Managing Our Watersheds

A Systems Approach To Maintaining Water Quality
Managing Our Water
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Editor’s Note: This article is an update by the original authors of an article first published in the October 1993 issue of the Small Flows newsletter, the National Small Flows Clearinghouse publication which preceded the Small Flows Quarterly.

Why do we publish the Small Flows Quarterly? Why do we have a National Small Flows Clearinghouse? Why does anyone bother to treat wastewater—with septic systems, advanced onsite systems, or large municipal sewage treatment plants?

A fundamental answer to all of these questions is “water quality”: water quality for drinking water supplies; water quality that ensures public health and decent living standards; water quality for commercial, agricultural, and recreational uses; and water quality that supports the earth’s living organisms. Yet those of us who work with wastewater sometimes become so busy with the means—designing a sand filter, administering state revolving fund (SRF) dollars, revising state codes, publishing a newsletter—that sometimes we may forget the essential goal of protecting and restoring water quality. In light of federal and state activities promoting watershed and groundwater protection, maybe it’s time to dive into the basic subject of water so that we can better understand the role of decentralized wastewater in watershed management.

Water Cycle

Earth’s water is best described in terms of the water cycle, or hydrologic cycle, a system of continuous circulation of water from atmosphere to land (both above and below ground) to sea to atmosphere again. (See figure 1.)

Water moves upward into the atmosphere by evapotranspiration, a combination of evaporation from land and water bodies and transpiration from the leaves of plants. Water condenses in the atmosphere and falls back onto land and water surfaces as precipitation, rain, or snow. Precipitation can follow several pathways after it falls back onto the earth’s surface. It may fall onto an ocean or lake or other body of water and become incorporated...
dependent on the aquifer material: approximately 50 feet per year in a "typical" aquifer, although water in cavernous aquifers may travel many feet per day. The water table itself does not stand still. It rises when more water infiltrates into the ground, and it drops during drought or if excessive amounts of water are pumped from wells.

Aquatic Systems

To really understand and protect the earth’s water, it is important to go beyond even the water cycle and examine aquatic systems. These systems consist of all water in an area (atmospheric, surface, and groundwater), as well as topography, soils, and rocks (surface and subsurface), biological components (plants, animals, and microbes), and all activities and impacts of a very powerful biological component: humans.

Aquatic systems have several important functions. Their numerous environmental functions include purifying water, recharging (replenishing) groundwater, collecting and retarding floodwaters, maintaining flow in rivers, and providing habitats for plants and animals. These systems also provide many domestic, agricultural, commercial, and recreational functions for human activities: transportation, dilution of industrial and domestic wastes, drinking water, laundry and cleaning, crop irrigation, cooling for power plants and factories, industrial uses, fishing, sailing, swimming, and many other activities.

Unfortunately, increased population and increasingly complex demands on aquatic systems have caused problems in many of these systems: pollution (by agricultural and urban runoff, sewage, chemicals, landfill leachate), decreased supply, sediment, flooding, aesthetic degradation, and loss of habitat and some plant and animal species.

Remember the terms cycle and system, and notice how all the parts and processes in the water cycle are interconnected in a cohesive system. It is also important to remember that the water cycle is dynamic—water doesn’t just sit there, it moves! We have all observed surface water movement as runoff and streamflow, and have made the common sense observation that water flows downhill. Both the speed of movement and the balance between runoff and infiltration are influenced by a number of factors: steepness of slope, permeability of materials (e.g., loose grass-covered soil versus asphalt parking lots), intensity and length of rainstorms, etc.

Although it may be harder to visualize, groundwater is dynamic, too. Unlike a pool table, the water table is seldom flat; it consists of “hills” and “valleys” that mimic the overlying surface topography. In a rough sense, groundwater also moves “downhill.” Notice that the arrows indicating groundwater flow in figure 1 move downward away from hills. In general, the steeper these water table “hills,” the faster the groundwater moves. Groundwater moves much more slowly than surface water, with velocity also

![Figure 1: The Water Cycle](image-url)
Like water systems and cycles themselves, many of the problems are interrelated. For example, decreased water supply means not only less available water for drinking or industrial uses, but also less available water for diluting wastes, thus making pollutant concentrations even worse. Building a shopping mall with buildings and pavement in a former open field not only increases runoff and flooding potential but also covers areas that formerly allowed infiltration and recharge of groundwater. As a consequence of these multiple demands, physical, chemical, and biological components of many aquatic systems are altered.

How do we untangle this complicated web of problems? To work effectively toward solutions, we need to develop integrated programs of management, protection, and restoration of our aquatic resource systems.

Regulatory History

Historically, approaches to water problems have been fragmented or piecemeal. Unlike the actual interconnected cycle in nature, surface water and groundwater have often been addressed separately by regulatory agencies. (For example, a number of states strictly regulated water withdrawals from streams and rivers, but had no limitations on groundwater withdrawals.) Because it could not be seen, groundwater was virtually ignored in many earlier government regulations. Multiple agencies (state or several states, municipal, river authority, water utilities) might have jurisdiction within a single river basin. Water quality was frequently characterized by analyses of instream water samples and by investigation of obvious, discrete (point source) pollution sources located at the stream (e.g., a sewage treatment plant outfall or an opening from an abandoned mine).

In many cases, communities of aquatic organisms were not thoroughly examined as indicators of the water’s “health,” and adjacent land use patterns were not studied. Non-point source pollution (diffuse input originating from large land areas or many small scattered sources) was seldom addressed as an important contribution to water contamination. Many non-point source pollutants (agricultural fertilizers, stormwater runoff) are strongly related to land uses. Although federal and state water regulations became gradually more stringent, they generally did not address water problems within an aquatic system framework. Data collection, needed to understand streams and aquifers and their problems, often received low priority and minimal funding.

More recent regulations and recommendations from federal and state governments have begun to recognize that a holistic or systems approach is necessary to solve water problems; several government research programs (e.g., in the U.S. Geological Survey and the U.S. Department of Agriculture) and a number of academic institutions have also acknowledged the importance of this approach. The Coastal Zone Management Act, Section 319 Nonpoint Programs of the Clean Water Act, total maximum daily loads (TMDL) legislation (see “TMDL Rule Finalized” on page 6), and the Clean Water Action Plan include elements of a comprehensive watershed framework. The 1986 amendments to the Safe Drinking Water Act (SDWA) established the federal wellhead protection program, and the 1996 SDWA amendments reauthorized funding for wellhead programs, underground injection control, and critical aquifer protection. It also mandated that states perform source water protection assessments and funded groundwater protection programs.

In addition, a number of states (e.g., Kentucky and Tennessee) have reorganized their agency programs to better integrate groundwater protection and watershed management in a manner more closely allied to the behavior of the natural water cycle and aquatic systems. Water Watch, Save Our Streams, Groundwater Guardian, and similar local and volunteer initiatives have proliferated.
Despite this progress, many governmental and academic programs still maintain divisions among the pieces of the water puzzle—between watershed and aquifer, source water protection and TMDLs, engineering and soil science, and geology and biology departments—and continued improvement in interagency and interdisciplinary cooperation are important to advances in protecting our water resources.

What Is a Watershed?

A watershed can be defined comprehensively as an area that contributes to recharging of surface and subsurface water bodies such as rivers, lakes, and aquifers. (See figure 2.) Any activities people conduct in this area will have direct effects on the quality of these waters. Farming, forestry, urban development, road construction, and use of onsite wastewater systems are just some of the activities that will have an environmental impact on the area and need to be considered as part of a watershed management scheme. To maintain adequate water quality, we must look at all activities that take place in a watershed and make sure that their environmental impacts are minimal. Watershed management is simply a systems approach to environmental protection.

To clean up a particular contaminant, we must recognize that it may come from multiple sources, identify which sources are significant contributors, and prioritize our efforts accordingly. For example, excess nitrate can originate from septic systems, sewage treatment plants, livestock manure, agricultural fertilizers, air pollutants in precipitation, or urban landscape maintenance, but land use patterns and population densities will dictate the proportion contributed by any of these sources within a particular area.

Because groundwater is part of the total water cycle, wellhead and aquifer protection follow similar concepts and approaches. Groundwater itself commonly discharges to the surface in valleys and topographic depressions. (See figures 1 and 3.) Springs that seep from cliff faces and roadcuts are one illustration of this phenomenon, and streams that flow perennially, even in times of low precipitation, are another example. If malfunctioning septic systems introduce contaminants into the groundwater, this contaminated water may eventually discharge to streams or other water bodies, polluting the surface water. For example, groundwater containing nutrients from subsurface wastewater disposal is a major source of high nitrate and phosphate concentrations in some New England coastal waters and several of the bays of eastern Long Island.

Role of Onsite Systems

So why does any of this matter to the wastewater professional who works with onsite and other small wastewater systems? Are onsite wastewater issues critical components of watershed protection? Absolutely! One survey of state water regulators lists septic tanks as the second greatest concern for potential adverse water quality impacts (Fetter, 1993). Some areas in the U.S. have identified onsite wastewater as an important issue within their watershed programs: Florida, New York City, Puget Sound, Cape Cod, southwestern Missouri, and parts of the Shenandoah Valley.

In agricultural and urban sewered areas, other contaminant sources may dominate, but in many other areas, lack of attention to the role of onsite systems—or at the other extreme, blaming onsite systems when multiple contaminant sources exist—may result from incomplete or in-progress watershed investigations. Professionals who work with onsite systems should become involved in watershed programs and lend expertise to identifying and correcting onsite problems, identifying areas where onsite systems provide adequate water quality protection, and assisting with educational efforts.

Figure 3

Groundwater Resurfacing. Septic Tank effluent can move through groundwater flow to the stream.
Watershed Management Terms

**Editor’s Note:** The following list of working definitions is intended as a guide to some of the terms commonly associated with watershed management, many of which appear in this issue. They are a quick reference to help you better understand watershed management and are not intended to be used for legal purposes.

Most of the definitions are adapted from *Surface and Ground Water Terminology*, a glossary prepared by the Ohio Cooperative Extension Service at The Ohio State University (see below for ordering information).

**Aquifer:** A geologic formation, group of formations, or part of a formation capable of storing, receiving, and transmitting water.

**Drainage basin:** The land area that gathers water and contributes it to a body of surface water. The area is also called the watershed of the receiving water body.

**Erosion:** The detachment and movement of soil and rock particles by gravity, wind, water, freezing and thawing, and/or other natural phenomena.

**Estuary:** A semi-enclosed coastal body of water that has a free connection with the open sea. It is strongly affected by tidal action, and within it seawater is mixed, and usually diluted, with fresh water.

**Groundwater:** All subsurface water that fills the pores, voids, fractures, and other spaces between soil particles and in rock strata in the saturated zone of geologic formations.

**Hydraulic conductivity:** A measure of the rate at which water will move through soil or a rock layer.

**Infiltration:** The downward entry of water into the soil.

**Nonpoint sources:** Sources of water pollution that are not associated with a distinct discharge source, including rainfall; runoff from roads, farms, and parking lots; and seepage from soil-based wastewater disposal systems.

**Perched water table:** A layer of saturated soil that results when an underlying impermeable layer, composed of soil and/or rock, restricts the downward movement of water.

**Point sources:** Specific discharges that are traceable to distinct sources (pipe, ditch, container, well, etc.), such as from wastewater treatment plants or industry.

**Recharge:** The replenishment of groundwater by infiltration (deep percolation) of precipitation, runoff, and other point and nonpoint sources.

**Runoff:** The portion of precipitation or irrigation water that moves across land as surface flow and enters streams or other surface receiving waters. Runoff occurs when the infiltration rate exceeds the infiltration rate.

**Surface water:** The water from all sources that occurs on the earth’s surface, either as diffused water or as water in natural channels, artificial channels, or other surface water bodies.

**Water cycle:** The constant process of water movement from the earth to the atmosphere by evaporation and transpiration and from the atmosphere to the earth in various forms of precipitation (also called hydrologic cycle).

**Water quality:** The chemical, physical, biological, and radiological condition of a surface or groundwater body.

**Watershed:** A geographic area in which water, sediments, and dissolved materials drain to a common outlet—a point on a larger stream, a lake, an underlying aquifer, an estuary, or an ocean. The area is also called the drainage basin of the receiving water body.

**Watershed management:** An integrated, holistic approach to the management, protection, and restoration of aquatic resource systems.

**Wellhead protection area:** A designated surface and subsurface area surrounding a well or wellfield that supplies a public water supply and through which contaminants or pollutants are likely to pass and eventually reach the aquifer that supplies the well or wellfield.


To order a copy of the four-page glossary, *Surface and Ground Water Terminology*, by Larry C. Brown and Leonard P. Black; contact Brown at 59@osu.edu. This fact sheet also can be downloaded from the Ohio State University Web site at ohiolines.ag.ohio-state.edu/aex-fact.html.
it may be necessary to use both technological adaptations and wastewater management programs to reduce impacts from onsite systems in sensitive areas. However, in these areas, it is also important to evaluate and control impacts from other pollutant sources accompanying residential growth (e.g., lawn and garden fertilizers, pet waste, and concentrated populations of waterfowl).

Evolution of Onsite Programs

Measures necessary for watershed and groundwater protection have stimulated rethinking of some of our long-standing practices. Many environments, including some coastal, lakeshore, and floodplain areas, have perennially or seasonally high groundwater levels with water tables located near or at the ground surface. In these areas, onsite discharges intended for subsurface disposal may actually reach the surface or affect surface waters. (See figure 4.) In other cases, it is important to examine the effects of subsurface wastewater disposal on patterns of groundwater flow. Groundwater “mounding” caused by input of water from effluent discharge may locally impact groundwater flow, sometimes directing effluent toward environmentally sensitive areas. (See figure 5.)

Historically, most state and local onsite system regulations have focused on hydraulic disposal of effluent in subsurface soil to prevent public health risks from contact with sewage. Septic system failure has been defined as failure to reduce these risks; sewage appears on the ground surface or backs up into the house. Although subsurface hydraulic disposal keeps the sewage away from human contact, it does not necessarily ensure treatment, and it is also, unfortunately, often equated with an “out of sight, out of mind” attitude about septic systems.

More recently, some state and local onsite regulations have incorporated design and soil/site criteria intended to address wastewater treatment as well as disposal. Many state and local regulations now also mandate that onsite wastewater systems protect water quality as well as human health, and some of these regulations have also redefined system failure to include groundwater and/or surface water contamination. Expanding the role of onsite systems to protect water quality raises several interesting—and at times perplexing—questions.

How can we monitor water quality to determine whether onsite systems are a source of problems? We can see yard and street runoff to a lake, or cattle walking in and out of an unfenced stream, but because septic systems are buried, it is difficult to verify a connection, even if stream sampling indicates pollution. Groundwater monitoring may provide more definitive clues, but it is generally more costly and difficult than surface water monitoring, as well as more “hit or miss” because aquifers are hidden below the surface. And if multiple sources (e.g., septic systems, agriculture, and lawn care) affect a stream or an aquifer, it may be extremely difficult to determine the actual contributions from each source. In addition to careful collection of surface water, groundwater, site and land use data, watershed studies may require special techniques—chemical and physical tracers, isotope studies, infrared and other geophysical detection methods, and DNA bacterial source typing—to identify and correct pollution sources.

What do we do about septic systems where the wastewater hydraulically disappears below the surface but moves through the soil too rapidly for sufficient treatment before reaching the water table, or where it rapidly reaches fractured bedrock and travels to groundwater or surface water without adequate treatment? Do we treat the wastewater to higher quality before releasing it into the soil? Slow down its movement within the soil to achieve better treatment? Treat it to high quality, disinfect it, and release it to surface water?

Although in some cases this last option may make sense for ease of water quality monitoring as well as treatment, in other instances it may be a difficult or even undesirable choice. Federal and state regulations governing discharges to streams
may require strict and laborious permitting procedures, and some states entirely prohibit any discharge of onsite effluent to surface waters. Even in localities where surface discharge is an option, ongoing management of system operation and maintenance is imperative. If a surface-discharging system fails, it can become a public health threat, releasing untreated or partially treated sewage directly to surface water without an intervening “safety factor” of soil.

Arid regions of the U.S.—or humid regions where water supplies are stressed—may have an additional concern with wastewater in a watershed context: the use of wastewater to augment or replenish water supplies. Issues may involve greywater reuse, effluent use for irrigation, and effluent use for groundwater recharge. Wastewater/water supply interactions in arid-climate watersheds may also present some legal and regulatory questions, particularly where effluent provides a major source of water for wetlands or instream flows (e.g., Santa Ana River Basin in southern California).

Technological Advancements

Technological advancement has played an important role in small-scale and onsite wastewater management. We now have systems that, with proper operation and maintenance, can be used for onsite wastewater management in a variety of soil and site conditions that may be unsuitable for “conventional” septic systems.

Traditional attitudes in many areas have regarded onsite systems as less desirable, stopgap solutions to wastewater treatment until central sewers can be installed. Although this approach may make sense in areas of rapid, dense development—particularly those adjacent to sewered communities—the cost of extending sewers to each household in rural or sparsely populated areas may be impractical or impossible to absorb. Other factors—aesthetic, growth, and water supply—may make onsite or small cluster systems a preferable alternative to central sewers and treatment plants. If conditions are not adequate for a conventional septic tank system and a sewer line is not available, there is a long list of alternative technologies available for treatment and disposal of wastewater on the site (refer to the list of informational products beginning on page 52). Sand filters, other media filters, aerobic treatment plants, and constructed wetlands are just some of the alternatives available for treating wastewater before discharge. Many newer technologies can produce secondary- or even tertiary-quality effluent.

Soil-based subsurface discharge requires adequate site conditions and sufficient area. The hydraulic capacity of the site will determine how much water can be discharged at a given site. Soil conductivity or infiltration rate (the ability of soil to move water from one place another) will determine the size of dispersal system you may need for a given amount of effluent. The rate of movement of wastewater effluent through the soil can also affect the soil’s ability to further treat the wastewater.

Alternatives available for subsurface discharge range from conventional soil absorption trenches or beds to highly effective drip systems. Shallow systems, low-pressure pipe systems, mound systems, and evapotranspiration/greenhouse systems are other alternatives that can improve distribution of wastewater in the soil and control the movement of wastewater to allow better treatment in the soil. Nondischarging systems (wetlands, evapotranspiration, and recycling) are in use in several areas of sensitive water quality, habitats, or site factors.

Although these treatment and soil absorption alternatives may cost more to build and operate than a conventional septic system, the cost may still be less than that of installing a centralized sewer system. Most importantly, using alternatives to treat and disperse wastewater onsite can often minimize adverse environmental impacts. However, two issues are paramount if a state or locality considers these alternatives: 1) because these systems generally involve more complex mechanical and/or electrical components, and because they may be used in more sensitive or “marginal” sites, it is essential to manage the systems from design through ongoing performance to provide public health and water quality protection; and 2) because the use of these systems can allow building on sites that cannot be developed otherwise, local and state officials may need to reconsider how decisions are made about land use planning and growth.

There is no doubt that we will see a continued emphasis on managing water quality by a watershed or systems approach in this new century. If we are to make the most of limited resources (natural, financial, and human), a systems approach is the only logical answer to the complex environmental issues we face. Water and wastewater professionals must play an increasingly important role in evaluating small scale and onsite wastewater treatment alternatives as viable options for watershed management.

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Reference