10. Swimmersitch	Flukes	Urine or faeces	Inhibit the veins of bladder, or large intestine

SMH

Other Effects of Water Borne Diseases : In addition to above some diseases are caused not due to intake of contaminated water, but, due to bites of some insects which depend upon the stagnant water bodies for their life cycles. Such as "*Sleeping Sickness*" (People suffer from fever, ache, fatigue and progressive confusion and difficulty in walking and talking) and "*Malaria*" (People suffer recurring attacks that causes shivers, fevers and aches) which are mainly passed onto people who are bitten by infected flies and mosquitoes breed in water.

Prevention and Solutions for Water Borne Diseases :

1) Provide people with wholesome water and good sanitation.
2) Construct sanitary latrines and treat waste waters.
3) Wash vegetables in clean water and thorough cooking.
4) Use bed nets and eliminate the natural breeding grounds of the disease vectors by maintaining water stagnant free area around house.
5) Use pesticides.

Protection of Well Waters :

New wells or wells after repairs have to be disinfected by heavy doses of chlorine. Chlorine is added in the form of bleaching powder. For dug wells, the procedure for applying chlorine is given as follows:

i) Remove all equipment and materials including tools, platforms, etc., from the top of well.
ii) Wash the interior of the well (lining) with a strong solution of bleaching powder (50 mg/lt) using a stiff brush or broom.
iii) Pump the water from the well until it is perfectly clear and remove the pumping equipment used temporarily for this purpose.
iv) Place the cover on the well and pour the required amount of bleaching powder solution through the manhole in the cover. The bleaching powder added is such that it gives a dose of 50mg/litre depending on the volume of water in the well. The chlorine solution should be introduced into the well by means of a hosepipe so that it will be distributed over. The entire surface of the well. This will allow the solution to mix well with the water.
v) Allow the chlorine solution to remain in the well for not less than 24 hours.
vi) After 24 hours or more, the well should be flushed by pumping the water to waste till the residual chlorine is brought to 1mg/ litre.

$KMNO_4$ Treatment :

Well waters can also be treated economically with Potassium Permanganate $KMNO_4$ solution. Disinfectant is taken in the range of 50 to 70 mg/lt dose and slurry is made with well water in a bucket. Then this prepared slurry is poured into the well and left for mix up and reaction period for about one to two weeks. During the reaction period well is not used. Only drawback of using $KMNO_4$ as a disinfection agent that it imparts pink color to the well water. Hence well water is not used during the disinfection process till the pink color gets diluted.

R-5

DRINKING WATER QUALITY STANDARDS:

Parameter	Indian standards I S 10500-1983		I C M R		WHO	
	Permissible	Excessive	Permissible	Excessive	Permissible	Excessive
Physical:						
1) Color (units)	10	50	5	25	5	50
(2) Taste and Odour	Unobjectionable		Nothing disagreeable		Unobjectionable	
(3) Turbidity (NTU)	10	25	5	25	5	25
Chemical :						
4) PH	6.5- 8.5	6.5 9.2	7- 8.5	6.5-9.2	7- 8.5	6.5- 9.2
5) Total Solids	-	-	-	-	500	1500
6) Total hardness	300	600	300	600	-	-
7) Calcium	75	200	75	200	75	200
8) Magnesium	30	100	50	150	50	150
9) Copper	0.05	1.5	1.0	3.0	1.0	1.5
10) Iron	0.3	1.0	0.3	1.0	0.3	1.0
11) Manganese	0.1	0.5	0.1	0.5	0.1	0.5
12) Chlorides	250	1000	250	1000	200	600
13) Sulphates	150	400	200	400	200	400
14) Nitrates	45	-	20	50	-	50-100
15) Fluoride	0.6-1.2	-	1.0	2.0	0.5	1.0-1.5
16) Phenolic substances	0.001	0.002	0.001	0.002	0.001	0.002
Toxic:						
17) Arsenic	0.05	-	-	0.2	-	0.2
18) Cadmium	0.05	-	-	0.05	-	0.05
19) Cyanide	0.05	-	-	0.01	-	0.01
20) Lead	0.1	-	-	0.1	-	0.1
21) Selenium	0.01	-	-	0.05	-	0.01
22) Zinc	5.0	10.0	-	-	-	-
23) Mercury	0.01	-	-	-	-	-
Bacteriological:	1 Coliform per 100ml		1 Coliform per 100ml		1 Coliform per 100ml	
Radio activity:						
25) Alpha emitters (μC/ml)	10^{-8}	-	-	10^{-9}	-	10^{-9}
26) Beta emitters (μC /ml)	10^{-7}	-	-	10^{-8}	-	10^{-8}
All units except pH, radioactivity, physical parameters mentioned above are in mg/lt.						
1 milligram per litre (mg/lt) = 1 parts per million (ppm).						

R-6

SMH

DISINFECTION:

Water after filtration still contains the following:

1) Bacterial impurities
2) Colour, taste and odour
3) Dissolved inorganic Salts

The process by which harmful bacteria are destroyed to make it safe for drinking is called disinfection. Chemicals used for this purpose are called disinfectants.

Criteria for a Good Disinfectant:

A chemical used as a disinfectant should satisfy the following criteria:

1) It should be capable of destroying pathogenic organisms within the contact time available.
2) It should not change the physical and chemical characteristics of water.
3) It should not leave products of reaction, which will make the water toxic and unpalatable.
4) It should be easily available at reasonable cost.
5) It should be capable of leaving residual concentration to deal with small recontamination.
6) It should be detected in the water by simple tests.

Methods of Disinfection:

The following methods are available for disinfection:

1) Boiling water
2) Ozone gas treatment
3) Excess lime treatment
4) Jodine and bromine treatment
5) Uitraviolet rays treatment
6) Potassium permanganate treatment
7) Chlorination

1) Boiling: When water is boiled for 15-20 minutes, the harmful bacteria are killed. Disadvantages are:

- Boiling changes taste of water
- Impracticable to boil water for large treatment plants
- This method is applicable to individual homes in times of emergency.

2) Ozone Gas Treatment: Ozone is an unstable is top of oxygen. It contains three atoms of oxygen and one easily breaks away. This produces nascent oxygen which is a powerful disinfectant. It does not produce any taste or odour . Disadvantages are:

- Treatment costly
- Ozone is unstable and cannot be stored for long time
- No residual disinfecting action

3) Excess Lime Treatment: When excess lime is added, it increases the pH value of water. It is not used for public water- supply schemes because:

- Water treated with lime cannot be consumed directly.
- Excess lime has to be removed by some suitable method.

R-7

4) Iodine and Bromine Treatment: Iodine and bromine are good disinfectants. These are available in the form of pills or pellets. Disadvantages are:

- Treatment costly
- Produces certain taste and odour

They may be used for swimming pools, army troops during war, etc. Not used for public water-supply.

5) Ultraviolet Treatment: Ultraviolet rays are powerful disinfectants. They are produced by passing electric current through mercury vapour lamps. Water is allowed to flow in thin layers. Disadvantages are:

- Treatment costly
- No residual disinfecting action
- Ineffective when turbidity is greater than 15ppm

6) Potassium Permanganate: This is very effective in killing cholera germs but not very effective for other bacteria. Widely used for disinfecting village wells.
Disadvantages:

- Not effective for all bacteria
- Produces coating on porcelain vessels and it stains difficult to remove

7) Chlorination: The process of applying chlorine to water is called chlorination. This is the most commonly and widely adopted method of disinfection for public water supply. Chlorination has several advantages over other methods:

- The process is economical and cheap
- It is harmless to human beings
- It is reliable and effective
- Residual CI can be maintained in the water

The quantity of chlorine to be applied should be right. Too little will not kill pathogenic bacteria: too much of it will cause bad taste and odour. Chlorination is done by a chlorinator. The chlorine is automatically fed into the water in proportion to the quantity of water flowing.

The chlorine should be in contact with water for at least 20-30 minutes before it reaches the consumer. The reasons for it are:

- It gives time for chlorine to kill the pathogenic bacteria
- It reduces the effect of possible over- chlorination, which causes odour and taste.

8) Chlorine Demand: Chlorine and its compounds are consumed by a variety of organic and inorganic materials present in water due to its oxidising power before disinfection is achieved. The difference between the amount of chlorine added to the water and the residual chlorine is called chlorine demand. This depends on the amount of chlorine added, time of contact, pH and temperature.

Application of Chlorine

Chlorine is applied for disinfection in one of the following ways depending upon its requirement:

1) Free chlorine
2) Chloramines
3) Bleaching powder

SMH

1) **Free Chlorine:** Free chlorine is available in gaseous or liquid form. Chlorine is stored in cylinders, 80% of the contents being in liquid form and the rest in gaseous form. The chlorine is fed to a water supply by means of a device called chlorinator. It regulates the flow of gas from the chlorine container at the desired rate. A pressure gauge indicates the cylinder pressure. The chlorine passes through a value containing sulphuric acid to remove moisture to prevent corrosion of parts by most chlorine.

Free chlorine is used in large public water-supply schemes. The advantages of using free chlorine are:

- It can be stored for long time without loss of quality
- It is a very powerful and effective disinfectant
- It is available cheaply
- Initial cost of chlorination plants is low
- There is no sludge formation
- Skilled supervision is not necessary for applying it.

2) **Chloramines:** Chlorine is not stable in water. Hence it is sometimes mixed with ammonia to form stable compounds called chloramines. These have adequately good disinfecting properties and are specially useful for disinfecting swimming pools.

Water treated with chloramines should be supplied to consumers after a laps of one or two hours.

3) **Bleaching Powder:** Bleaching powder is a compound of chlorine and contains about 30% chlorine. When bleaching powder is used as disinfectant, it is also called hypo-chlorination. Bleaching powder is available in the form of powder. It is unstable and loses chlorine when expose to atmosphere. Hence it has to be stored carefully. Its use is uneconomical and hence it is used for small water-supply installations.

A solution is first prepared by mixing it with a little quantity of water. The required quantity is then added to the water.

Different Forms of Chlorination:

The different forms of chlorination practice are:

a) Plain chlorination
b) Pre chlorination
c) Post chlorination
d) Double chlorination
e) Super chlorination
f) Dechlorination
g) Rechlorination
h)Breakpoint chlorination

Plain Chlorination : Water from deep lakes, reservoirs, etc., is comparatively clear with turbidity less than 30ppm. In such cases no treatment such as sedimentation, coagulation, etc., is necessary. When no other treatment except chlorination is given before supplying water to consumers, it is called plain chlorination. About 0.5 ppm of chlorine is added for disinfection of such water.

R-9

Pre chlorination: When chlorination of raw water is done before any treatment is given, then it is called pre chlorination. The point at which the chlorination has to be applied and the dosage depend on the following:

- Amount of growth of algae in sedimentation tanks and filters
- The amount of coagulation required
- The amount of objectionable taste and odor
- The bacterial load on filters
- The purification of sludge in sedimentation tanks

Post chlorination: Post chlorination is application of chlorine to water before it enters the distribution system to maintain the required amount of free chlorine. Thus when the water enters the distribution system, it should contain residual chlorine to the extent of 0.2 to 0.3 mg\l. This ensures that water will be safe from contamination when flowing in the distribution system.

Double chlorination: Post chlorination has to be carried out even if pre chlorination is done to ensure the water is safe for drinking. Thus application of chlorination twice i.e. both pre chlorination as well as post chlorination is known as double chlorination.

Super chlorination: This is adopted in cases of an emergency like a breakdown or in cases of waters, which are heavily polluted. It is practiced in waters where:

- Plain chlorination produces taste and odour
- The water is coloured
- Iron and manganese have to be oxidised

This is also resorted to when the contact time is limited at the pre-chlorination stage. Super chlorination effectively destroys organisms. The contact period is generally 10-30 minutes. Excess chlorine has to be again de chlorinated.

De chlorination : When water contains excess chlorine, as in the case of superchlorination. It gives a strong odour and taste. Then de chlorination is done to remove excess undesirable chlorine to such an extent that residual chlorine is not objectionable. De chlorination is done by the addition of sulphur dioxide or by aeration.

Re-chlorination: When the distribution system is long and complex, it may be difficult to maintain the residual chlorine content of 0.2 mg\l at the farther point. A very high dosage of chlorine at the post-chlorination stage makes the water unpalatable and also is costly. Therefore, the chlorine is applied at different stages in the distribution system. This is called re chlorination. Re chlorination is carried out in service reservoirs, booster pumping stations or at points where mains supply water to zones.

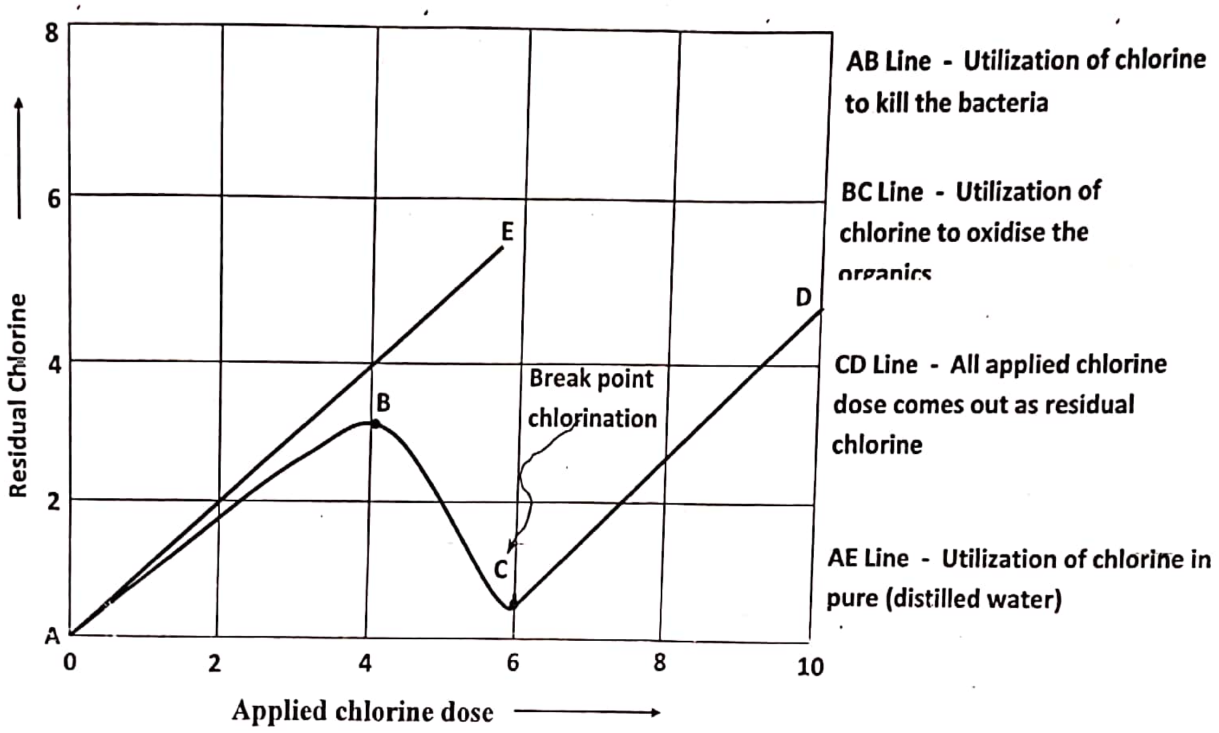
Break point Chlorination: Water contains the following impurities:

- Bacteria
- Organic impurities

Chlorine is required to destroy both. When chlorine is applied, it first kills the bacteria. Any further addition will appear as residual chlorine increases. After a certain point, the residual chlorine suddenly decreases with emanation of bad smell and objectionable taste. This indicates that chlorine is being used for oxidizing the organic impurities. Again, after some time, there is sudden increase in residual chlorine indicating that oxidation of impurities is over. The point at which both the demands are satisfied and residual chlorine increases is called breakpoint.

Beyond the break point, any further dose of chlorine only gets accumulated. The process of adding chlorine beyond the breakpoint is called breakpoint chlorination.

Fig shows the breakpoint.



In all public water- supply schemes chlorine is added up to breakpoint chlorination.

R-11

Getting Up to Speed

Ground Water Contamination

Ground water contamination is nearly always the result of human activity. In areas where population density is high and human use of the land is intensive, ground water is especially vulnerable. Virtually any activity whereby chemicals or wastes may be released to the environment, either intentionally or accidentally, has the potential to pollute ground water. When ground water becomes contaminated, it is difficult and expensive to clean up.

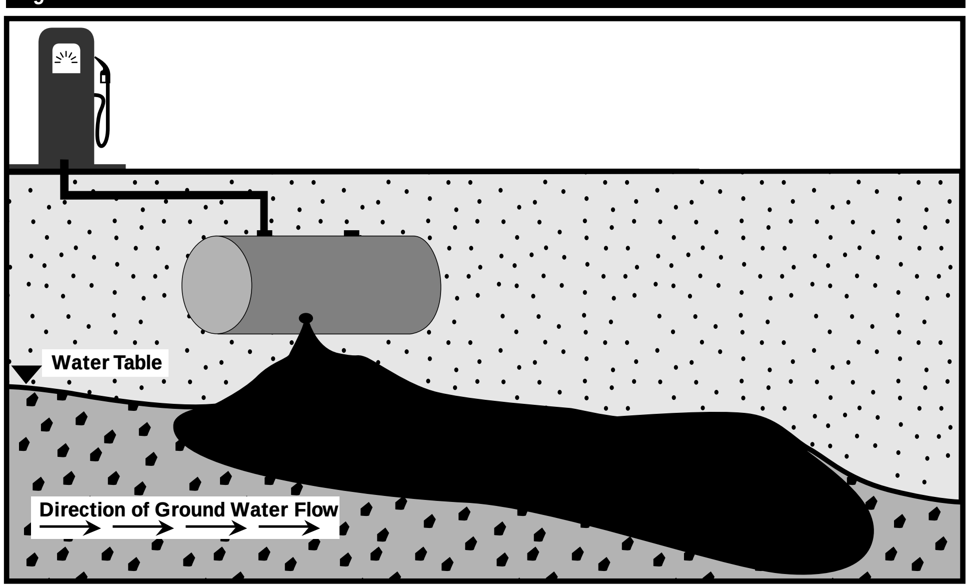
To begin to address pollution prevention or remediation, we must understand how surface waters and ground waters interrelate. Ground water and surface water are interconnected and can be fully understood and intelligently managed only when that fact is acknowledged. If there is a water supply well near a source of contamination, that well runs the risk of becoming contaminated. If there is a nearby river or stream, that water body may also become polluted by the ground water.

How Does Ground Water Become Contaminated?

Depending on its physical, chemical, and biological properties, a contaminant that has been released into the environment may move within an aquifer in the same manner that ground water moves. (Some contaminants, because of their physical or chemical properties, do not always follow ground water flow.) It is possible to predict, to some degree, the transport within an aquifer of those substances that move along with ground water flow. For example, both water and certain contaminants flow in the direction of the topography from recharge areas to discharge areas. Soils that are porous and permeable tend to transmit water and certain types of contaminants with relative ease to an aquifer below.

Just as ground water generally moves slowly, so do contaminants in ground water. Because of this slow movement, contaminants tend to remain concentrated in the form of a **plume** (see Figure 1) that flows along the same path as the ground water. The size and speed of the plume depend on the amount and type of contaminant, its solubility and density, and the velocity of the surrounding ground water.

Figure 1 Contaminant Plume



Ground water and contaminants can move rapidly through fractures in rocks. Fractured rock presents a unique problem in locating and controlling contaminants because the fractures are generally randomly spaced and do not follow the contours of the land surface or the hydraulic gradient. Contaminants can also move into the ground water system through macropores—root systems, animal burrows, abandoned wells, and other systems of holes and cracks that supply pathways for contaminants.

In areas surrounding pumping wells, the potential for contamination increases because water from the **zone of contribution**, a land area larger than the original recharge area, is drawn into the well and the surrounding aquifer. Some drinking water wells actually draw water from nearby streams, lakes, or rivers. Contaminants present in these surface waters can contribute contamination to the ground water system. Some wells rely on artificial recharge to increase the amount of water infiltrating an aquifer, often using water from storm runoff, irrigation, industrial processes, or treated sewage. In several cases, this practice has resulted in increased concentrations of nitrates, metals, microbes, or synthetic chemicals in the water.

Under certain conditions, pumping can also cause the ground water (and associated contaminants) from another aquifer to enter the one being pumped. This phenomenon is called **interaquifer leakage**. Thus, properly identifying and protecting the areas affected by well pumping is important to maintain ground water quality.

Generally, the greater the distance between a source of contamination and a ground water source, the more likely that natural processes will reduce the impacts of contamination. Processes such as oxidation, biological degradation (which sometimes renders contaminants less toxic), and adsorption (binding of materials to soil particles) may take place in the soil layers of the unsaturated zone and reduce the concentration of a contaminant before it reaches ground water. Even contaminants that reach ground water directly, without passing through the unsaturated zone, can become less concentrated by dilution (mixing) with the ground water. However, because ground water usually moves slowly, contaminants generally undergo less dilution than when in surface water.

SOURCES OF GROUND WATER CONTAMINATION

Ground water can become contaminated from natural sources or numerous types of human activities. (See Tables 1 and 2 and Figure 1.) Residential, municipal, commercial, industrial, and agricultural activities can all affect ground water quality. Contaminants may reach ground water from activities on the land surface, such as releases or spills from stored industrial wastes; from sources below the land surface but above the water table, such as septic systems or leaking underground petroleum storage systems; from structures beneath the water table, such as wells; or from contaminated recharge water.

■ Natural Sources

Some substances found naturally in rocks or soils, such as iron, manganese, arsenic, chlorides, fluorides, sulfates, or radionuclides, can become dissolved in ground water. Other naturally occurring substances, such as decaying organic matter, can move in ground water as particles. Whether any of these substances appears in ground water depends on local conditions. Some substances may pose a health threat if consumed in excessive quantities; others may produce an undesirable odor, taste, or color. Ground water that contains unacceptable concentrations of these substances is not used for drinking water or other domestic water uses unless it is treated to remove these contaminants.

■ Septic Systems

One of the main causes of ground water contamination in the United States is the effluent (outflow) from septic tanks, cesspools, and privies.

Table 1 TYPICAL SOURCES OF POTENTIAL GROUND WATER CONTAMINATION BY LAND USE CATEGORY

Category	Contaminant Source	
Agriculture	Animal burial areas	Irrigation sites
	Animal feedlots	Manure spreading areas/pits
	Fertilizer storage/use	Pesticide storage/use
Commercial	Airports	Jewelry/metal plating
	Auto repair shops	Laundromats
	Boat yards	Medical institutions
	Construction areas	Paint shops
	Car washes	Photography establishments
	Cemeteries	Railroad tracks and yards
	Dry cleaners	Research laboratories
	Gas stations	Scrap and junkyards
	Golf courses	Storage tanks
Industrial	Asphalt plants	Petroleum production/storage
	Chemical manufacture/storage	Pipelines
	Electronics manufacture	Septage lagoons and sludge sites
	Electroplaters	Storage tanks
	Foundries/metal fabricators	Toxic and hazardous spills
	Machine/metalworking shops	Wells (operating/abandoned)
	Mining and mine drainage	Wood preserving facilities
Residential	Fuel oil	Septic systems, cesspools
	Furniture stripping/refinishing	Sewer lines
	Household hazardous products	Swimming pools (chemical storage)
	Household lawns	
Other	Hazardous waste landfills	Recycling/reduction facilities
	Municipal incinerators	Road deicing operations
	Municipal landfills	Road maintenance depots
	Municipal sewer lines	Storm water drains/basins
	Open burning sites	Transfer stations

Source: U.S. EPA, 1991a.

Approximately one-fourth of all homes in the United States rely on septic systems to dispose of their human wastes. Although each individual system releases a relatively small amount of waste into the ground, the large number and widespread use of these systems makes them a serious contamination source. Septic systems that are improperly sited, designed, constructed, or maintained can contaminate ground water with bacteria, viruses, nitrates, detergents, oils, and chemicals. Along with these contaminants are the commercially available septic system cleaners containing synthetic organic chemicals (such as 1,1,1-trichloroethane or methylene chloride). These cleaners can contaminate water supply wells and interfere with natural decomposition processes in septic systems.

Most, if not all, state and local regulations require specific separation distances between septic systems and drinking water wells. In addition, computer models have been developed to calculate suitable distances and densities.

■ Improper Disposal of Hazardous Waste

Hazardous waste should always be disposed of properly, that is to say, by a licensed hazardous waste handler or through municipal hazardous waste collection days. Many chemicals should not be disposed of in household septic systems, including oils (e.g., cooking, motor), lawn and garden chemicals, paints and paint thinners, disinfectants, medicines, photographic chemicals, and swimming pool chemicals. Similarly, many substances used in industrial processes should not be disposed of in drains at the workplace because they could contaminate a drinking water source. Companies should train employees in the proper use and disposal of all chemicals used on site. The many different types and the large quantities of chemicals used at industrial locations make proper disposal of wastes especially important for ground water protection.

■ Releases and Spills from Stored Chemicals and Petroleum Products

Underground and aboveground storage tanks are commonly used to store petroleum products and other chemical substances. For example, many homes have underground heating oil tanks. Many businesses and municipal highway departments also store gasoline, diesel fuel, fuel oil, or chemicals in on-site tanks. Industries use storage tanks to hold chemicals used in industrial processes or to store hazardous wastes for pickup by a licensed hauler. Approximately 4 million underground storage tanks exist in the United States and, over the years, the contents of many of these tanks have leaked and spilled into the environment.

If an underground storage tank develops a leak, which commonly occurs as the tank ages and corrodes, its contents can migrate through the soil and reach the ground water. Tanks that meet federal/state standards for new and upgraded systems are less likely to fail, but they are not foolproof. Abandoned underground tanks pose another problem because their location is often unknown. Aboveground storage tanks can also pose a threat to ground water if a spill or leak occurs and adequate barriers are not in place.

Improper chemical storage, sloppy materials handling, and poor-quality containers can be major threats to ground water. Tanker trucks and train cars pose another chemical storage hazard. Each year, approximately 16,000 chemical spills occur from trucks, trains, and storage tanks, often when materials are being transferred. At the site of an accidental spill, the chemicals are often diluted with water and then washed into the soil, increasing the possibility of ground water contamination.

■ Landfills

Solid waste is disposed of in thousands of municipal and industrial landfills throughout the country. Chemicals that should be disposed of in hazardous waste landfills sometimes end up in municipal landfills. In addition, the disposal of many household wastes is not regulated.

Once in the landfill, chemicals can leach into the ground water by means of precipitation and surface runoff. New landfills are required to have clay or synthetic liners and leachate (liquid from a landfill containing contaminants) collection systems to protect ground water. Most older landfills, however, do not have these safeguards. Older landfills were often sited over aquifers or close to surface waters and in permeable soils with shallow water tables, enhancing the potential for leachate to contaminate ground water. Closed landfills can continue to pose a ground water contamination threat if they are not capped with an impermeable material (such as clay) before closure to prevent the leaching of contaminants by precipitation.

■ Surface Impoundments

Surface impoundments are relatively shallow ponds or lagoons used by industries and municipalities to store, treat, and dispose of liquid wastes. As many as 180,000 surface impoundments exist in the United States. Like landfills, new surface impoundment facilities are required to have liners, but even these liners sometimes leak.

Table 2 POTENTIAL HARMFUL COMPONENTS OF COMMON HOUSEHOLD PRODUCTS

Product	Toxic or Hazardous Components
Antifreeze (gasoline or coolants systems)	Methanol, ethylene glycol
Automatic transmission fluid	Petroleum distillates, xylene
Battery acid (electrolyte)	Sulfuric acid
Degreasers for driveways and garages	Petroleum solvents, alcohols, glycol ether
Degreasers for engines and metal	Chlorinated hydrocarbons, toluene, phenols, dichloroperchloroethylene
Engine and radiator flushes	Petroleum solvents, ketones, butanol, glycol ether
Hydraulic fluid (brake fluid)	Hydrocarbons, fluorocarbons
Motor oils and waste oils	Hydrocarbons
Gasoline and jet fuel	Hydrocarbons
Diesel fuel, kerosene, #2 heating oil	Hydrocarbons
Grease, lubes	Hydrocarbons
Rustproofers	Phenols, heavy metals
Car wash detergents	Alkyl benzene sulfonates
Car waxes and polishes	Petroleum distillates, hydrocarbons
Asphalt and roofing tar	Hydrocarbons
Paints, varnishes, stains, dyes	Heavy metals, toluene
Paint and lacquer thinner	Acetone, benzene, toluene, butyl acetate, methyl ketones
Paint and varnish removers, deglossers	Methylene chloride, toluene, acetone, xylene, ethanol, benzene, methanol
Paint brush cleaners	Hydrocarbons, toluene, acetone, methanol, glycol ethers, methyl ethyl ketones
Floor and furniture strippers	Xylene
Metal polishes	Petroleum distillates, isopropanol, petroleum naphtha
Laundry soil and stain removers	Hydrocarbons, benzene, trichloroethylene, 1,1,1-trichloroethane
Other solvents	Acetone, benzene
Rock salt	Sodium concentration
Refrigerants	1,1,2-trichloro-1,2,2-trifluoroethane
Bug and tar removers	Xylene, petroleum distillates
Household cleansers, oven cleaners	Xylenols, glycol ethers, isopropanol
Drain cleaners	1,1,1-trichloroethane
Toilet cleaners	Xylene, sulfonates, chlorinated phenols
Cesspool cleaners	Tetrachloroethylene, dichlorobenzene, methylene chloride
Disinfectants	Cresol, xylenols
Pesticides (all types)	Naphthalene, phosphorus, xylene, chloroform, heavy metals, chlorinated hydrocarbons
Photochemicals	Phenols, sodium sulfite, cyanide, silver halide, potassium bromide
Printing ink	Heavy metals, phenol-formaldehyde
Wood preservatives (creosote)	Pentachlorophenols
Swimming pool chlorine	Sodium hypochlorite
Lye or caustic soda	Sodium hydroxide
Jewelry cleaners	Sodium cyanide

Source: "Natural Resources Facts: Household Hazardous Wastes," Fact Sheet No. 88-3, Department of Natural Science, University of Rhode Island, August 1988.

■ Sewers and Other Pipelines

Sewer pipes carrying wastes sometimes leak fluids into the surrounding soil and ground water. Sewage consists of organic matter, inorganic salts, heavy metals, bacteria, viruses, and nitrogen. Other pipelines carrying industrial chemicals and oil brine have also been known to leak, especially when the materials transported through the pipes are corrosive.

■ Pesticide and Fertilizer Use

Millions of tons of fertilizers and pesticides (e.g., herbicides, insecticides, rodenticides, fungicides, avicides) are used annually in the United States for crop production. In addition to farmers, homeowners, businesses (e.g., golf courses), utilities, and municipalities use these chemicals. A number of these pesticides and fertilizers (some highly toxic) have entered and contaminated ground water following normal, registered use. Some pesticides remain in soil and water for many months to many years. Another potential source of ground water contamination is animal wastes that percolate into the ground from farm feedlots. Feedlots should be properly sited and wastes should be removed at regular intervals.

Between 1985 and 1992, EPA's Office of Pesticides and Toxic Substances and Office of Water conducted a National Pesticide Survey to determine the number of drinking water wells nationwide that contain pesticides and nitrates and the concentration of these substances. The survey also analyzed the factors associated with contamination of drinking water wells by pesticides and nitrates. The survey, which included samples from more than 1,300 public community and rural domestic water supply wells, found that approximately 3.6 percent of the wells contained concentrations of nitrates above the federal maximum contaminant level, and that over half of the wells contained nitrates above the survey's minimum reporting limit for nitrate (0.15 mg/L).

The survey also reported that approximately 0.8 percent of the wells tested contained pesticides at levels higher than federal maximum contaminant levels or health advisory levels. Only 10 percent of the wells classified as rural were actually located on farms. There is a higher incidence of contamination by agricultural chemicals in farm wells used for drinking water.

After further analysis, EPA estimated that for the wells that contain pesticides, a significant percentage probably contain chemical concentrations that exceed the federal health-based limits (e.g., maximum contaminant levels or health advisory levels). Approximately 14.6 percent of the wells tested contained levels of one or more pesticides above the minimum reporting limit set in the survey. The most common pesticides found were atrazine and metabolites (breakdown products) of dimethyl tetrachloroterephthalate (DCPA, commonly known as Dacthal), which is used in many utility easement weed-control programs and for lawn care.

■ Drainage Wells

Drainage wells are used in wet areas to help drain water and transport it to deeper soils. These wells may contain agricultural chemicals and bacteria.

■ Injection Wells/Floor Drains

Injection wells are used to collect storm water runoff, collect spilled liquids, dispose of wastewater, and dispose of industrial, commercial, and utility wastes. These wells are regulated by the U.S. EPA's Underground Injection Control Program. In New England, these wells may not be used to inject hazardous wastes from industrial, commercial, and utility operations. The injection wells used in this region are typically shallow and include sumps and dry wells used to handle storm water.

Floor drains were historically used by businesses to handle spills. Today, if a business operates or handles waste fluids that drain to a septic system, dry well, or floor drain, it is required to submit information regarding its operation to the U.S. EPA or its state environmental protection agency. Disposal wells that pose threats to drinking water supplies are prohibited and must be closed, connected to a public sewage system, or connected to a storage tank.

■ Improperly Constructed Wells

Problems associated with improperly constructed wells can result in ground water contamination when contaminated surface or ground water is introduced into the well.

■ Improperly Abandoned Wells

These wells can act as a conduit through which contaminants can reach an aquifer if the well casing has been removed, as is often done, or if the casing is corroded. In addition, some people use abandoned wells to dispose of wastes such as used motor oil. These wells may reach into an aquifer that serves drinking supply wells. Abandoned exploratory wells (e.g., for gas, oil, or coal) or test hole wells are usually uncovered and are also a potential conduit for contaminants.

■ Active Drinking Water Supply Wells

Poorly constructed wells can result in ground water contamination. Construction problems, such as faulty casings, inadequate covers, or lack of concrete pads, allow outside water and any accompanying contaminants to flow into the well. Sources of such contaminants can be surface runoff or wastes from farm animals or septic systems. Contaminated fill packed around a well can also degrade well water quality. Well construction problems are more likely to occur in older wells that were in place prior to the establishment of well construction standards and in domestic and livestock wells.

■ Poorly Constructed Irrigation Wells

These wells can allow contaminants to enter ground water. Often pesticides and fertilizers are applied in the immediate vicinity of wells on agricultural land.

■ Mining Activities

Active and abandoned mines can contribute to ground water contamination. Precipitation can leach soluble minerals from the mine wastes (known as spoils or tailings) into the ground water below. These wastes often contain metals, acid, minerals, and sulfides. Abandoned mines are often used as wells and waste pits, sometimes simultaneously. In addition, mines are sometimes pumped to keep them dry; the pumping can cause an upward migration of contaminated ground water, which may be intercepted by a well.

EFFECTS OF GROUND WATER CONTAMINATION

Contamination of ground water can result in poor drinking water quality, loss of water supply, degraded surface water systems, high cleanup costs, high costs for alternative water supplies, and/or potential health problems.

The consequences of contaminated ground water or degraded surface water are often serious. For example, estuaries that have been impacted by high nitrogen from ground water sources have lost critical shellfish habitats. In terms of water supply, in some instances, ground water contamination is so severe that the water supply must be abandoned as a source of drinking water. In other cases, the ground water can be cleaned up and used again, if the contamination is not too severe and if the municipality is willing to spend a good deal of money. Follow-up water quality monitoring is often required for many years.

Because ground water generally moves slowly, contamination often remains undetected for long periods of time. This makes cleanup of a contaminated water supply difficult, if not impossible. If a cleanup is undertaken, it can cost thousands to millions of dollars.

Once the contaminant source has been controlled or removed, the contaminated ground water can be treated in one of several ways:

- Containing the contaminant to prevent migration.
- Pumping the water, treating it, and returning it to the aquifer.

- Leaving the ground water in place and treating either the water or the contaminant.
- Allowing the contaminant to attenuate (reduce) naturally (with monitoring), following the implementation of an appropriate source control.

Selection of the appropriate remedial technology is based on site-specific factors and often takes into account cleanup goals based on potential risk that are protective of human health and the environment. The technology selected is one that will achieve those cleanup goals. Different technologies are effective for different types of contaminants, and several technologies are often combined to achieve effective treatment. The effectiveness of treatment depends in part on local hydrogeological conditions, which must be evaluated prior to selecting a treatment option.

Given the difficulty and high costs of cleaning up a contaminated aquifer, some communities choose to abandon existing wells and use other water sources, if available. Using alternative supplies is probably more expensive than obtaining drinking water from the original source. A temporary and expensive solution is to purchase bottled water, but it is not a realistic long-term solution for a community's drinking water supply problem. A community might decide to install new wells in a different area of the aquifer. In this case, appropriate siting and monitoring of the new wells are critical to ensure that contaminants do not move into the new water supplies.

Potential Health Problems

A number of microorganisms and thousands of synthetic chemicals have the potential to contaminate ground water. Drinking water containing bacteria and viruses can result in illnesses such as hepatitis, cholera, or giardiasis. Methemoglobinemia or "blue baby syndrome," an illness affecting infants, can be caused by drinking water that is high in nitrates. Benzene, a component of gasoline, is a known human carcinogen. The serious health effects of lead are well known—learning disabilities in children; nerve, kidney, and liver problems; and pregnancy risks. Concentrations in drinking water of these and other substances are regulated by federal and state laws. Hundreds of other chemicals, however, are not yet regulated, and many of their health effects are unknown or not well understood. Preventing contaminants from reaching the ground water is the best way to reduce the health risks associated with poor drinking water quality.

Regulations to Protect Ground Water

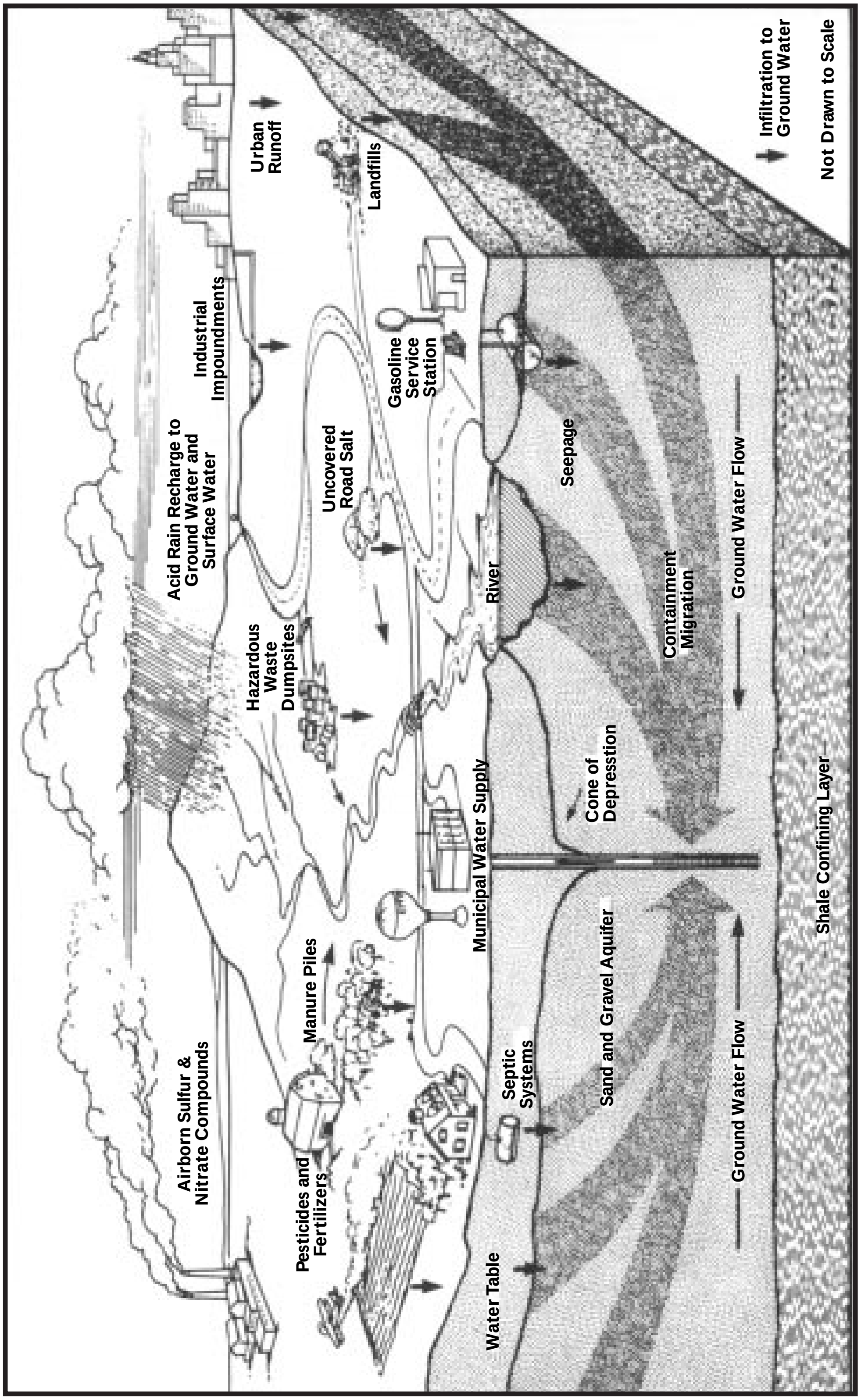
Several federal laws help protect ground water quality. The **Safe Drinking Water Act (SDWA)** established three drinking water source protection programs: the Wellhead Protection Program, Sole Source Aquifer Program, and the Source Water Assessment Program. It also called for regulation of the use of underground injection wells for waste disposal and provided EPA and the states with the authority to ensure that drinking water supplied by public water systems meets minimum health standards. The **Clean Water Act** regulates ground water that is shown to have a connection with surface water. It sets standards for allowable pollutant discharges to surface water. The **Resource Conservation and Recovery Act (RCRA)** regulates treatment, storage, and disposal of hazardous and nonhazardous wastes. The **Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA, or Superfund)** authorizes the government to clean up contamination or sources of potential contamination from hazardous waste sites or chemical spills, including those that threaten drinking water supplies. CERCLA includes a "community right-to-know" provision. The **Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA)** regulates pesticide use. The **Toxic Substances Control Act (TSCA)** regulates manufactured chemicals.

KEY TERMS

- **Clean Water Act**
- **Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA, or Superfund)**
- **Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA)**
- **Interaquifer Leakage**
- **Plume**
- **Resource Conservation and Recovery Act (RCRA)**
- **Safe Drinking Water Act**
- **Toxic Substances Control Act (TSCA)**
- **Zone of Contribution**

"Getting Up to Speed" for section C, "Ground Water Contamination" is adapted from US EPA Seminar Publication. *Wellhead Protection: A Guide for Small Communities*. Chapter 3. EPA/625/R-93/002.

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.