1. OVERVIEW OF THE NONPOINT SOURCE PROBLEM

1.1 DEFINITION OF A NONPOINT SOURCE

Nonpoint sources of water pollution are both diffuse in nature and difficult to define. Nonpoint source pollution can generally be defined as the pollution of waters caused by rainfall or snowmelt moving over and through the ground. As water moves over or through the soil, it picks up and carries away natural pollutants and pollutants resulting from human activity, finally depositing them into lakes, rivers, wetlands, coastal waters, and ground waters. Habitat alteration (such as the removal of riparian vegetation) and hydrologic modification (such as damming a river or installing bridge supports across the mouth of a bay) can cause adverse effects on the biological and physical integrity of surface waters and are also treated as nonpoint sources of pollution. Atmospheric deposition, the deposition of airborne pollutants onto the land and into waterbodies, is also considered to be nonpoint source pollution. At the federal level, the term *nonpoint source* is defined to mean any source of water pollution that does not meet the legal definition of *point source* in section 502(14) of the Clean Water Act:

> The term "point source" means any discernible, confined and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, or vessel or other floating craft, from which pollutants are or may be discharged. This term does not include agricultural storm water discharges and return flows from irrigated agriculture.

The distinction between nonpoint sources and diffuse point sources is sometimes unclear. Although diffuse runoff is usually treated as nonpoint source pollution, runoff that enters and is discharged from conveyances, such as those described above, is treated as a point source discharge and hence is subject to the federal permit requirements under section 402 of the Clean Water Act.

1.2 EXTENT OF NONPOINT SOURCE PROBLEMS IN THE UNITED STATES

Over the last two decades, significant achievements have been made nationally in the protection and enhancement of water quality. Much of this progress, however, has resulted from controlling point sources of pollution. Although some state, tribal, and local nonpoint source management programs have been developed and are being implemented, pollutant loads from nonpoint sources present continuing problems for achieving water quality goals and maintaining designated uses in many parts of the United States.

Data provided by state water quality officials and contained in the *National Water Quality Inventory 1994 Report to Congress* (USEPA, 1995), referred to as the "1994 305(b) report," indicate that nonpoint sources negatively affect rivers and streams in 49 of the 52 states and territories that reported data; lakes, reservoirs, and ponds in 41 of the 52 states and territories that reported data; estuaries and coastal waters in 20 of the 26 coastal states and territories that reported data; and the Great Lakes in 4 of the 8 Great Lakes states (Figure 1-1). The categories of nonpoint source pollution affecting these waterbodies include agriculture, atmospheric deposition, channelization, construction, contaminated sediment, contaminated ground water, flow regulation, forest harvesting (silviculture), ground water loading, highway maintenance/runoff, hydrologic and habitat modification, in-place contamination, land development, land disposal, marinas, onsite disposal systems, recreational activities, removal of riparian vegetation, resource extraction, shoreline modification, streambank destabilization, and unspecified or other nonpoint source pollution.

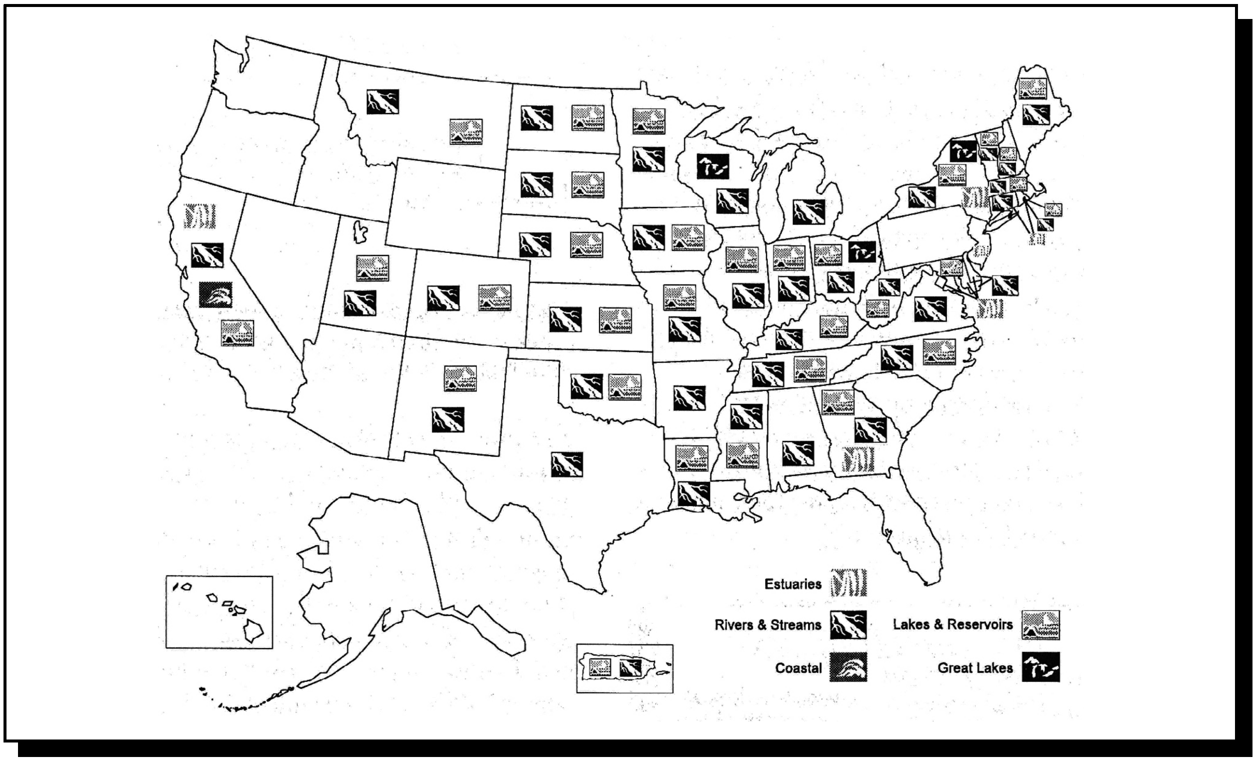

Figure 1-1. Waterbody types affected by nonpoint sources of pollution, by state (USEPA, 1995).

According to the 1994 305(b) report, agriculture is the primary source of pollution affecting rivers and streams. Forty-six states and territories list it as a major source of water quality impairment. Sixty percent of impaired river and stream miles are reported to be negatively affected by agricultural sources of pollution. Other sources that affect rivers and streams include natural sources[1] (reported as affecting 19% of impaired river miles), municipal point sources (17%), hydrologic and habitat modification (17%), urban runoff/storm sewers (12%), resource extraction (11%), removal of riparian vegetation (10%), forest harvesting (9%), industrial point sources (7%), unspecified or other nonpoint source pollution (7%), stream bank destabilization (6%), channelization (5%), petroleum activities (5%), construction (5%), land disposal (5%), recreational activities (3%), flow regulation (3%), onsite disposal systems (2%), highway maintenance and runoff (2%), and land development (2%) (Figure 1-2).

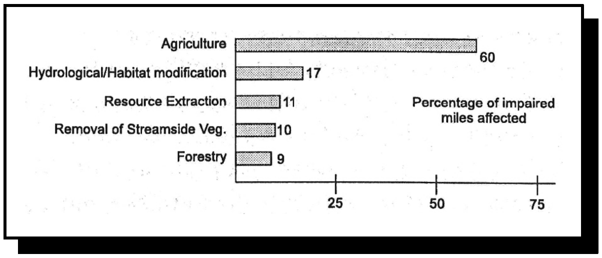

Figure 1-2. Leading sources of nonpoint pollution that impair rivers and streams (USEPA, 1995).

Agriculture is also considered the most significant pollution source affecting lakes, reservoirs, and ponds. Twenty-seven states list agriculture as a major source of impairment to the water quality of lakes, reservoirs, and ponds. Fifty percent of

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[1] Natural sources refer to a variety of naturally occurring water quality problems, including natural deposits of salts, nutrients, and metals in soils that leach into surface and ground waters; warm-weather and dry-weather conditions that raise water temperatures, depress dissolved oxygen concentrations, and dry up shallow waterbodies; and low-flow conditions and tannic acids from decaying leaves that lower pH and dissolved oxygen concentrations in swamps that drain into streams (USEPA, 1995).

impaired lake, reservoir, and pond surface acres are reported to be negatively affected by agriculture, followed by municipal point sources (which affect 19% of impaired river miles), urban runoff/storm sewers (18%), unspecified and other nonpoint source pollution (15%), natural sources (14%), hydrologic and habitat modification (12%), industrial point sources (11%), land disposal (11%), construction (9%), flow regulation (7%), highway maintenance and runoff (6%), contaminated sediment (6%), atmospheric deposition (6%), onsite disposal systems (5%), forest harvesting (5%), resource extraction (4%), shoreline modification (3%), land development (3%), recreational activities (3%), and spills (2%) (Figure 1-3).

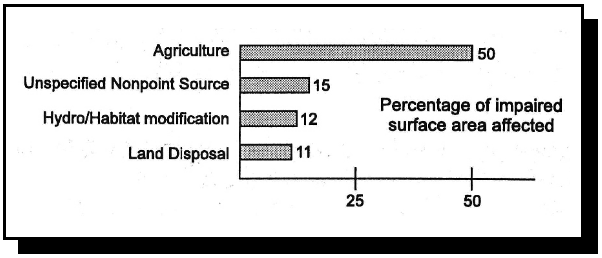

Figure 1-3. Leading sources of nonpoint pollution that impair lakes, reservoirs, and ponds (USEPA, 1995).

The water quality of estuaries is impaired more by urban runoff/storm sewers than by any other pollution source. Twelve states list urban runoff/storm sewers as a major source of impairment to estuarine water quality. Forty-six percent of impaired estuarine waters are reported to be negatively affected by urban runoff/storm sewers, followed by municipal point sources (39%), agriculture (34%), natural sources (30%), industrial point sources (27%), petroleum activities (13%), construction (13%), land disposal (13%), upstream sources (11%), unspecified and other nonpoint source pollution (10%), spills (8%), combined sewer outfalls (5%), resource extraction (5%), contaminated sediment (4%), marinas (3%), onsite disposal systems (3%), wastewater lagoons (3%), forest harvesting (5%), atmospheric deposition (2%), and recreational activities (2%) (Figure 1-4).

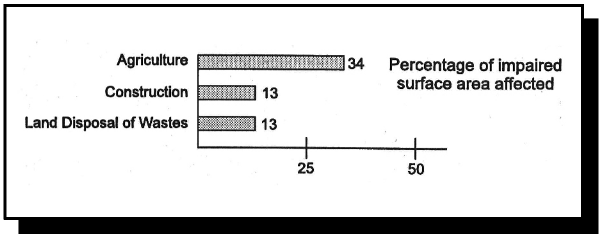

Figure 1-4. Leading sources of nonpoint pollution that impair estuaries (USEPA, 1995).

Ocean shoreline waters are impaired more by urban runoff/storm sewers than by other source of pollution. Two states and Puerto Rico list urban runoff/storm sewers as a major source of impairment to ocean shoreline water quality. Forty-eight percent of impaired ocean shoreline waters are reported to be negatively affected by urban runoff/storm sewers, followed by industrial point sources (34%), natural sources (25%), land disposal (25%), onsite disposal systems (23%), agriculture (20%), unspecified and other nonpoint source pollution (19%), combined sewer outfalls (11%), recreational activities (11%), municipal point sources (7%), atmospheric deposition (3%), spills (3%), ground water loading (3%), and land development (2%) (Figure 1-5).

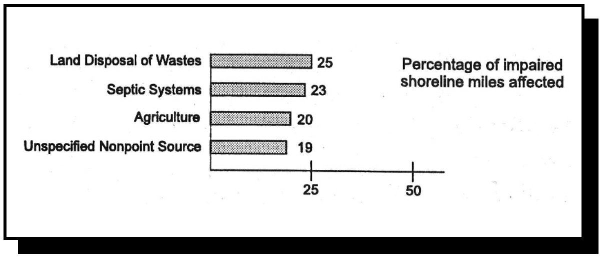

Figure 1-5. Leading sources of nonpoint pollution that impair ocean shorelines (USEPA, 1995).

Four of the eight Great Lakes states list nonpoint source pollution as negatively affecting the quality of their Great Lakes shoreline miles, with atmospheric deposition as the most damaging source of pollution to the lakes. Three states list atmospheric deposition as a source of impairment to Great Lakes shoreline miles, though none list it as a major source of impairment. Twenty-one percent of impaired Great Lakes shoreline miles are reported to be negatively affected by atmospheric deposition, followed by discontinued discharges (20%), contaminated sediment (15%), land disposal (9%), unspecified and other nonpoint source pollution (6%), agriculture (4%), urban runoff/storm sewers (4%), industrial point sources (4%), municipal point sources (4%), combined sewer outfalls (3%), onsite disposal systems (2%), spills and illegal dumping (2%), streambank destabilization (1%), construction (1%), in-place contamination (1%), contaminated ground water (<1%), highway maintenance and runoff (<1%), and hydrologic and habitat modification (<1%) (Figure 1-6).

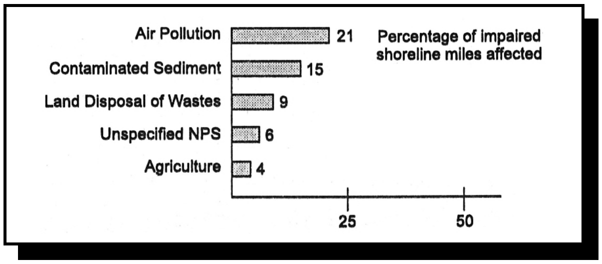

Figure 1-6. Leading sources of nonpoint pollution that impair Great Lakes shoreline miles (USEPA, 1995).

Table 1-1 summarizes the information on the impairment of the Nation's water quality by nonpoint sources of pollution.

1.3 EFFECTS OF NONPOINT SOURCE POLLUTANTS

Nonpoint sources can generate both conventional pollutants (e.g., bacteria, oxygen-demanding substances) and toxic pollutants (e.g., pesticides, petroleum products), just as point sources do. Even though nonpoint sources can contribute many of the same kinds of pollutants as point sources, however, these pollutants are usually generated in different volumes, combinations, and concentrations.

Pollutants from nonpoint sources are mobilized primarily during rainstorms or snowmelt. Consequently, waterborne nonpoint source pollution is generated irregularly, in contrast to the more continuous discharges of point sources of pollution. However, the adverse impacts of NPS pollution downstream from its source, or on downgradient waterbodies, can effectively be continuous under some circumstances. For example, sediment-laden runoff that is not completely flushed out of a surface water prior to a subsequent storm can combine with runoff from that storm to create a continuous adverse impact; toxic pollutants carried in runoff and deposited in sediment can exert a continuous adverse impact long after a rainstorm; physical alterations to a stream course caused by runoff can have a permanent and continuous effect on the watercourse; and the chemical and physical changes caused by NPS pollution can have a continuous adverse impact on resident biota. Hence, the noncontinuous generation of NPS pollution does not necessarily translate into noncontinuous impacts on receiving waterbodies.

Sediment, nutrients, pathogens, salts, toxic substances, petroleum products, and pesticides are the pollutants contributed to surface and ground waters by various nonpoint sources. Each of these pollutants, as well as habitat alteration and hydrologic modification, can have adverse effects on aquatic systems and, in some cases, on human health.

- Nitrogen and phosphorus are contained in commercial fertilizers and manure. The addition of excessive amounts of these nutrients to marine and freshwater systems, where nitrogen and phosphorus, respectively, are generally limiting to plant growth, can lead to accelerated eutrophication.

- Waste from livestock and pets also contains bacteria that contaminate swimming, drinking, and shellfishing waters, as well as oxygen-demanding substances that deplete dissolved oxygen levels in aquatic systems. Suspended sediment generated by construction, overgrazing, logging, and other activities in riparian areas, along with that carried in runoff from cropland, highways,

Table 1-1. Sources of nonpoint pollution and their contribution to the impairment of water quality in the United States (USEPA, 1995).

		Rivers & Streams	Lakes, Ponds & Reservoirs	Estuaries	Ocean Shoreline	Great Lakes Shoreline
Agriculture	Major[a]	36	28	4	1	1
	Length/Area Percent[b]	134,557 miles 60%	3,349,585 acres 50%	3,321 mi^2 34%	74 miles 20%	226 miles 4%
Land Disposal	Major	18	10	4	1	1
	Length/Area Percent	10,360 miles 5%	712,890 acres 11%	1,217 mi^2 13%	92 miles 25%	458 miles 9%
Onsite Disposal Systems	Major	13	6	3	0	1
	Length/Area Percent	5,428 miles 2%	335,702 acres 5%	271 mi^2 3%	87 miles 23%	96 miles 2%
Construction[c]	Major	13	13	2		1
	Length/Area Percent	10,365 miles 5%	624,901 acres 9%	1,253 mi^2 13%		48 miles 1%
Recreational Activities	Major	7	4	1	0	
	Length/Area Percent	7,796 miles 3%	189,828 acres 3%	180 mi^2 2%	40 miles 11%	
Atmospheric Deposition	Major		5	0	0	0
	Length/Area Percent		369,348 acres 6%	236 mi^2 2%	12 miles 3%	1,068 miles 21%
Hydrologic and Habitat Modification	Major	28	13			0
	Length/Area Percent	37,080 miles 17%	832,152 acres 12%			11 miles < 1%
Resource Extraction	Major	28	14	2		
	Length/Area Percent	24,059 miles 11%	236,999 acres 4%	514 mi^2 5%		
Silviculture	Major	13	9	1		
	Length/Area Percent	20,315 miles 9%	307,366 acres 5%	235 mi^2 2%		
Contaminated Sediment	Major		8	1		2
	Length/Area Percent		381,183 acres 6%	395 mi^2 4%		749 miles 15%
Unspecified and Other Nonpoint Source Pollution	Major	12	6	2	1	2
	Length/Area Percent	16,318 miles 7%	988,714 acres 15%	991 mi^2 10%	72 miles 19%	296 miles 6%
Total Impared[d]		224,236 miles	6,682,200 acres	9,700 mi^2	374 miles	5,077 miles

Source: USEPA, 1995.

[a] Number of states and/or territories in which the source is reported as a major source of water quality impairment.

[b] Length or area of waterbody type impaired by the source, and percent of total impaired length or area of waterbody type (reported at bottom of column) that is impaired by the particular source.

[c] Does not include road construction and maintenance.

[d] Figures in columns might not add to total at bottom if multiple sources impair the same stretch or area of surface water.

and bridges, reduces sunlight to aquatic plants, smothers fish spawning areas, and clogs filter feeders and fish gills.

- Salts from irrigation water concentrate at the soil surface through evapotranspiration. Salts used on roads accumulate along the edges of roads and are often carried via storm sewer systems to surface waters. Salts cause the soil structure to break down, decrease water infiltration, and decrease the productivity of cropland, and they can be toxic to plants at high concentrations.

- Some pesticides are persistent in aquatic systems and biomagnify in animal tissue (primarily fish tissue) as they are passed up through the food chain. Biomagnification has detrimental physiological effects in animals and negative human health impacts. Herbicides that are toxic to aquatic plants remove a food source for many aquatic animals, as well as the protective cover that aquatic vegetation offers to many organisms.

- Finally, the trampling of stream bottoms by livestock and equipment; stream bank erosion caused by grazing, logging, and construction; conversion of natural habitats to agricultural, urban, and other land uses; flow regulation; and activities in riparian areas can reduce the available habitat for aquatic species, increase erosion, and create flow regimes that are detrimental to aquatic life.

1.4 MAJOR CATEGORIES OF NONPOINT SOURCE POLLUTION

1.4.1 Agriculture

Agriculture is the leading source of impairment to the Nation's rivers, affecting 60 percent of the impaired river miles in the United States, according to the 1994 305(b) report (USEPA, 1995). Agriculture was also reported as a source of impairment to 50 percent of impaired lake, reservoir, and pond acres; 34 percent of impaired estuary square miles; 20 percent of impaired ocean shoreline miles; and 4 percent of impaired Great Lakes shoreline miles. Wetland loss and wetland degradation were attributed to agriculture by 10 states and 8 states, respectively (USEPA, 1995).

The primary agricultural nonpoint source pollutants are nutrients, sediment, animal wastes, salts, and agricultural chemicals. Direct impacts on habitats are also associated with agriculture. Nitrogen and phosphorus are the two major nutrients from agricultural land that degrade water quality. Nutrients are applied to agricultural land in several different forms and come from various sources, including commercial fertilizer, manure from animal production facilities, municipal and industrial treatment plant sludge and/or effluent applied to agricultural lands, legumes and crop residues, irrigation water, and atmospheric deposition.

Greatly increased loadings of sediment to runoff and surface waters can result from land disturbance and clearing for agricultural operations and from stream bank erosion due to increased instream flows. Sediment loss and runoff are especially high if it rains or if high winds occur while the soil is being disturbed or soon afterward.

Animal waste includes the fecal and urinary wastes of livestock and poultry; process water; and the feed, bedding, litter, and soil from confined animal facilities. Runoff water and process wastewater from confined animal facilities can contain oxygen-demanding substances; nitrogen, phosphorus, and other nutrients; organic solids; salts; bacteria, viruses, and other microorganisms; and sediment.

Large amounts of salt can be added to agricultural soils by irrigation water that has a natural base load of dissolved mineral salts, regardless of whether the water is supplied by ground water or surface water sources. Irrigation water is consumed by plants and lost to the atmosphere by evaporation, and the salts in the water remain on and become concentrated in the soil. Salt accumulation leads to soil dispersion, soil compaction, and possible toxicity to plants and soil fauna.

Agricultural chemicals—including pesticides, herbicides, fungicides, and their degradation products—can enter ground and surface waters in solution, in emulsion, or bound to soil colloids. Some types of agricultural chemicals are resistant to degradation and can persist and accumulate in aquatic ecosystems. Normal application to agricultural fields is a major source of pesticide contamination of surface water and ground water. Other sources are atmospheric deposition; drift during application; misuse; and spills, leaks, and discharges associated with pesticide storage, handling, and disposal.

Impacts on habitats and adjacent surface waters result from planting crops too close to surface waters and from livestock grazing. Riparian vegetation and its pollutant buffering capacity are lost when crops are planted too close to surface waters. Livestock grazing can cause loss of cover vegetation on pasturelands, resulting in erosion, loss of plant diversity on pasturelands, and adverse impacts on stream courses and surface waters. If allowed access to streams, cattle can trample riparian vegetation and disturb stream bank soils, leading to bank erosion, and can alter riparian vegetation species composition through selective grazing. Grazing animals also add fecal contamination to streams and ponds.

1.4.2 Urban Sources

Urban runoff and pollutants carried in storm sewers reportedly impair 12 percent of the Nation’s impaired river miles; 18 percent of impaired lake, reservoir, and pond acres; 46 percent of impaired estuary square miles; 48 percent of impaired ocean shoreline miles, and 4 percent of impaired Great Lakes shoreline miles (USEPA, 1995). Wetland degradation is attributed to pollution from urban runoff/storm sewers by six states (USEPA, 1995).

The major pollutants in runoff from urban areas are sediment, nutrients, oxygen-demanding substances, road salts, heavy metals, petroleum hydrocarbons, pathogenic bacteria, viruses, and toxic chemicals. These are generated directly from the use of insecticides, road salts, and fertilizers, and indirectly from automobile exhaust, oil drippings from trucks and cars, brake lining wear, and various urban activities (USEPA, 1977).

During urbanization, pervious, vegetated ground is converted to impervious, unvegetated land. Land imperviousness in urban areas—as rooftops, roads, parking lots, and sidewalks—can range from 35 percent or lower in lightly urbanized areas to nearly 100 percent in heavily urbanized areas. Increases in pollutant loadings generated from human activities are associated with urbanization, and imperviousness results in increased stormwater runoff volumes and altered hydrology in urban areas. Urban runoff carries these increased pollutant loadings to surface waters, typically without treatment.

Imperviousness results in large volumes of stormwater runoff delivered to surface waters much more quickly than normal, which can result in scouring of stream banks and streambeds and increased sediment loadings to surface waters. Combined with the increased runoff velocities that occur during spring snowmelts and rain-on-snow events in urbanized watersheds, floods often occur more frequently and with greater severity in urbanized areas (Buttle and Xu, 1988). Major snowmelt events can produce peak flows with as much as 20 times the volume of baseflows in urban areas (Pitt and McLean, 1992).

1.4.3 Removal of Streamside Vegetation

Removal of streamside vegetation is reported to be a leading source of impairment to rivers and streams and was reported to affect 10 percent of impaired river and stream miles in the 1994 305(b) report (USEPA, 1995). Somewhere between 70 and 90 percent of natural riparian ecosystems in the United States have been lost to human activities (Windell, 1983, cited in USEPA, 1991).

Losses of riparian vegetation are attributed to conversion to farmland, drainage for agriculture, forest harvesting, channelization, damming, creation of impoundments, irrigation diversions, ground water pumping, and overgrazing (Brinson et al., 1981).

The biological communities in streams depend on inputs of energy from outside sources. The primary source of energy and nutrients in small, low-order streams is organic debris (e.g., leaf litter) deposited from riparian vegetation. When riparian vegetation is removed, this source of energy and nutrients is eliminated or reduced. Stretches of streams and rivers are left with sunlight as the only source of energy and largely devoid of nutrient inputs. Other essential inputs to rivers and streams, such as woody debris—which provides microhabitats for fish and invertebrates, are also lost when streamside vegetation is removed (USEPA, 1991).

Riparian habitats, regardless of regional location, have many characteristics important to surrounding communities. They have a high rate of energy, nutrient, and species exchange; they are highly productive; they provide a unique microclimate with respect to upslope conditions; they have high edge-to-area ratios (similar to ecotone areas); and they support diverse faunal assemblages that are often unique within the local environment (USEPA, 1991). Loss of riparian vegetation therefore has negative effects on surrounding biotic communities.

Riparian vegetation also has an enormous capacity to store water. When it is removed, the natural hydroperiods of streams and rivers are altered and the loss of the buffering effects of water released by riparian vegetation during low flow periods and water stored by riparian vegetation during periods of flooding can cause severe stress to aquatic plant and animal communities. Riparian vegetation protects stream banks from erosion due to flowing water, and this protection is also lost when the vegetation is removed. Increases in erosion, turbidity, and sedimentation usually result (Brinson et al., 1981).

Riparian vegetation also removes sediment as water passes through it, rebuilds floodplains, provides shelter for aquatic animals and wildlife under overhanging banks, provides food to aquatic and terrestrial wildlife, buffers water temperatures, and improves water quality for downstream users (USDOI, 1991). Degraded water quality, increased severity of flooding, loss of wildlife, increased stream temperatures, and increased expense to purify water for public uses are therefore some of the consequences of the removal of riparian vegetation.

1.4.4 Hydromodification

Hydromodification and habitat alteration are reported to be a source of impairment to 17 percent of impaired river and stream miles and 12 percent of impaired lake, reservoir, and pond acres, and a source of wetland degradation in five states and wetland loss in one state (USEPA, 1995).

Hydromodification includes channelization or channel modification and flow alteration. Channel modification is river and stream channel engineering undertaken for the purpose of flood control, navigation, drainage improvement, and reduction of channel migration potential (Brookes, 1990). Straightening, widening, deepening, or relocating existing stream channels; excavation of borrow pits, canals, underwater mining, and other practices that change the depth, width, or location of waterways or embayments in coastal areas; and clearing or snagging operations are examples of channel modification. Channel modification typically results in more uniform channel cross sections, steeper stream gradients, and reduced average pool depths.

Flow alteration describes a category of hydromodification activities that result in either an increase or a decrease in the usual supply of fresh water to a stream, river, or estuary. Flow alterations include diversions, withdrawals, and impoundments. In rivers and streams, flow alteration can also result from transportation embankments, tide gates, sluice gates, weirs, and the installation of undersized culverts. Levees and dikes are also flow alteration structures.

Channel modification can deprive wetlands and estuarine shorelines of enriching sediment; change the ability of natural systems to both absorb hydraulic energy and filter pollutants from surface waters; increase transport of suspended sediment to coastal and near-coastal waters during high-flow events; increase instream water temperature; and accelerate the discharge of pollutants (Sherwood et al., 1990). Hydromodification often diminishes the suitability of instream and riparian habitat for fish and wildlife through reduced flushing, lowered dissolved oxygen levels, saltwater intrusion, interruption of the life cycles of aquatic organisms, and loss of streamside vegetation.

1.4.5 Mining

Mining, or resource extraction, is reported as a source of impairment to 11 percent of impaired river and stream miles; 4 percent of impaired lake, pond, and reservoir acres; and 5 percent of impaired estuary square miles. It also accounts for wetland loss in two states and wetland degradation in one state (USEPA, 1995).

Numerous pollutants are released from coal and ore mining. Acid mine drainage from coal mining contains sulfates, acidity (low pH), heavy metals, ferric hydroxide or "yellow boy," and silt (USEPA/USDOI, 1995; Zielinski, n.d.). The heavy metals released from mining activities include silver, arsenic, copper, cadmium, mercury, lead, antimony, and zinc (Horowitz et al., 1993).

Ore mining, both past and present, is a significant source of mercury contamination (Leigh, 1994). Mercury was used to separate gold and silver from ore and is contained in waste piles from the amalgamation process (Oak Ridge National Laboratory, 1993). It is estimated that 5.5×10^9 g of metallic mercury was released into the Carson River Drainage Basin during processing of the Comstock Ore at Virginia City, Nevada, in the 1800s. The mill no longer stands, but mercury-contaminated tailings were left behind to create a long-term, significant source of mercury contamination of soil and air (Gustin et al., 1995). Mercury was also used in eastern mining. Gold mining in the Georgia piedmont from 1829 to 1940 left mercury-contaminated alluvium. Mercury concentrations in historical alluvium have been found to exceed background by as much as two orders of magnitude near the core of the mining district (Leigh, 1994).

Public health can be threatened by contaminants released from ore mining. Exposure pathways for this contamination include ingestion of fish and waterfowl, as well as ingestion, inhalation, and direct contact with contaminated soil, sediment, and surface water. Potential exposure is also possible through ingestion of crops irrigated with contaminated surface water or grown in contaminated soil (Oak Ridge National Laboratory, 1993).

Coal mining creates significant acidity problems. The results of a study done to characterize the causes of acidity in lakes and streams in the United States show that 26 percent of streams were acidified primarily by acid mine drainage and 47 percent by atmospheric deposition (Kaufmann et al., 1992).

Three types of mines are created for coal extraction. *Drift or slope mines* are driven into valley walls to expose coal. *Shaft mines* are driven perpendicular to the ground. These mines must be pumped continuously to extract infiltrating water, and when abandoned they fill with water. *Surface mining* extracts coal from the surface after overlying soil and rock have been removed. Surface mines leach metals and acids as seeps or springs, and they can have flows of up to 500 gallons per minute (SCRIP, 1996).

Abandoned, self-draining underground mines and coal cleaning refuse piles are the worst potential sources of acid mine drainage. Contamination from them can continue for 800 to 3,000 years as all of the exposed acidic materials from the mines slowly leach pollutants to ground waters (USDOI, n.d.; Zielinski, n.d.). Acid mine drainage from surface mines is also a problem but is more controllable (USDOI, n.d.). Of the acidification caused by acid mine drainage, an estimated 40 percent is from active surface and underground mines and 60 percent is from abandoned mines (Zielinski, n.d.).

The effects of acid mine drainage can be devastating. In severely affected streams, ferric hydroxide blankets stream bottoms, smothering eggs, and covers gills and body surfaces (Zielinski, n.d.). Once a stream's acid-neutralizing capacity has been depleted by acidity entering the stream, the acidity begins to alter the biota. Fish are absent from streams with a pH less than 4.5, and vascular plants are lacking in streams with a pH less than 4 (Zielinski, n.d.).

Approximately 11,990 miles of streams are reported to be degraded by acid mine drainage in Pennsylvania, West Virginia, Ohio, Kentucky, Maryland, Indiana, Illinois, Oklahoma, Iowa, Missouri, Kansas, Tennessee, Virginia, Alabama, and Georgia (USDOI, n.d.; Zielinski, n.d.). Eighty percent of these (10,507 miles) are in Pennsylvania, West Virginia, Ohio, Kentucky, Tennessee, Maryland, and Alabama (Zielinski, n.d.). The worst acid mine drainage pollution is in Pennsylvania and West Virginia and a few areas of southeastern Ohio (USDOI, n.d.). Pennsylvania alone has 7,800 abandoned or inactive underground mines below the water table; one billion gallons is the estimated daily influx of acid mine drainage to surface waters from these mines (Zielinski, n.d.).

Most water quality problems associated with mining, however, are considered to be point source problems and are regulated under state and federal NPDES permits (USEPA, 1978a).

1.4.6 Forest Harvesting

Forest harvesting is reported as a source of impairment to 9 percent of impaired river and stream miles; 5 percent of impaired lake, pond, and reservoir acres; and 5 percent of impaired estuarine square miles. Two states attribute wetland degradation to forest harvesting and three states attribute wetland loss to forest harvesting (USEPA, 1995). On federal lands, such as national forests, many water quality problems can be attributed to the effects of timber harvesting and related activities (Whitman, 1989).

Forest harvesting operations can degrade water quality in several ways in waterbodies that receive drainage from forest lands. Sediment, organic debris, nutrients, and silvicultural chemicals are pollutants associated with forest harvesting operations. Construction of forest roads and yarding areas, as well as log dragging during harvesting, can accelerate erosion and sediment deposition in streams, which fouls instream habitats. Removal of overstory riparian shade can increase stream water temperatures; harvesting operations can leave slash and other organic debris to accumulate in waterbodies, which can deplete dissolved oxygen and alter instream habitats. Fertilizer applications can add excessive nutrients to aquatic habitats and accelerate eutrophication. Pesticide applications can increase organic and inorganic chemical concentrations in waterbodies, which can lead to adverse wildlife and habitat impacts (Brown, 1985).

1.4.7 Construction

Construction is reported as a source of impairment to 5 percent of impaired river and stream miles; 9 percent of impaired lake, pond, and reservoir acres; 13 percent of impaired estuarine square miles; and 1 percent of impaired Great Lakes shoreline miles. Two states attribute wetland degradation to construction and four states attribute wetland loss to construction (USEPA, 1995).

Many potential pollutants are associated with construction activities. These include sediment; pesticides (insecticides, fungicides, herbicides, and rodenticides); fertilizers used for vegetative stabilization; petrochemicals (oils, gasoline, and asphalt degreasers); construction chemicals such as concrete products, sealers, and paints; paper; wood; garbage; and sanitary wastes (Washington State Department of Ecology, 1991). The variety of pollutants present and the severity of their effects depend on the nature of the construction activity, the physical characteristics of the construction site, and the proximity of surface waters to the nonpoint pollutant source.

Runoff from construction sites is by far the largest source of sediment in urban areas under development (York County Soil and Water Conservation District, 1990). Soil erosion accounts for over 90 percent of sediment losses by tonnage in urbanizing areas, where most construction activities occur (Canning, 1988). Uncontrolled construction site sediment loads have been reported to be on the order of 35 to 45 tons per acre per year (Novotny and Chesters, 1989; Yorke and Herb, 1976, 1978). Loadings from undisturbed woodlands are typically less than 1 ton per year (Leopold, 1968).

Petroleum products used during construction include fuels and lubricants for vehicles, power tools, and general equipment maintenance. Asphalt paving also can be particularly harmful since it releases various oils for a considerable time period after application.

Solid waste on construction sites includes trees and shrubs removed during land clearing and structure installation, wood and paper from packaging and building materials, scrap metal, sanitary wastes, rubber, plastic, glass, and masonry and asphalt products.

Chemical pollutants, such as paints, acids for cleaning masonry surfaces, cleaning solvents, asphalt products, soil additives used for stabilization, pollutants in wash water from concrete mixers, and concrete-curing compounds, can also be used on construction sites and carried in runoff.

1.4.8 Marinas

Marinas are reported as a source of impairment to 3 percent of impaired estuarine square miles. Puerto Rico reports port construction as a source of wetland degradation, and the construction of wharves, piers, and bulkheads is reported as a source of wetland loss by two states (USEPA, 1995).

Marinas are located right at the water's edge, so there is often no buffering of the release of pollutants from them to waterways. Consequently, the concentrations of pollutants in marina waters and sediment, and in the tissues of organisms living in or near marinas, can be elevated.

The primary pollutants associated with marinas are sewage discharged from boats, which contains high concentrations of fecal coliform bacteria and organics; metals; and petroleum hydrocarbons. These pollutants enter the water in marinas through discharges and spills from boats and docks, and stormwater runoff from marina uplands. The concentration of dissolved oxygen in marina basins can be lowered by inadequate flushing and the decomposition of organics, such as those in sewage and fish offal.

Marina or port construction can negatively affect the ecology of an area; effects include loss of habitat and alterations to local hydrodynamics. Protective measures like bulkheads and jetties are built near marinas to prevent damage to boats and shoreline structures, and marinas and ports are areas of concentration of boat traffic. Both the attenuation of waves by in-water structures and the creation of waves by boat passage affect shoreline processes, which can increase turbidity, resuspend pollutants in sediment, and increase shoreline erosion (USFWS, 1982).

Studies have shown that boats can be a source of fecal coliform bacteria in estuaries with high boat densities and poor flushing (Fisher et al., 1987; Gaines and Solow, 1990; Milliken and Lee, 1990; NCDEM, 1990; Sawyer and Golding, 1990; Seabloom et al., 1989). Fecal coliform levels in marinas and mooring fields become most elevated during periods of high boat occupancy and usage, such as holiday weekends.

Metals and metal-containing compounds are contained in fuel additives, antifoulant paints, ballast, and other marina structures. Arsenic is used in paint pigments, pesticides, and wood preservatives. Zinc anodes are used to deter corrosion of metal hulls and engine parts. Copper and tin are used as biocides in antifoulant paints. Other metals (iron, chrome, etc.) are used in the construction of marinas and boats. These metals are released to marina waters through spillage, incomplete fuel combustion, wear on boat hulls and marina structures, and boat bilge discharges (NCDEM, 1991). Elevated levels of copper, zinc, cadmium, chromium, lead, tin, and PCBs have been found in oysters, other bivalves, and algae in some marinas (CARWQCB, 1989; Marcus and Stokes, 1985; McMahon, 1989; NCDEM, 1991; Nixon et al., 1973; SCDHEC, 1987; Wendt et al., 1990; Young et al., 1979).

1.5 WATER RESOURCE CONSIDERATIONS

Before a monitoring plan that will provide sufficient information for meeting monitoring objectives can be developed, the water resource to be monitored must be understood. Each type of water resource—rivers and streams; lakes, reservoirs, and ponds; estuaries; open coastal waters; and ground waters—possesses unique hydrologic and biological features that must be taken into consideration, and a monitoring program must be structured to either adapt to those features or avoid them.

All water resource types exhibit both temporal (long- and short-term) and spatial (small- and large-scale) variability. Placement of monitoring stations and timing of sampling are affected by these variabilities. For instance, suspended sediment concentrations vary across the width and length of reservoirs; salinity concentrations in estuaries vary vertically and temporally as they are affected by relatively light fresh water flowing over heavier salt water; and ground water quality varies with soil type and geozone. The monitoring guidance provided in this document is appropriate for temporal variability of minutes to a few years.

1.5.1 Rivers and Streams

Generally, streams are of two types, intermittent and perennial. Clearly, sampling cannot be done in intermittent streams when they do not have flow, and year-to-year variations in precipitation affect the duration of their flows, their pollutant loads, and their water quality. Variability in perennial streams and rivers is also affected by seasonal variations in precipitation, including snowfall, reservoir discharge management, and irrigation management. The highest concentrations of suspended sediment and nutrients often occur during spring runoff, winter thaws, or rainstorms.

Other features of streams and rivers that affect monitoring program design include, but are not limited to:

- Lateral spatial variability is most important in streams. Velocity varies vertically and horizontally in streams and affects pollutant concentrations at a given location (Figure 1-7) (USDA-NRCS, 1996).

- Tributary mixing affects lateral variability. Mixing below tributary junctions might be incomplete, with tributary flow primarily following one bank. Meanders produce increased velocities at the outside bank and reduced velocities at the inside bank (USDA-NRCS, 1996).

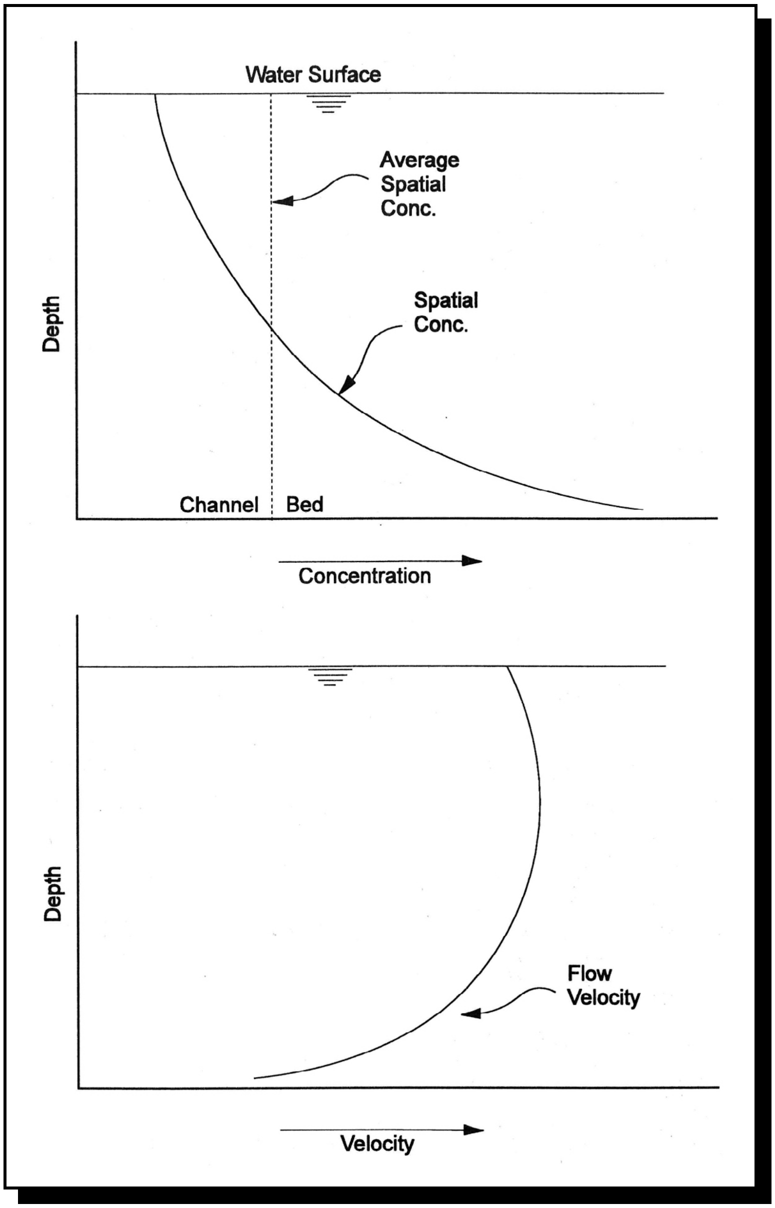

Figure 1-7. Vertical sediment concentration and flow velocity distribution in a typical stream cross section (Brakensiek et al., 1979).

- The complexity of currents at obstructions makes them poor monitoring sites (USDA-NRCS, 1996).
- Vertical variability is particularly important during runoff and in slow-moving streams because suspended solids, dissolved oxygen, and algal productivity can vary substantially with depth (Figure 1-8).
- Toxic contaminants in bed sediment vary laterally and vertically.
- Biological communities vary with type of bed substrate, water temperature, and amount and type of aquatic and riparian vegetation.

Also, when designing a stream or river monitoring program, the effects of tributary flows must be considered. Such flows can add pollutant loads, dilute pollutant loads, and create lateral gradients. Segmentation of a stream into fairly homogeneous segments prior to monitoring might be necessary or prudent. One to several monitoring stations might be necessary in each segment (Coffey et al., 1993). When dividing a stream into homogeneous segments, both land use and drainage area should be considered, since both affect the quantity and quality of flows.

1.5.2 Lakes, Reservoirs, and Ponds

Shape is an important factor that affects spatial variability in lakes, reservoirs, and ponds. Lakes and ponds commonly have simple, roundish shapes, whereas reservoirs usually have complex, dendritic shapes (Figure 1-9). Some lakes and reservoirs are well mixed and homogeneous, while others are stratified and heterogeneous. Stratification in lakes and reservoirs depends on depth and hydraulic residence time (HRT) (Figure 1-10). Deeper lakes and reservoirs are more likely to be strongly stratified, while shallow lakes and reservoirs are usually more uniform vertically.

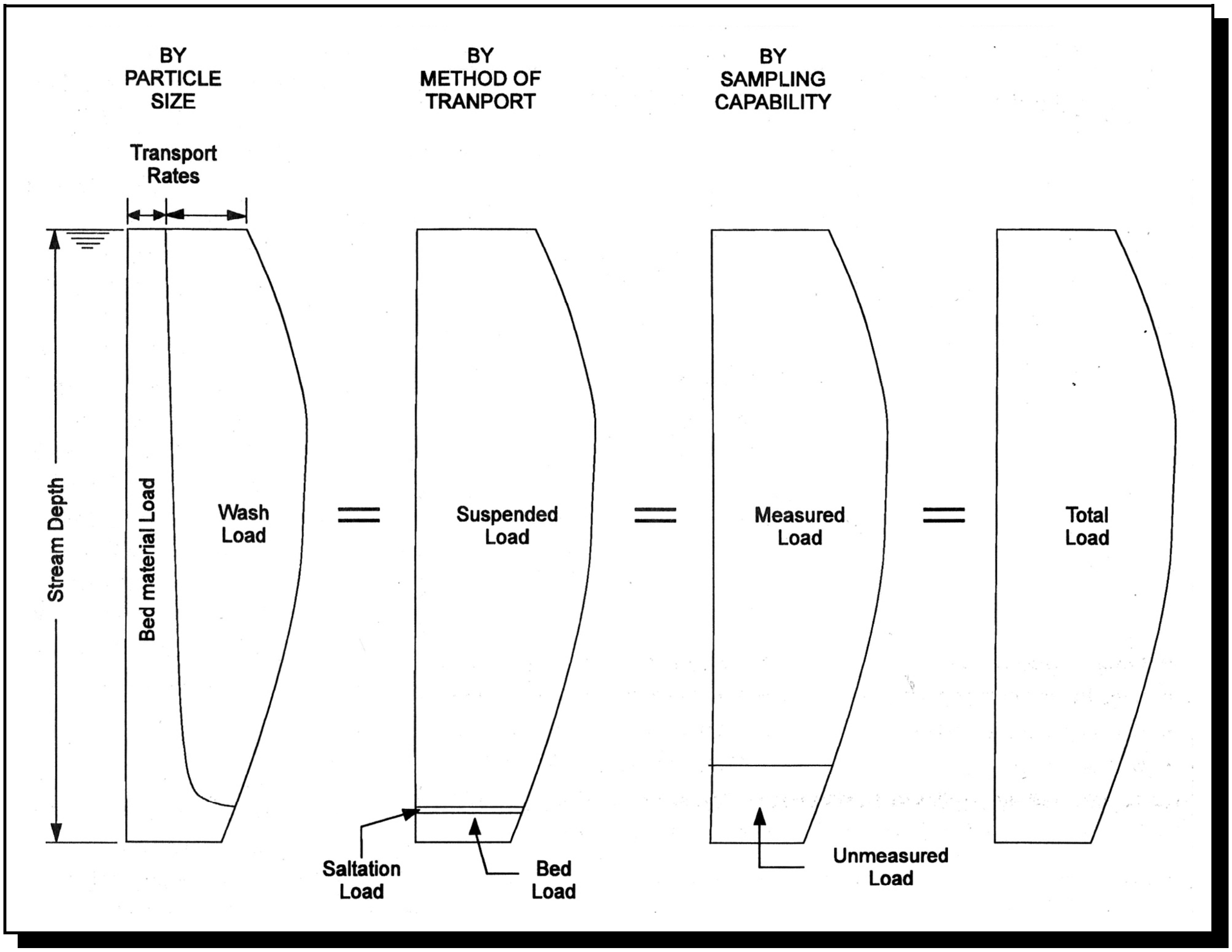

Figure 1-8. Schematic diagram of stream vertical showing relative position of sediment load terms (Brakensiek et al., 1979).

Stratification creates vertical variability in temperature, dissolved oxygen, and nutrient concentrations (Figure 1-11). Stratified lakes and reservoirs can also exhibit little vertical variability in DO and nutrient concentrations, depending on their productivity. Deep, eutrophic lakes and reservoirs exhibit more vertical variability than deep, oligotrophic lakes and reservoirs (USEPA, 1990a).

The implication of HRT for monitoring and the water quality effects of pollution control is that there can be a delay between changes in inflow water quality and a noticeable effect on lake water quality. The length of the delay depends on the HRT of the lake or reservoir and other water quality factors (e.g., biota, sediment, existing water chemistry) (USEPA, 1990a).

Features of lakes, reservoirs, and ponds to keep in mind when designing a monitoring program for them include, but are not limited to, the following:

- Lakes and reservoirs with HRTs of days or weeks might respond to seasonal pollutant loads, whereas lakes and reservoirs with much longer HRTs might not respond so quickly to seasonal loads (USEPA, 1990a).

- The distribution and concentrations of water quality parameters in individual lakes and reservoirs vary seasonally (Figure I-11).

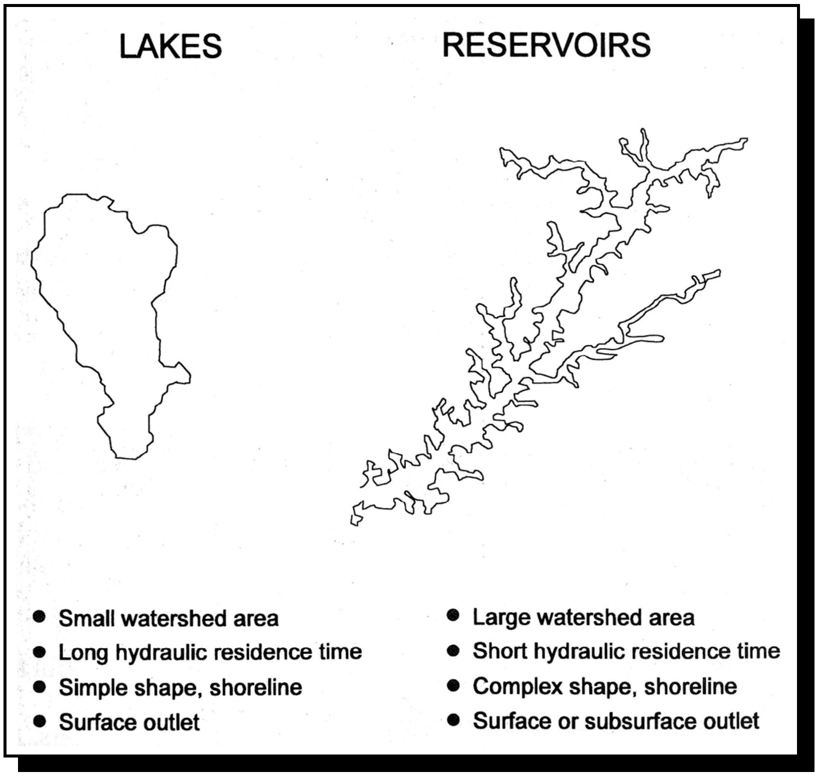

Figure 1-9. Important differences between lakes and reservoirs.

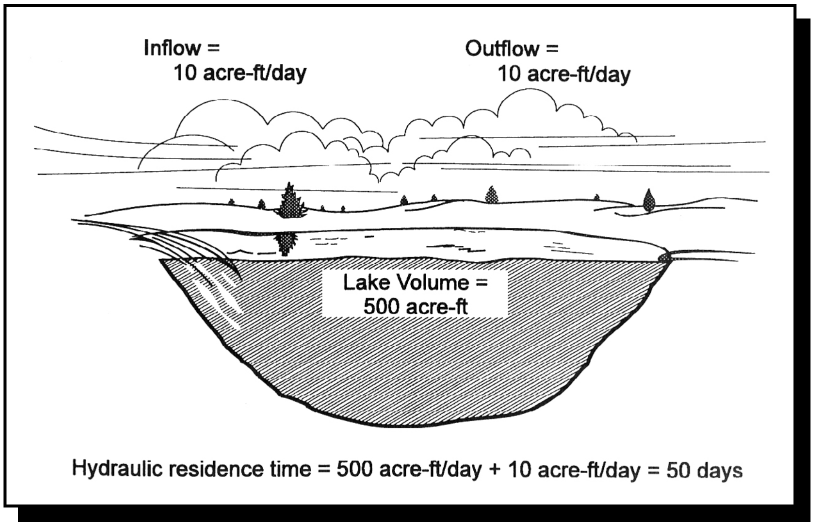

Figure 1-10. Hydraulic residence time, assuming inflow = outflow (After USEPA, 1990).

- Separate lakes and reservoirs in the same geographic area do not necessarily undergo seasonal changes at the same time.

- Pollutants are generally not distributed uniformily throughout lakes and reservoirs due to inflow points and circulation patterns.

- Pollutants such as phosphorus can have residence times in lakes and reservoirs very different from the HRTs of the lakes and reservoirs in which they are found. Some lakes and reservoirs do not respond to reductions in phosphorus loads because of phosphorus contained in lake sediment, which is released when the phosphorus concentration in the water column decreases and sequestered when it increases.

- Short-term variability is an inherent characteristic of most still (lentic) waterbodies. Dissolved oxygen, pH, and temperature can vary considerably over the course of a day.

- Small lakes and reservoirs can respond rapidly to the addition of runoff, which has implications if lake water quality is to be correlated with land treatment or stream water quality.

- The lateral variability of chlorophyll *a* concentrations can vary based on water depth and the diurnal migrations of phytoplankters (Davenport and Kelly, 1984a).

In summary, some important lake and reservoir characteristics and processes that must be considered when designing a monitoring program include productivity, depth, stratification, seasonality, HRT, and the locations and sources of inflows. Since sampling locations must accurately represent lake or reservoir conditions, monitoring a round, simply shaped lake might require only a single sampling station, whereas monitoring a dendritic reservoir might require numerous stations to reflect its spatial variability accurately (USEPA, 1990a).

To simplify both sample collection and data interpretation, it can be useful to monitor within the strata of stratified lakes and reservoirs, and to achieve some monitoring objectives, it could be necessary to monitor during periods of peak stratification. Finally, biological monitoring programs must be tailored to the diurnal variations in lakes and reservoirs.

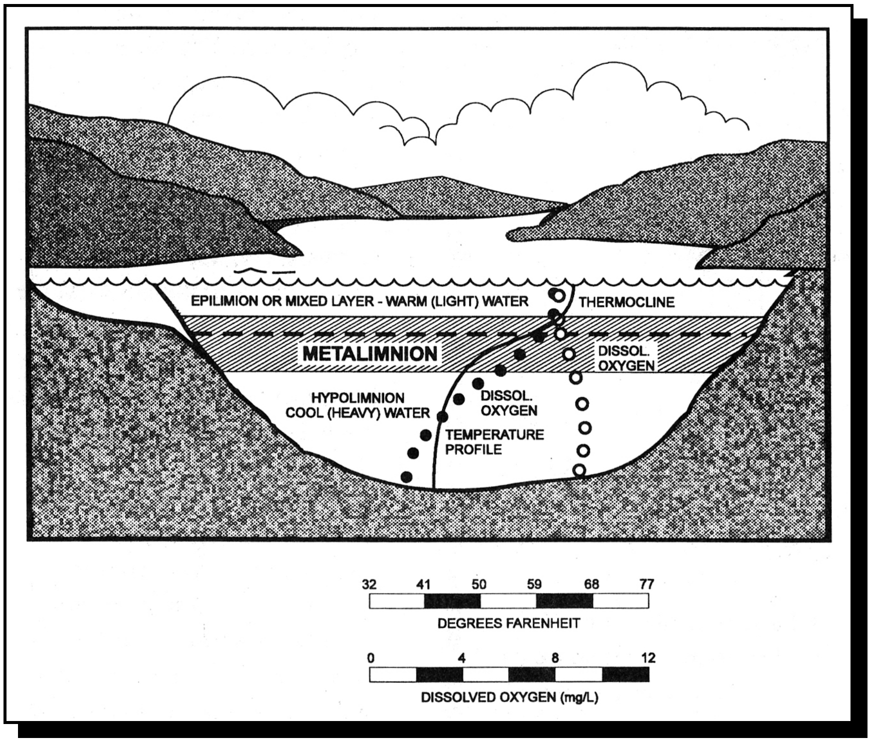

Figure 1-11. A cross-sectional view of a thermally stratified lake in mid-summer. The water temperature profile (curved solid line) illustrates how rapidly the water temperature decreases in the metalimnion compared to the nearly uniform temperatures in the epilimnion and hypolimnion. Open circles represent the dissolved oxygen (DO) profile in an unproductive (oligotrophic) lake: the DO concentration increases slightly in the hypolimnion because oxygen solubility is greater in colder water. Solid circles represent the DO profile in a productive (eutrophic) lake in which the rate of organic matter decomposition is sufficient to deplete the DO content of the hypolimnion (USEPA, 1990).

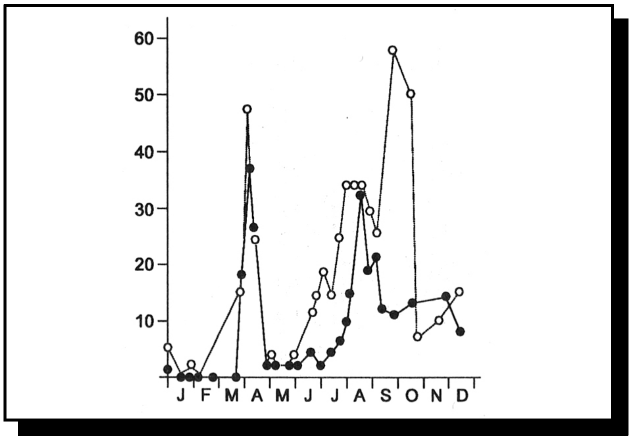

Figure 1-12. Phytoplankton chlorophyll *a* concentration in Chautaugua Lake's northern basin and southern basin, 1977 (Storch, 1986).

1.5.3. Estuaries

The major difference between estuaries and freshwater bodies is in the mixing of fresh water with salt water, and the influence of tides on spatial and temporal variability in estuaries. Incoming tides affect estuaries by pushing salt watershoreward while fresh water is entering(Figure 1-13). Fresh water is lighter, so it flows over the top of salt water, while the force of the tide forces the salt water shoreward and under the inflowing fresh water. Outgoing tides pull the entire water mass oceanward, and the freshwater input fills the gap left by the receding submerged salt water.

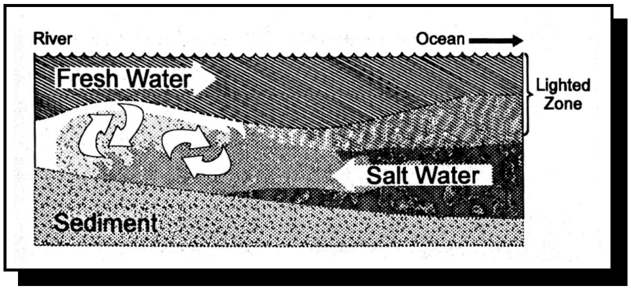

Figure 1-13. Mixing of salt water and fresh water in an estuary (Chesapeake Bay Program, 1995).

These processes affect daily and seasonal salinity distributions (Figure 1-14).

Features to consider when designing a monitoring plan for estuaries include, but are not limited to, the following:

- The volume of an estuary is an important factor in determining its ability to dilute pollutants (NOAA, 1990).
- Short-term variability is related to tidal cycles, which affect the mixing of fresh and salt waters and the position of the fresh water-salt water interface.
- The size of the estuarine drainage area (EDA; Figure 1-15) of an estuary relative to watershed size determines the overall impact of pollutant inputs from the EDA on the estuary (NOAA, 1990).
- In estuaries with large fluvial drainage areas (FDA; Figure 1-15), pollutants added from sources in the EDA might have less overall impact on estuarine water quality than in estuaries with small FDAs (NOAA, 1990).
- Freshwater inflow is a major determinant of the physical, chemical, and biological characteristics of most estuaries. It affects the concentration and retention of pollutants, the

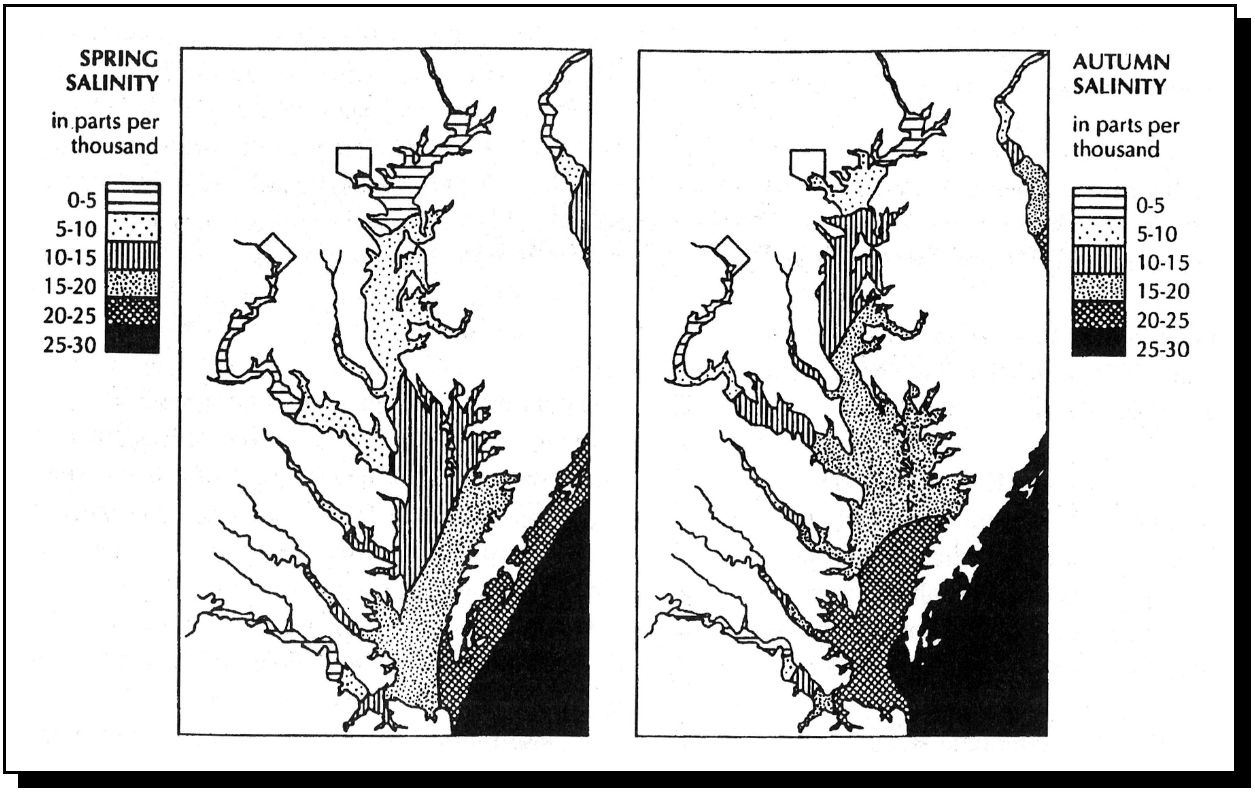

Figure 1-14. Chesapeake Bay salinity levels over time and space (Chesapeake Bay Program, 1995).

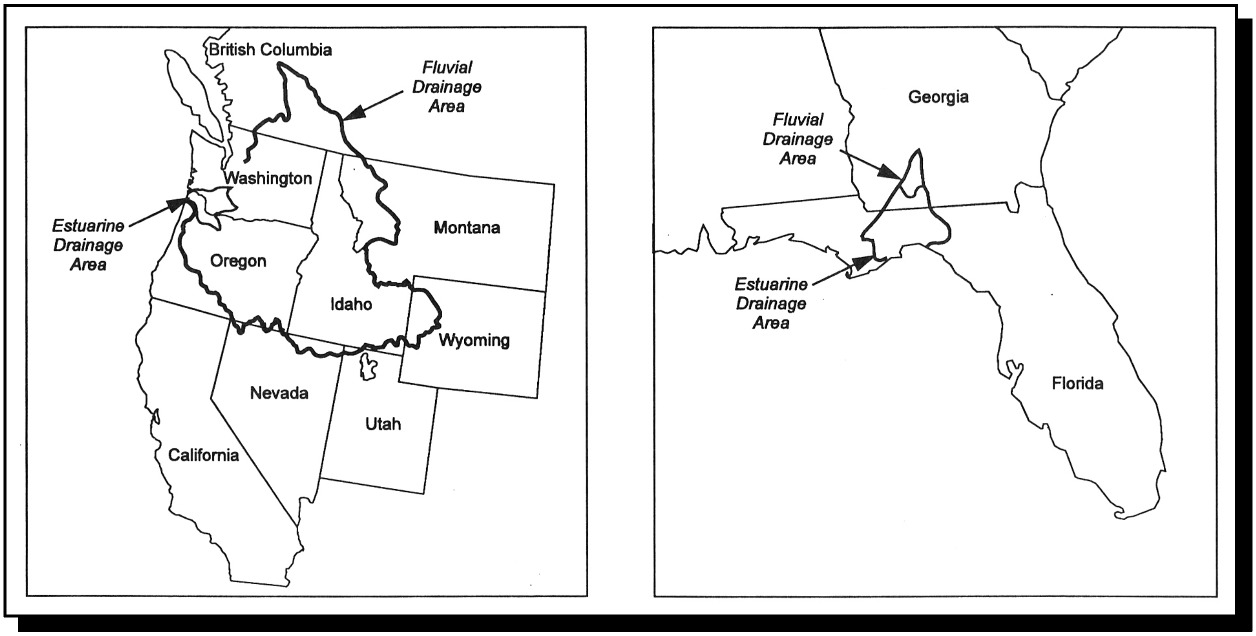

Figure 1-15. Estuarine drainage area versus fluvial drainage area (NOAA, 1990).

distribution of salinity, and the stratification of fresh water and salt water in an estuary (NOAA, 1990).

- Temperature profiles vary seasonally in estuaries.
- Freshwater input to estuaries varies seasonally, and spatial variability in estuaries is affected by the location of freshwater inflows.
- Due to spring runoff, salinity in estuaries is generally higher in fall and lower in spring (Chesapeake Bay Program, 1995).
- The earth's rotation (Coriolis effect), barometric pressure, and bathymetry (submerged sills and banks, islands) affect circulation and spatial variability in estuaries. For instance, Puget Sound contains numerous islands that affect circulation within it.

Stellwagen Bank, a submerged sand bank located across the boundary of Massachusetts Bay and the Atlantic Ocean, has a strong effect on circulation within the bay and within neighboring Cape Cod Bay.

In summary, the most important factors that determine the characteristics of individual estuaries are the sizes of the EDA and the FDA, water surface area, water volume, tidal range, salinity regime, and freshwater inflow. Also, an estuary might contain subestuaries—portions of a large estuary having definable subbasin drainage areas and constituting a significant percentage of either freshwater inflow or water surface area (NOAA, 1990). For instance, San Francisco Bay has very separate northern and southern reaches. The southern reach has a longer HRT, less inflow, and more sewage input, which give it characteristics very different from those of the northern reach and would require a different monitoring program design.

1.5.4 Open Coastal Waters

The major difference between open coastal waters and estuaries is that open coastal waters are not directly influenced by freshwater inflows. To design a monitoring program for open coastal waters, knowledge of local salinity and circulation patterns is necessary. This helps to identify relatively discrete units of coastal water for monitoring purposes. In open coastal waters, it is particularly important to identify such discrete segments or units from which to sample in order to be able to track conditions over time. An example of a discrete segment or unit of open coastal water is a semienclosed embayment.

Features to consider when designing a monitoring program for open coastal waters include, but are not limited to, the following:

- Monitoring should focus on units for which there is reasonable likelihood that changes in water quality will result from BMP implementation.
- Consider segment or unit size and circulation patterns to estimate the likelihood of water quality improvements from pollution reduction efforts.
- Open coastal waters exhibit gradients in salinity, temperature, and water chemistry both spatially and temporally.
- Surface salinity varies with amount of rainfall input and evaporation (Tchernia, 1980).

1.5.5 Ground Water

Ground water is monitored less than surface waters because of the complexity of ground water systems and the difficulty of obtaining samples. However, ground water monitoring is important

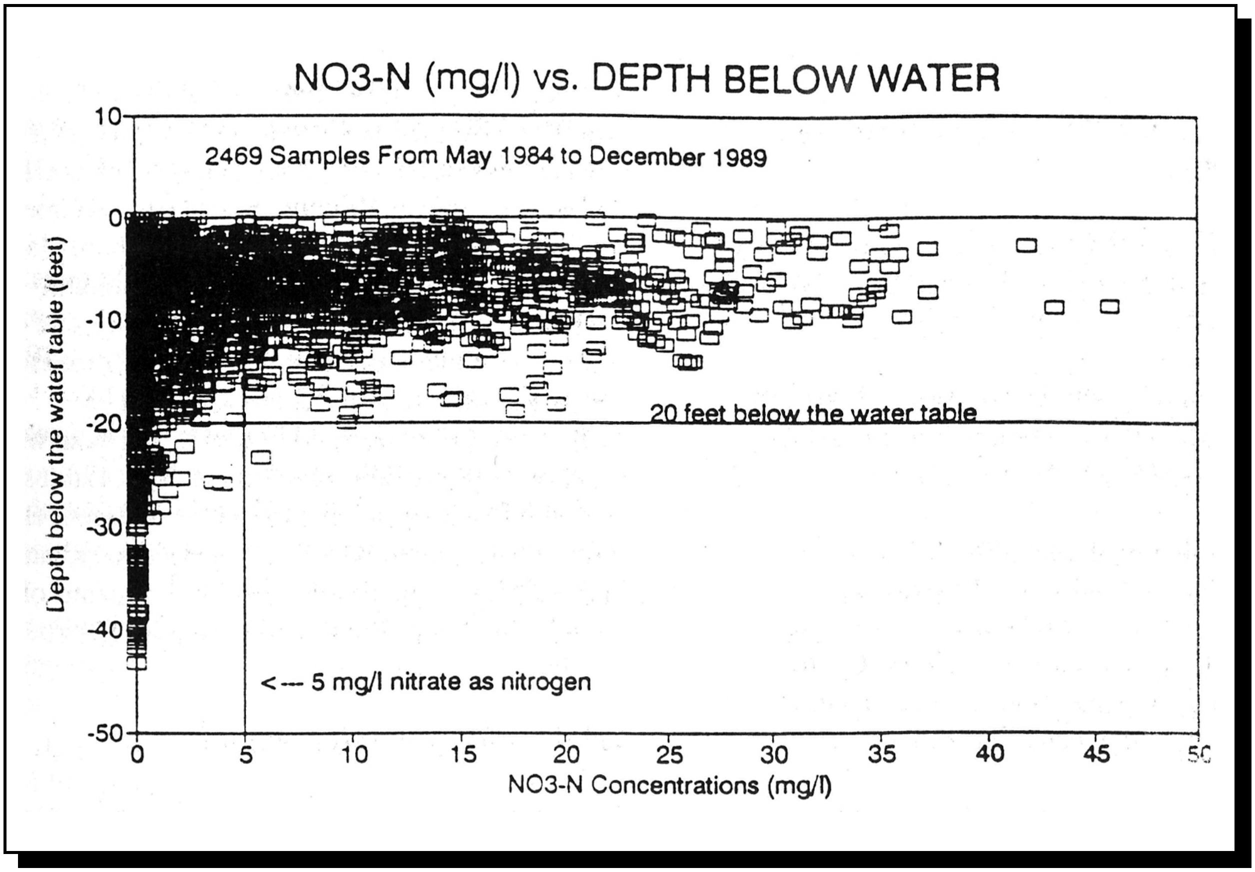

Figure 1-16. Nitrate concentration (mg/L) versus depth below water table (Goodman, 1991).

because of contamination of drinking water supplies and the interplay between surface water quality and ground water quality. In 1990, ground water was the source of drinking water for over half of the Nation's population and for 95 percent of the population in rural areas (USEPA, 1995). The purposes of ground water monitoring include the following:

- To determine the ground water component of a hydrologic/chemical budget for a surface waterbody.
- To document the impact of a polluting activity.
- To identify background water quality.
- To identify trends and variations in water quality.
- To determine the effectiveness of BMPs.

Ground water monitoring often requires a two-stage approach. The first stage consists of a hydrogeologic survey to determine ground water surface elevations and flow directions. This survey requires numerous sampling locations. The second stage is an investigation of water quality, with stations selected based on the results of the first stage and monitoring objectives (Bishoff et al., 1995; Goodman et al., 1996; USDA-NRCS, 1996). More than with surface waters, site-specific information is absolutely necessary to design a ground water monitoring program. Water quality in an aquifer can vary considerably with depth and location (Figure 1-16).

Features to consider when designing a ground water monitoring program include, but are not limited to, the following:

- Local soils and geology.
- The direction of ground water flow.
- The type of ground water system. There are two general types of aquifers, confined and unconfined. Unconfined (water table) aquifers are in direct contact with the atmosphere through the soil. Confined (artesian) aquifers are separated from the atmosphere by an impermeable layer (USDA-NRCS, 1996).
- Selection of well locations depends on the variability of the aquifer's water quality and is complicated by the presence of confining beds, multiple aquifer systems, effects of pollutant density on pollutant transport, and changes in permeability.
- Spatial and temporal variabilities in aquifers cannot be generalized. Some respond to precipitation quickly, whereas others respond slowly.
- Sampling depth and depth to aquifer are important variables to consider in determining initial sampling frequency.

1.6 CLIMATE

Climate introduces elements of temporal variability into a monitoring program's design. When designing a monitoring program, the characteristics of seasonal variability, measurable as both the degree to which seasons are distinguishable (e.g., the difference between winter and summer in Alabama versus the difference in Maine), and the severity of the seasons (e.g., winter in Minnesota versus winter in South Carolina), must be considered. These characteristics determine when and for what amount of time specific variables can be monitored. For some monitoring objectives, year-round monitoring might be necessary, and in cold climates this could call for some means of heating if automated sample collection is to be used (USDA-NRCS, 1996).

Climate also affects the quantity, timing, and intensity of precipitation, the likelihood of catastrophic events (e.g., hurricanes, floods,

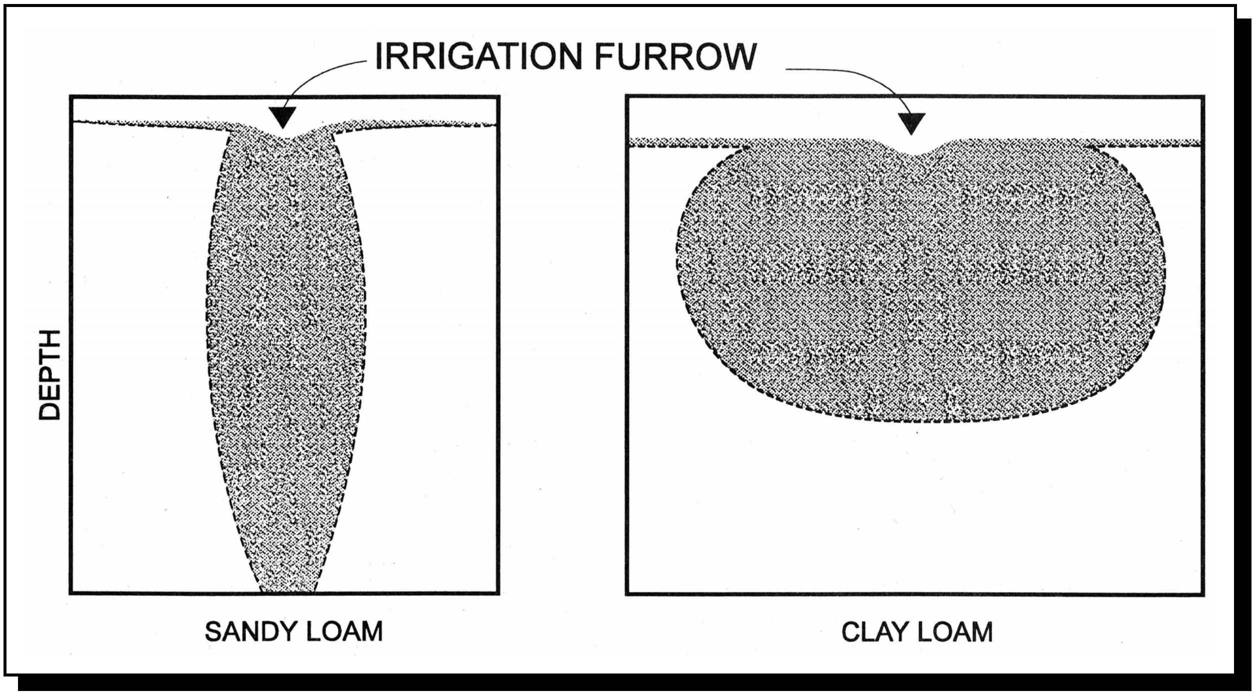

Figure 1-17. Comparison of water movement from irrigation furrows into two different soil types. The zone of infiltration represents water movement after 24 hours (after Brady, 1984).

droughts) that could interrupt sampling, seasonal variations in biological activity, and seasonal variations in water quality parameters (e.g., addition of organic matter to streams and rivers from overhanging vegetation). These regional and local features must be factored into monitoring program design.

A few examples of climatic factors that affect monitoring program design follow (MacDonald et al., 1991):

- Variability in precipitation is inversely proportional to average annual precipitation. Drier areas tend to have more year-to-year variation in precipitation.
- Areas with more rainfall tend to have lower concentrations of nutrients and other dissolved ions.
- Climate affects the weathering rate, erosion rate, and vegetation type and the productivity of aquatic biota.

1.7 SOILS, GEOLOGY, AND TOPOGRAPHY

Soils, geology, and topography are local or regional features that must be considered in monitoring program design (MacDonald et al., 1991). The permeability, depth, and porosity of soil and bedrock affect background levels of nutrients and dissolved ions in ground water and surface waters. The texture, depth, and permeability of soils also influence the quantities of fertilizers, pesticides, and herbicides that are leached into surface waters and the amount of leaching that occurs immediately after application and during runoff events (Figure 1-17). Slope is an important factor that must be considered when designing a monitoring program. Slope affects the rate and duration of runoff from a watershed, rate of erosion, depth of soil (steep slopes often have less soil overlying the bedrock), and stream characteristics. Slope also affects the likelihood of landslides and debris flow, erosional processes, and weathering rates.