9. TURBIDITY IN SOURCE WATER

9.1 Introduction

The characteristics of turbidity in surface water supplies are a function of many factors. Watershed features, such as geology, human development (i.e., agricultural uses or urban development), topography, vegetation, and precipitation events can all greatly influence raw water turbidity. In addition, reservoirs and ponds can often dampen the impact of increased turbidity events by acting as points in a stream or river where particles can settle before being drawn into the intake of a treatment plant. Wells and infiltration galleries along streams or rivers can also reduce the impact of turbidity increases in streams by their use of a natural aquifer as a filter. This chapter will discuss the turbidity in surface water and ground water under the direct influence (GWUDI) of surface water, and other source water characteristics as they relate to turbidity in raw water supplies.

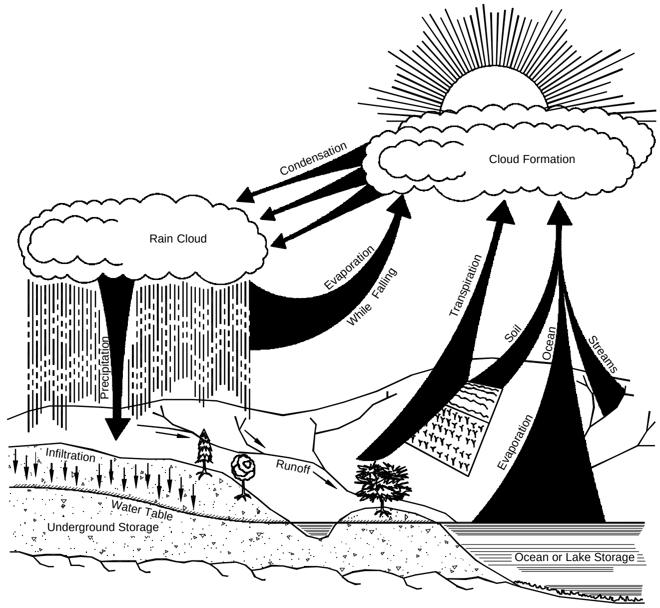
9.2 Occurrence of Turbidity in Surface Water Supplies

There are many natural processes by which turbidity is created and conveyed to a raw water intake for a water treatment plant. The following discussion focuses on the origins of turbidity in surface water supplies including rivers, lakes and reservoirs.

9.2.1 Rivers

The largest component comprising the mix of particles creating turbidity found in rivers is caused by erosion of materials from the contributing watershed. Turbidity may be created from a wide variety of eroded materials, including clay, silt, or mineral particles from soils, or from natural organic matter created by the decay of vegetation. Particles may capture and hide, or mask, other inorganic and organic constituents that are present in the watershed.

To help understand the formation of turbidity in rivers, it is important to understand the natural hydrologic cycle. The diagram shown in Figure 9-1 illustrates the hydrologic cycle. Natural evaporation occurs from water bodies, such as oceans and lakes, and forms clouds, which then condense into precipitation. As precipitation falls to the earth, it first infiltrates the soil and replaces soil moisture and eventually recharges ground water aquifers. Runoff occurs when the rate of precipitation exceeds the rate of water infiltrating the soil. As runoff flows over the land surface, the water can cause soil and other materials to erode, which results in increased turbidity. Runoff then collects in streams and rivers that flow back into water bodies such as lakes and oceans. From there, the hydrologic cycle begins again.



Source: AWWA, 1990.

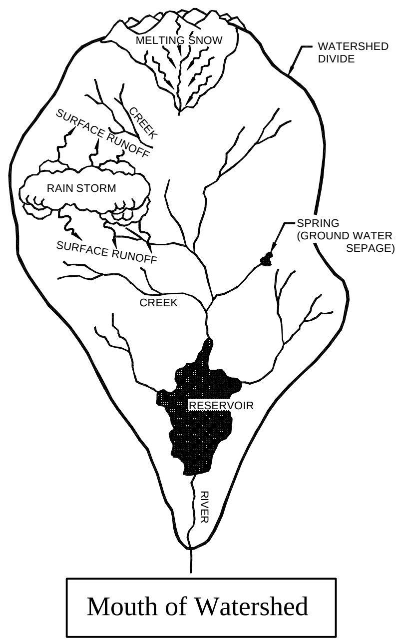
Figure 9-1. The Natural Hydrologic Cycle

Thus, during precipitation events, river turbidities are higher than during periods between precipitation events when the ground water may be supplying nearly all flow to the stream.

Watersheds have great influence on the resulting stream turbidity during a precipitation event. Figure 9-2 illustrates the various components of a watershed. Watersheds can be very large, such as the Mississippi River drainage basin, which drains most of the central United States. A large drainage basin usually consists of runoff that has large amounts of turbidity from the various sources of urban and agricultural runoff and the differing soil types present. Smaller watersheds may be highly urbanized and create high turbidity runoff. However, areas which have been protected from development can produce lower levels of turbidity even during runoff events.

Mountainous watersheds generally contain turbidity particles that are largely colloidal rock matter. In glacial areas, the grinding of mountain glaciers often produces rock particles that add a blue or green color to the mountain rivers. Mountain watersheds that contain little development usually have much lower turbidities than those that may be from an agricultural area in the plains or seacoast areas. Although low in turbidity, these type of watersheds may still be contaminated by *Giardia* and *Cryptosporidium* and other enteric viruses due to wildlife.

Rivers in the plains or coastal areas generally have watersheds which have farming and urban runoff that add turbidity from topsoil and organic matter. The topsoil particles are largely clay, and can hide or carry many different types of contaminants which are a concern to water utilities. These trapped contaminants can include agricultural chemicals and compounds such as fertilizers and pesticides.



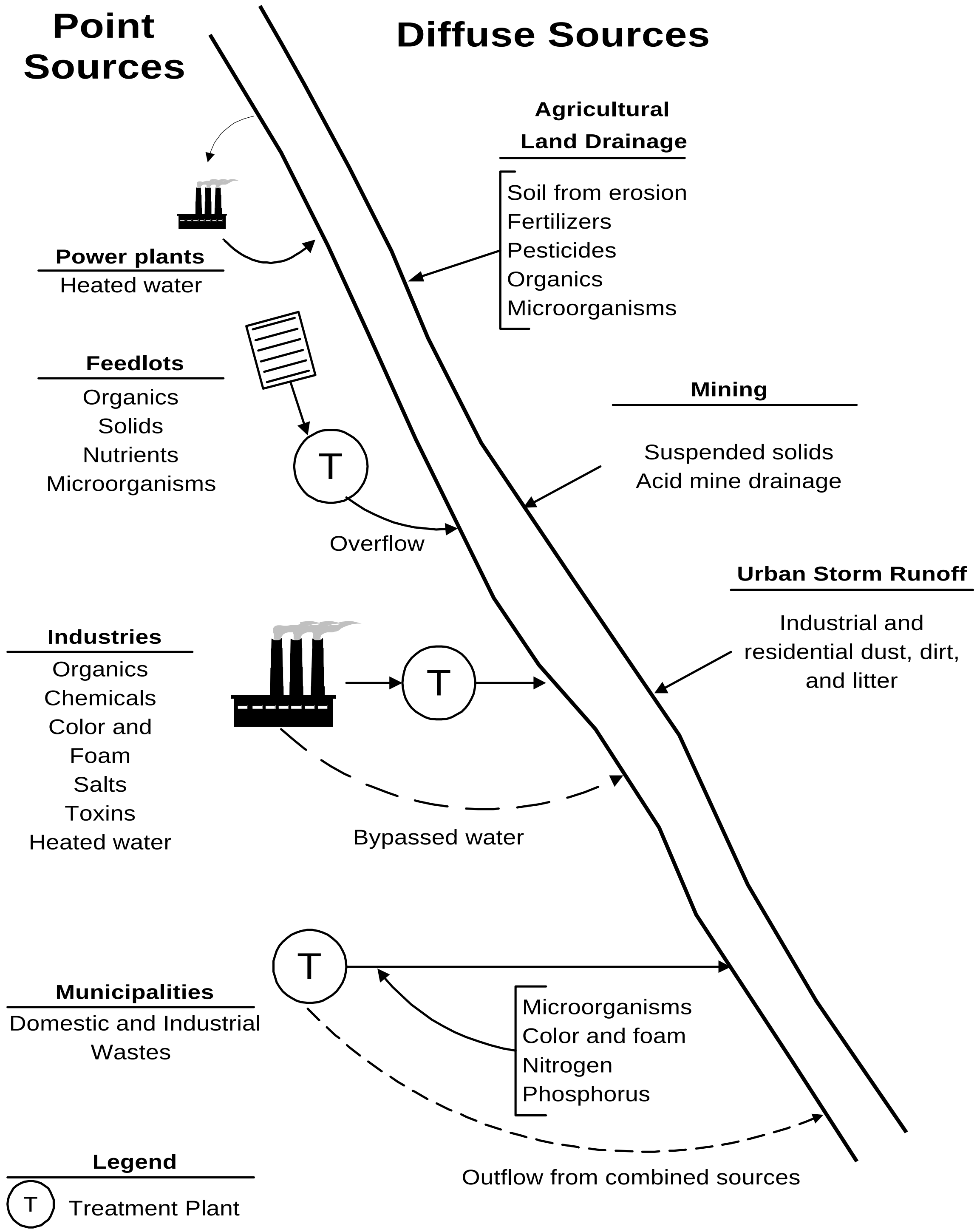
Source: AWWA, 1990.

Figure 9-2. Typical Watershed

One agricultural practice of particular concern is confined animal feeding operations, such as feed lots. This type of development can produce runoff with high concentrations of organic material and nutrients. In addition, many microorganisms, including *Giardia* and *Cryptosporidium* which are known to be present in animal wastes, can be carried downstream.

Because of the high percentage of impermeable surfaces in urban areas, the magnitude of runoff often increases leading to the increased levels of turbidity and related contaminants. In addition to eroded soils, runoff can include domestic and industrial wastes, fertilizers, road de-icing salts, overflows from combined sewers, eroded material from construction sites, and contaminants from roadways and parking lots. Significant industrial development can result in high levels of toxic materials, and power generating facilities can cause elevated water temperatures.

Figure 9-3 shows the possible sources of contaminants that can comprise or be found in turbidity particles.



Source: Hammer, 1997.

Figure 9-3. Sources of Contaminants in Raw Water Supplies

Organic materials reaching the rivers from both undeveloped and urbanized land can serve as a food source for bacteria and other microorganisms. Inorganic nutrients such as nitrogen and phosphorus from wastewater and agricultural runoff can provide nutrients to stimulate the growth of algae, resulting in increased turbidity during low flow times.

The turbidity in streams and rivers is a constantly changing phenomenon. During dry periods, when no precipitation occurs, turbidity levels usually drop to a somewhat stable value for the stream. A precipitation event in the watershed can then bring additional suspended material into the stream and greatly increase the turbidity. Generally, the more intense the precipitation event, the higher the turbidity values experienced in the stream. In addition, turbidity levels are typically found to be higher further downstream in a watershed due to the amount contributed from upstream, the variety of contributing factors it contains, and biological growth that accumulates in the stream as the water moves through the basin.

Low Turbidity in Rivers

Low turbidity streams and rivers (less that 20 NTU) are those which are usually located at the upper reaches of a undeveloped watershed. These watersheds include high mountain areas, as well as those watersheds with little or no development. Characteristics of these watersheds generally include:

- Little or no development;
- No agricultural activity;
- Heavy natural vegetation along streambanks; and
- Little streambank erosion.

Although these streams are usually low in turbidity, Total Organic Carbon (TOC) levels can be high during runoff events resulting in an increase in turbidity from biological growth or the presence of significant natural color. In addition, higher mountain streams with low turbidities are often low in alkalinity due to the lack of natural buffering materials in the water. This makes the treatment of these waters subject to swings in pH with the addition of coagulants. A pH adjustment chemical and the resulting increase in alkalinity is usually needed to achieve good coagulation and produce stabilized water.

High Turbidity in Rivers

High turbidity streams and rivers tend to be located in watersheds which have erodible soils and/or significant agricultural farming activity. They can also be streams which receive runoff from urban and industrialized areas. Large rivers such as the Missouri, Ohio and Mississippi, have consistently high levels of turbidity in the lower reaches of its watersheds.

Rapidly Changing Turbidity Case Study

There are many rivers which experience rapid changes to turbidity in response to precipitation events. One such example of rapidly changing turbidity involves the Metropolitan Utilities District (MUD) of Omaha, Nebraska. The Florence Water Treatment Plant in Omaha is located on the Missouri River. In the spring, the combination of snowmelt and rainwater runoff, can cause turbidity levels in the Missouri River to rise rapidly. The upstream drainage area is largely agricultural with several urban centers. The Florence Water Treatment Plant receives water directly from the Missouri River through a surface intake. The plant has pre-sedimentation using cationic polymer followed by split-treatment with lime softening and alum. Disinfection and filtration complete the treatment.

During the period between March 5th and March 9th of 1995, the plant experienced a severe increase in the raw water turbidity associated with spring precipitation. Turbidity values increased from under 100 NTU on March 5th to over 1,000 NTU on March 8th. A graph of the turbidity increases is shown on Figure 9-4. While the Florence Plant has experienced similar episodes in the past, the 1995 event was one of the largest swings in turbidity due to runoff in recent years.

During the four day time period, the plant operators were able to manage the increasing turbidity levels by increasing chemical dosages while monitoring raw water quality parameters such as color, hardness, and turbidity. Over the years, the plant operators have noticed the raw water color will begin to increase and hardness will begin to drop prior to the arrival of the high turbidity water from snow melts or precipitation events. The increased color results from the suspension of decayed organic matter in the spring runoff. The reduction in hardness experienced is typical of runoff.

By observing color and hardness during a runoff event, the plant adjusted polymers and coagulants slightly ahead of the turbidity event so that optimal treatment could be maintained through the plant. In fact, no appreciable increase in turbidity from the pre-sedimentation basins were recorded throughout the event. The quality of the finished water effluent was unimpacted.

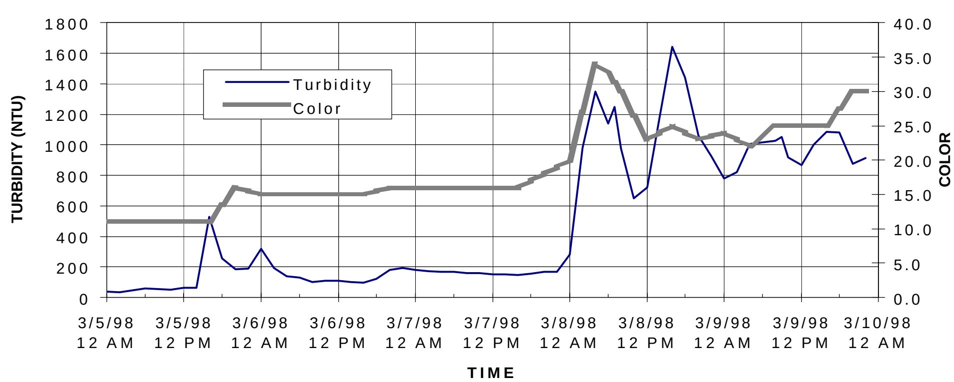


Figure 9-4. Turbidity Increase Event on the Missouri River at Omaha

High turbidity streams and rivers are usually subject to large increases in turbidity as the result of precipitation events. Larger amounts of precipitation cause erosion by bringing topsoil and decaying organic matter into the rivers. Increases in turbidities can sometimes occur within short periods of time as large flushes of precipitation runoff pass through the watershed.

9.2.2 Lakes and Reservoirs

Lakes and reservoirs capture water either naturally or through man-made impoundments through the construction of dams on streams or rivers. Because of the quiescent nature in a reservoir, turbidity levels are generally lower than streams or rivers due to the settling of particles.

Low Turbidity in Lakes and Reservoirs

In general, larger reservoirs or lakes have lower turbidity levels. For example, the Great Lakes usually have turbidity levels below 100 NTU, whereas rivers can have turbidities reaching over 1000 NTU. Lakes and reservoirs provide longer detention times, allowing for adequate settling of the larger turbidity particles and suspended solids. Of course, intakes near a river inlet to the lake may be subject to greater swings in turbidity since they may experience carryover of the river turbidity into the lake before settling can occur.

Low turbidity levels can also be found in smaller reservoirs receiving drainage from higher quality streams serving non-agricultural watersheds such as those found in mountainous areas. These reservoirs have watersheds which have streams carrying low sediment loads due to a great deal of snow melt runoff. They usually produce relatively stable sources of supply with little swings in turbidity. However, because they are small they sometimes do not have the capacity to deal with the extremes caused by severe intense precipitation or destruction of vegetation by fire. Such was the case experienced by the Denver Water Department in the spring of 1996.

High Turbidity in Lakes and Reservoirs

High turbidity events in reservoirs usually occur in smaller reservoirs or lakes that receive water from a agricultural watershed or urban drainage area. Larger reservoirs also experience high turbidity as a result of water quality changes during annual thermal changes in the lake, and may experience high turbidity events associated with severe flooding. During periods of heavy watershed runoff, smaller reservoirs are usually not large enough to effectively settle out the turbidity particles before they reach the intake location of a water treatment plant. In addition, if a reservoir or lake is shallow, wave action created by high winds can stir up sediments from the bottom and re-suspend particles.

Reservoir turbidity events can also be caused by seasonal turnover of the thermal stratification levels which form in the reservoirs. In deep reservoirs (i.e., those over 20 feet) de-stratification often occurs in the fall when the upper levels of the reservoir become cooler and denser, drop to the lower levels, and destroy the stratification. This "overturning" effect can happen quickly and may bring anoxic water that is nutrient-rich from the lower depths to the surface where algae is present. Sudden algal blooms can then severely raise turbidity levels. The resulting impacts on raw water supplies can be minimized through the construction of intake structures with multiple level draw-off points.

Lake Reservoir Turbidity Case Study

A forest fire in the watershed area of Buffalo Creek near Denver has caused some long-lasting impacts on the tributary area turbidities. The Foothills Water Treatment Plant receives water from this watershed via a storage reservoir in Watertown Canyon. In May 1996, the Buffalo Creek watershed experienced a forest fire which destroyed many trees and ground vegetation. Prior to the fire, the highest turbidities observed were around 40 NTU (Denver Water). Usually, the turbidities from the reservoir were less than 20 NTU.

During and after the fire, increased erosion has caused the turbidity to reach as much as 400 NTU during peak runoff events. Figure 9-5 shows a comparison of the maximum average day turbidities before and after the fire. The watershed is still recovering from the fire and so these higher turbidities may still occur during precipitation events. Since the fire, Denver Water Department has installed a turbidimeter on the intake tower at the Strontious Springs Dam, as well as instituting an observation system of spotters who live in Buffalo Creek that will inform the Department when heavy rainfalls are occurring so that appropriate flow and chemical adjustments can be made at the downstream plant so that finished water quality is not effected.

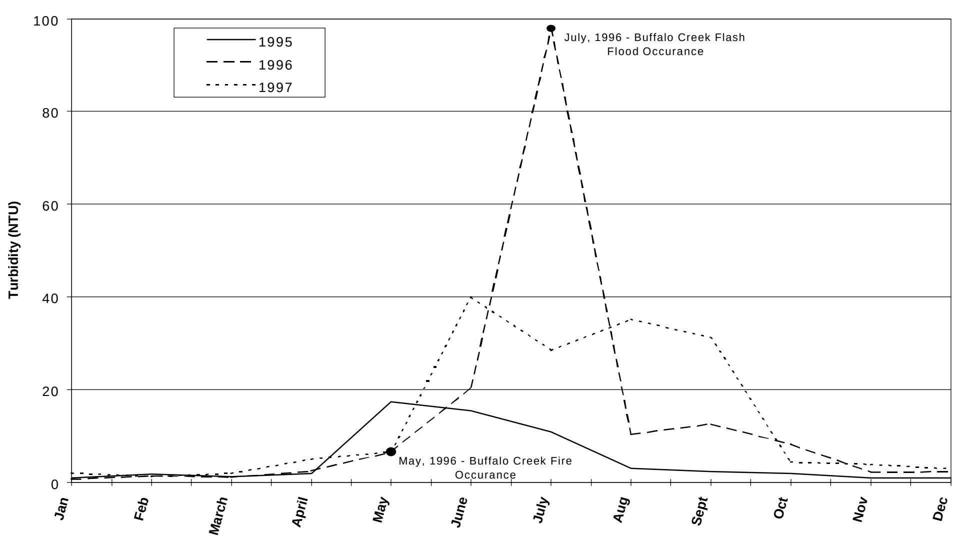


Figure 9-5. Turbidity Increase Due to Forest Fire in Buffalo Creek

9.3 Ground Water Under the Direct Influence (GWUDI)

GWUDI is also a water supply source that can be subject to changes in turbidity. These sources usually consist of a well or infiltration gallery located adjacent to or under a stream, river or lake. However, wells that are located significant distances away from surface water sources can also be influenced by surface water runoff due to geologic conditions that transport water quickly from the ground surface to the well.

The classification of a water source as GWUDI is usually the result of a Microscopic Particulate Analysis (MPA) test that examines the source for certain surface water organisms in the water supply. The presence of these organisms is an indication that the supply is influenced by surface water. In addition, if raw water turbidities or temperatures rise and fall with the source water this can also be an indicator of a connection between the surface water source and the well.

The degree to which these types of raw water sources are subject to changes in turbidity are usually a function of how far the well is from the surface water source and the type of linking aquifer. Wells in very close proximity to a river with a coarse gravel aquifer may mirror the turbidity changes in the river very closely. On the other hand, wells that are several hundred feet from a surface water source in a tight sandy aquifer may not experience noticeable changes in turbidity in response to a surface water turbidity event.

9.4 Additional Watershed Considerations

Water facilities should also be aware of the nature of their watershed and any contamination sources. Some sources of contamination may be present which are not a concern under normal circumstances, but may become a problem during a large precipitation event. For example, some U.S. cities have combined sanitary and storm sewers which can result in surface water contamination during large rain events.

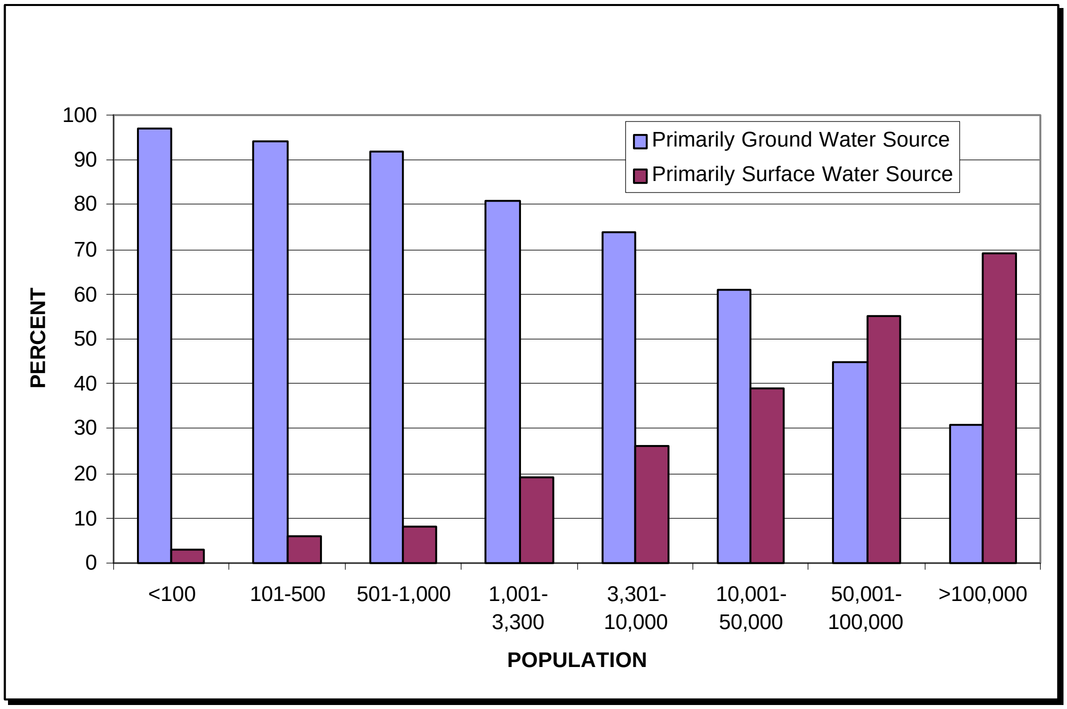
During dry periods, combined sewer systems collect wastewater and convey it to the wastewater treatment plant. However, during periods of high precipitation these systems also collect storm water which also travels to the wastewater treatment plant. When extreme precipitation events occur, wastewater plant can be overloaded by the high combined flows. This causes sewerage to bypass the plant and undergo only preliminary treatment prior to discharge to a river. If flows are extremely high, preliminary treatment may also be bypassed and raw sewage may be discharged directly to the river. These events, termed combined sewer overflows (CSOs), can cause increases in river turbidity. However, at times turbidity levels in the receiving stream may actually drop due to the large amount of sewage flow, but the levels of bacteria and protozoa in the raw water supply may rise significantly.

Another similar situation may exist where water treatment plants are situated immediately downstream of livestock operations. These feeding operations can be sources for runoff containing elevated levels of *Giardia* and *Cryptosporidium* during runoff events. Downstream utilities should be aware of these situations and take the necessary treatment precautions to ensure adequate treatment.

9.5 Water Sources Occurrence in the United States

Turbidity occurrence in raw water supplies is generally associated with surface water sources or GWUDI. An indication of the percentage of utilities using surface water sources of raw water supply was presented in the 1997 *Community Water System Survey* (USEPA, 1997). Figure 9-6 illustrates the percentage of utilities using ground water versus surface water sources by water system size. These percentages were developed from the data presented in the 1997 study, which is a representative sample of systems in the U.S.

The figure indicates that smaller systems typically use ground water while larger systems typically use surface water. Since turbidity occurrence is generally greater with surface water sources, larger water systems may be more concerned with potential difficulties arising from high turbidity levels.



Source: USEPA, 1997.

Figure 9-6. Raw Water Source by Water System Size

9.6 References

1. AWWA. 1990. *Water Quality and Treatment.* Fourth Edition. McGraw-Hill, New York.
2. Hammer, M.J. 1977. *Water and Wastewater Technology.* First Edition. John Wiley & Sons.
3. LeChevallier, M.W. and W.D. Norton. 1992. "Examining Relationships Between Particle Counts and Giardia, Cryptosporidium, and Turbidity." *J. AWWA.* 84(12):54-60.
4. USEPA. 1997. *Community Water System Survey (CWSS), Volumes I and II*. Office of Water, Washington, D.C. EPA/815-R-97-001a and -001b.

THIS PAGE INTENTIONALLY LEFT BLANK