CHAPTER 1

INTRODUCTION: COMPREHENSIVE WATERSHED ASSESSMENT AND MANAGEMENT

1.0 INTRODUCTION

A *watershed* is an area of land that captures water in any form, such as rain, snow, or dew, and drains it to a common water body, i.e., stream, river, or lake. All land is part of the watershed of some creek, stream, river, or lake. The watershed boundary is defined by the higher elevations or ridges that define which direction the rainwater will flow, as shown in Figures 1.1 and 1.2. It is analogous to a bathtub, where water that falls on the inside brim of the bathtub, or watershed, will flow to the drain, or outlet. Water that falls outside the brim, or watershed, divides, and ends up on the floor—in the case of a bathtub—or in another watershed. The entire continental landmass is made up of watersheds.

The downstream-most point of a watershed is defined by the required point of analysis, or where flows, samples, or design criteria might be required. These are usually stream *confluences* (where two streams merge), bridges, problem areas, dams, or some other type of outlet where the analysis ends. The downstream-most location is referred to as the *point of interest* for analysis purposes.

Delineating the watershed begins by identifying the point of interest, then drawing a line perpendicular to the contours, picking the high points on a topographic map, and continuing until returning back to the point of interest. A typical watershed, as defined on a United States Geological Survey (USGS) 7½-minute topographic quadrangle, is shown in Figure 1.3.

A *watershed assessment* is a detailed evaluation of the specific processes, influences, and problems in a watershed so that a plan of action to preserve the watershed can be developed. The watershed management plan should be

Figure 1.1 A watershed boundary is defined by the higher elevations or ridges that direct the flow in one direction or another, as shown from the ground.

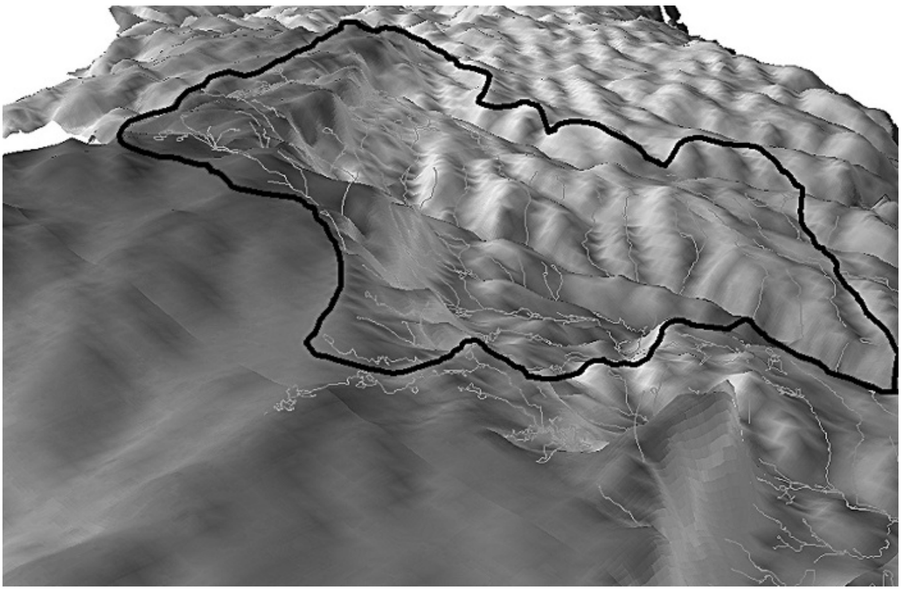

Figure 1.2 A watershed boundary as shown in a GIS digital elevation model (DEM).

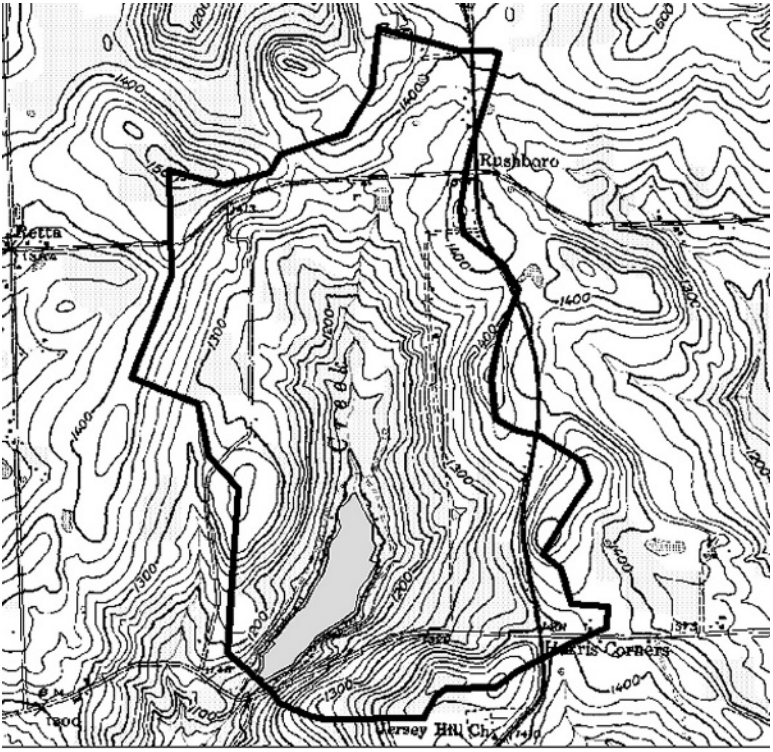

Figure 1.3 Typical watershed defined by high points or ridges, draining to the point-of-interest, in this case the dam of a lake.

a systematic approach to preserve or restore the watershed and its hydrologic regime, or to correct problems based on the comprehensive assessment. A detailed implementation program should be a component of the management plan.

1.1 SUSTAINABILITY

Sustainability can be defined as "creating, to pass along to our children and to theirs, a natural resource base whose yields in economic prosperity, social improvement, environmental quality, and natural beauty will go on and on—tomorrow and forever—because of the political choices we are willing to make today" (Bucks County Planning Commission, 2002). As seen throughout this text, a watershed in hydrologic equilibrium should be the goal for sustainability of water resources and for the health, safety, and welfare of humans in general. Lives depend upon it, thus water resource sustainability is paramount for the survival of human beings. Sustainability can be achieved through "good science and smart planning" (Schaffhausen, 2002).

1.2 WATERSHED ASSESSMENT AND MANAGEMENT

Each watershed has a unique personality that needs to be explored to develop a truly personalized management plan. For instance, the Rio Santa Catarina watershed evaluated in Nueva Leon, near Monterrey, Mexico, has an elevation relief from 3,100 to 1,420 meters or 1,680 vertical meters within 6,500 meters horizontal, for an average slope of twenty-five (25) percent and hard desert soils with very little infiltration capability. The result: flash flooding with loss of life during Gulf Coast storm events. The urban Darby Creek watershed near Philadelphia, Pennsylvania, suffered flash flooding, reduced base flow, and water quality problems due to urbanization and the increase in impervious area. In contrast, the Wysox Creek watershed in rural Bradford County, Pennsylvania, had stream bank erosion and agricultural nonpoint source pollution problems due to stream banks comprised of *unconsolidated glacial deposits* and mismanaged cattle grazing. The Solomon Creek in Wilkes-Barre, Pennsylvania, watershed had a severe acid mine drainage (AMD) problem due to past mining activities. As a recommendation of the assessment, funds were procured to design and install an AMD treatment facility. The analogy of a doctor seeing a patient for the first time can be used, whereby the doctor first evaluates the individual's entire body before concentrating on the symptoms and then recommending a remedy, as shown in Figure 1.4.

A watershed is like an interdisciplinary puzzle; that is, the watershed assessment collects the biological, physiographic, hydrologic, hydraulic, political and social pieces of the puzzle and the management plan puts all the pieces of the puzzle together. The puzzle can fall apart, however, unless it is laminated and preserved in a frame for long-term enjoyment, hence the implementation phase. Perhaps the most important phase of a project is the implementation phase, thus it must be in the preparer's mind throughout the project, for if the plan cannot be implemented, it will become a typical report collecting dust on the shelf. The best watershed management plans are those whose covers are the most worn.

1.3 COMPREHENSIVE WATERSHED MANAGEMENT CONCEPTS

Why manage our land and water resources on a watershed-wide basis? Because watersheds are formed by natural land masses and water flows into a common waterbody. In other words, watersheds are defined by natural hydrology. Streams and rivers do not follow political boundaries, and the flow of water, pollution, problems, etc. does not stop at political boundaries. In addition, managing the whole is better than managing or correcting the sum of its parts.

The Federal Emergency Management Agency (FEMA) used to conduct Flood Insurance on a municipality-by-municipality basis. Unobstructed 100-year flood flows were reported less in downstream communities than those

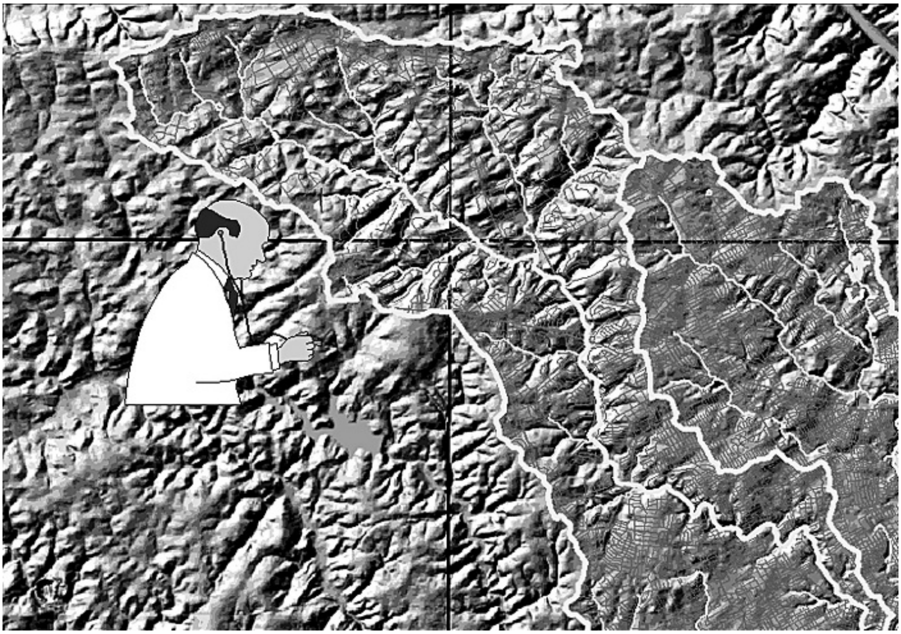

Figure 1.4 A watershed assessment involves closely examining the physical features of the watershed, determining what ails it, and prescribing a prescription plan to improve its health.

upstream, a concept we know not to be practical. This was caused by the studies being performed at separate points in time and by different consultants. It is good to see that FEMA is now conducting flood insurance studies on a watershed basis. Studies performed on a watershed basis allow efficiency in data collection, monitoring, report writing, grant appropriation, and eventual permitting. Managing on a watershed basis provides consistency amongst municipalities within a watershed and takes into account how changes in one portion of the watershed may affect it in another area.

The watershed approach is a coordinating framework for environmental management that focuses on public- and private-sector efforts to address the highest-priority problems within hydrologically defined geographic areas, taking into consideration both ground and surface water.

Watershed management can be undertaken in two ways: the proactive approach and the reactive approach. Humans typically react to floods, water quality problems, and stream bank erosion. Once an event or series of events creates a problem, then people react to fix the problem they created. People build in the floodplain, then build levees to protect their buildings. A flood greater than the levee capacity occurs, and the government pays for the cleanup and to make the levees higher. However, as we are slowly learning, taking a proactive approach—performing a watershed assessment and putting a watershed management plan in place to strive to maintain the natural hydrologic regime—prevents flooding, maintains groundwater quantity and quality, maintains stream flow and quality, prevents stream bank erosion, preserves environmentally sensitive areas, and so on.

Natural, undisturbed watersheds are in geologic equilibrium. As humankind alters the land surface, the landform, hydrologic budget, and stream processes are ultimately affected. Improper use of our natural resources causes a number of problems, including flooding, erosion and sedimentation, stream bank erosion, water quality problems, and reduction of groundwater and base flow augmentation. The goal of any watershed management plan should therefore be to maintain the hydrologic budget. In order to properly manage a watershed, the comprehensive picture or holistic approach must be followed. This book summarizes the physical features that must be analyzed in order to accomplish true comprehensive stormwater management.

Ensuring sustainable water resources requires comprehensive management of the many facets of water, including water supply (i.e., groundwater and surface water), stormwater management, flood control, nonpoint pollution control, and wastewater treatment and reuse. Water resources management begins with understanding the various sources, paths and uses of surface and groundwater, stormwater, floodwaters, recreational waters, drinking water, irrigation water, and so on. Generally, surface water includes rivers, streams, reservoirs, lakes, and ponds. Groundwater can be classified as shallow and deep. Water uses include municipal, industrial, and commercial uses, and residential wells and springs. Human water uses include irrigation, manufacturing, recreation, and consumption. An adequate supply of clean water is essential for maintaining the quality and health of natural ecosystems such as fisheries, forests, wetlands, and aquatic habitats.

Water resources management is a broad and wide-ranging effort that encompasses activities such as identifying and delineating source water protection areas, minimizing discharges, and managing stormwater. Zoning and land use regulations and growth management techniques are effective mechanisms for directing development to areas that can best support it. Using a watershed-based approach further ensures that down gradient areas are not adversely impacted.

In order to develop a comprehensive watershed management plan, a number of steps must be followed. Most important, a comprehensive analysis of all of the physical features of the watershed should be conducted. These features include geology, soils, topography or slopes, stream channel sections, floodplains, and wetlands. In addition to the physical feature parameters, socioeconomic and political parameters should also be considered. Once these physical feature, socioeconomic, and political parameters are analyzed, first individually, then as a connected whole, the goals and objectives of each individual watershed management plan can be developed. For instance, in southeastern Pennsylvania, long-term groundwater supply is a crucial physical, socioeconomic, and political issue. Development of a plan for southeastern Pennsylvania may concentrate on replenishing the groundwater by recharging stormwater. The following checklist itemizes factors to consider when developing a comprehensive watershed management plan. The list is not exhaustive; other items can be added to address the physical characteristics, issues, and goals within the study area.

Stormwater management
Stormwater-related problems
Floodplain management
Flood control
Hydrologic regime
Wellhead protection areas
Sinkholes
Regional facilities
Wildlife habitat management
Wetlands preservation
Invasive species
Fluvial geomorphology assessment
Natural channel restoration
Stream bank erosion protection
Erosion/sedimentation problems
Sustainable development
Conservation planning
Public health, safety, and welfare
Infill/redevelopment
Urbanization
Urban sprawl
Riparian buffers
Lumbering activities
Agriculture activities
Bridge capacities/obstructions
Existing flood control facilities
Agricultural concerns
Citizen concerns
Water quality
Nonpoint source pollution
Total maximum daily loads (TMDLs)
Geology
Limestone
Water supply areas
Base flow augmentation
Steep slopes
Gravel bars
Cost/benefits
Other

The items in this list, which have been incorporated into seven major classifications in the following sections, may dictate the goals and objectives of the watershed plan. Determining the primary goals and objectives of a watershed management plan is one of the first steps in developing a watershed assessment and plan. Geographic Information Systems (GIS) is an efficient tool to aid in developing a comprehensive watershed management plan.

1.3.1 Stormwater Management: Maintain the Hydrologic Regime

As development occurs in a watershed, the amount of infiltration/recharge decreases while the runoff generated from increased impervious areas increases the peak and volume of stormwater runoff. Since stormwater runoff is a major component of the hydrologic cycle, increasing the runoff has a major impact on the hydrology, biology, chemistry, and other physical features of the watershed. Therefore, the stormwater management plan must be an integral part of any watershed management plan. Developing one is complex and involves detailed hydrologic modeling and development of standards and criteria for new development, as will be discussed in Chapters 12, 18, and 19.

The ultimate stormwater management scenario to achieve zero runoff would be to maintain the existing hydrologic regime, recharging that which originally infiltrated to maintain both the existing peak *and* volume. Although in the majority of the situations this may not be practically feasible, keeping this goal in mind will aid in the prevention of stormwater problems. Another goal of comprehensive stormwater management should be to coordinate stormwater management, erosion and sedimentation control, and water quality control for best management practices (BMPs).

1.3.2 Groundwater Recharge

As mentioned in the introduction, if base flow augmentation is a priority, the plan should encourage groundwater recharge by providing relevant standards and criteria. This could include such measures as infiltration and recharge structures, porous pavement, and impervious surface reduction. However, caution should be exercised in limestone areas so as not to create sinkholes or provide a direct conduit to groundwater reserves.

Maintaining groundwater *quality* is another factor that must be considered when developing a plan. Evaluating the pollution vulnerability of specific sites would be imperative in proposing recharge structures. GIS can be utilized in a number of applications, including development of pollution vulnerability mapping from physical feature overlays (Reese and DeBarry, 1994). The features that would affect the vulnerability of groundwater to potential contamination—geology (fractures, limestone, etc.), soils (permeability), land slope, and streams (inflow or outflow)—can be overlaid to determine pollution vulnerability. A pollution vulnerability map can be utilized not only to aid in evaluating the pollution potential of recharge structures but also for new well siting, developing emergency spill response plans, and transportation planning (by overlaying major commercial highways).

Another facet that should be considered in development of watershed stormwater management plans in critical water supply areas are individual well recharge areas or zones of influence. These land areas could be mapped into the GIS from MODFLOW or related groundwater programs, and specific recharge evaluation criteria developed for these areas.

1.3.3 Surface Water Quality

Maintaining or improving water quality should always be a goal of any storm-watershed management plan because of long-term implications. With an increased emphasis on managing the quality of stormwater runoff and controlling nonpoint source pollution through the use of BMPs, the use of GIS can again provide watershed managers with a significant tool to analyze pollutant loads and target priority management areas. As early as 1991, GIS was used to compute nonpoint source pollution loads on a subwatershed basis utilizing the unit aerial loading approach based upon National Urban Research Project (NURP) and local area land use/loading data (DeBarry, 1991). Those subwatersheds contributing the most pollution for existing and proposed conditions could then be displayed graphically in the GIS to develop priority management areas or require BMPs in those areas. A similar approach using grids to determine pollutant loads by multiplying event mean concentrations (EMCs) by the expected runoff also utilizes GIS (Quenzer and Maidment, 1998). Water quality models have also been programmed into ArcView (Quenzer and Maidment, 1998). The Environmental Protection Agency's (EPA) total maximum daily load (TMDL) program, established under Section 303(d) of the Clean Water Act, is a written, quantitative assessment of water quality problems and contributing pollutant sources, and should be coordinated with any watershed management plan.

1.3.4 Flood Control

The objective of most watershed plans is to prevent flooding, whether at a local drainage level or on a regional stream level. The past history of flooding on a local and regional level should be determined, and the existing and potential development in a floodplain should be identified. Where there will be major damage in a floodplain during a specific flooding event, a watershed plan should manage that storm to reduce or prevent further exacerbating flooding problems. In typical floodplains, this may include placing design criteria for stormwater detention on new development for the larger storms—that is, the 50- and 100-year—as well as the smaller storms. However, where flood damage is not a problem due to lack of development in floodplains, the emphasis should be on prevention. In this case, it may be more prudent to concentrate on the smaller design storms—that is, the 2-, 5-, and 10-year storms—than to detain the 100-year storm. This objective can be further accomplished by placing tighter restrictions on developing in the floodplains, even preventing development in floodplains. Regional stormwater management facilities should also be considered to maintain the hydrologic regime of the watershed.

1.3.5 Stream Bank Erosion

In one particular study, through input from concerned citizens, it was found that a stream was causing property damage because it had very erodible stream banks. Studies have shown that stream banks begin to erode when the velocities in the stream reach the "critical velocity" (DeBarry and Stolinas, 1994). This velocity has been found to correspond to approximately the bank full flow or the one- and one-half-year storm. Theoretically, preventing the flows in the stream from ever reaching this threshold would prevent the stream banks from eroding. Naturally, this is impossible to achieve, but if the watershed management plan incorporates reducing the peak flows from development to these smaller (1.5-year) storms through the use of a subregional detention facility, for instance, the frequency of stream bank erosion would be reduced. Detention of the larger storms would typically be in the overbank areas and would not significantly contribute to the erosion in the stream. However, in implementing such a scheme, care should be taken to ensure that one is not increasing the duration of flows above the critical value for the larger storms.

1.3.6 Conservation Planning (Nonstructural Stormwater Management) Master Planning: Opportunity and Constraints

One of the most effective means of stormwater management is through open space conservation planning. By minimizing impervious areas and concentrating development in those areas most suitable for development, runoff can be minimized.

Large- or small-scale master planning can be developed utilizing the GIS. By identifying areas that are suitable for development and, conversely, those areas that are most sensitive, a development approach that best conserves the environment can be undertaken. Mapping development constraints (wetlands, floodplains, steep slopes, historic structures, critical habitat, sinkholes, erodible soils, etc.), and then overlaying each of these within the GIS, will conversely display those areas most suitable for development. By preserving the conservation areas and developing only in those areas most suitable for development, the ‘‘cluster’’ method of development occurs. Thus, many objectives for sound stormwater management can be achieved, such as floodplain preservation, impervious surface reduction, determining the best location for stormwater management measures, and preservation of natural drainage patterns.

1.3.7 Habitat Identification/Preservation

Habitat preservation should be a prime concern in any watershed management program. Identifying stream buffers, wetlands, and even prime trout habitat through geomorphologic techniques should be performed. The use of GIS can aid in this evaluation. Once identified through the process outlined in the previous section on conservation planning, the preservation/management of each area can be accomplished. As can be seen by this example, this process should be coordinated with the conservation planning and stream bank erosion strategies mentioned previously.

1.4 POLITICAL VERSUS NATURAL RESOURCE MANAGEMENT

Management of our land and water resources in the past has been based mostly on areas defined by political boundaries, and proper water resource management can be accomplished only by evaluating the comprehensive picture. However, as will be explained in this text, our land and water resources are not separated by political boundaries. Land and water resources are integrated and are divided by drainage areas, and ground- and surface waters are interconnected. A watershed is a natural resource management unit; therefore, for a sustainable future, land and water resources must be managed on a watershed basis, which includes an understanding and coordination of surface and groundwater systems, reservoirs and aquifers, point and nonpoint source pollution, wetlands and uplands, wastewater and drinking water, lakes and streams, and physical, biological, and chemical characteristics of water. Physical characteristics would include parameters such as temperature, flow, mixing, and habitat. Biological characteristics would include the health and integrity of biotic communities; chemical characteristics would include ambient conditions as well as pollutants.

Water resources are increasingly being addressed at the watershed level instead of only at the political boundary level. When watersheds cross political boundaries, land use regulations need to be consistent across borders to ensure that upstream land and water uses in one jurisdiction do not conflict or adversely impact water quality and quantity in downstream jurisdictions.

Regulations also tend to follow various disciplines. For instance, there are individual regulations relating to water for flood control, stormwater management, erosion and sediment pollution control, point source discharges, nonpoint source discharges, groundwater withdrawal, and drinking water supply. As we will see, water is water; it is all connected through the hydrologic cycle. So why, then, are different aspects of water resources regulated differently? Our lack of integrated water resources management is illustrated by state regulations that require *waste water disposal drain fields* to be a minimum of 100 feet from existing wells, but don't require that wells be drilled at least 100 feet from *waste water disposal drain fields.* Theoretically, a well could be drilled right next to a drain field. Likewise, in the past, we have seen channelization or levee projects constructed for flood control that have so drastically altered the flow regime that they totally undermine the stream's capability to support a viable aquatic habitat, and biota was lost.

Water resources management requires cooperation between state, county, and local officials, and involves proper planning, engineering, construction, operation, and maintenance. This involves educating the public and local officials, program development, financing, revising policy, and development of workable criteria and adoption of ordinances. The goal of a watershed management plan should be to enable future development to occur within the watershed, while using both structural and nonstructural measures to properly manage water resources.

Regulations in the past have tended to be *reactive,* those passed due to an observed problem such as water pollution or flooding. In the future, hopefully, now that we better understand the sciences relating to watersheds and the integration between them, future regulations and policy can be developed to be *proactive,* putting into place measures to prevent problems from occurring.

One option for the protection of water resources is to incorporate the development of a standardized "water resources protection plan" for each new or increased land development or water withdrawal. Such a plan would incorporate all the existing water-related requirements such as stormwater management and floodplain management items, and it would include additional computations to balance land use with water budget. These plans would comprehensively describe specific performance requirements that, when implemented, would strive to ensure that the land development proposal does not adversely affect water resources.

By necessity, all policies, standards, and recommendations included in the watershed plan should be consistent with sound environmental planning and engineering practices and applicable laws, regulations, policies, and procedures in effect at the federal, regional, state, and municipal levels. Examples include best management practices for stormwater management, stream water quality standards, riparian protection areas, and wetland buffer standards.

Although a comprehensive watershed approach had been utilized in a variety of projects in early years, the Watershed Protection Approach (WPA) Framework was not formalized until 1991 by the U.S. EPA to meet the nation's water quality goals. It is encouraging to note that things are changing. Pennsylvania, for example, is drafting a new "comprehensive water management" policy and regulations that tie together many aspects of water issues to be regulated. The U.S. Army Corps of Engineers, which had been criticized in the past for destruction of aquatic ecosystems, is now employing biologists and fluvial geomorphologists and incorporating natural channel design and water quality concerns into its projects. Societies are now opening their doors to other disciplines, forming new "institutes" for multidisciplinary interaction through cosponsored conferences and workshops. For instance, the American Society of Civil Engineers has formed the Environmental and Water Resources Institute for just this reason.

The Federal Clean Water Act's National Pollutant Discharge Elimination System (NPDES) regulations utilize the WPA, and many states are now revising or developing new regulations to manage water resources on a watershed-wide basis, as opposed to political boundaries. Some states are also providing funding for watershed assessment and management plans. And, although plans are now being accomplished on a watershed basis, many programs still artificially separate groundwater from surface water, wastewater from "clean water," nonpoint sources of pollution from point sources of pollution, water supply from stormwater runoff, even though "water resources" is really one integrated, connected, continuous system.

Funding and grant programs are also set up accordingly, whereas certain grants, for instance, may have to address only nonpoint source pollution; and even though this pollution may be indirectly affecting a groundwater supply by recharging within the wellhead delineation zone, funding from a drinking water source program would not allow for the nonpoint source pollution assessment. Or a state stormwater management fund would not allow a nonpoint source pollution assessment because water quality was not specifically mentioned in the legislative document providing the funding. These are two real-world examples encountered when applying for funds for a comprehensive water resource approach. Ideally, state and federal funds relating to water should be combined to allow funding of comprehensive watershed assessment and management plan implementation. Legislatures, whose members typically do not have a water resources background, should be educated as to the economic and scientific advantages of performing the comprehensive water resources management approach.

The plan should be comprehensive, with the intent to present all information that may be required in order to implement the plan. It should cover legal, scientific, and municipal government topics, which, when combined, form the basis for development of model ordinance language that will be considered for adoption by each municipality. Sample stormwater management and wellhead protection ordinances should be incorporated into the plan.

Plan implementation will require working within existing regulatory programs and applying available regulatory, planning, and management tools to implement the plan at the municipal level. The intent of the plan should not be to limit growth but to provide a scientific approach for analysis of the water resources and to apply sound planning principles to implement the recommendations of the plan for the benefit of future generations.

EPA (1997) has developed a publication entitled “Top 10 Watershed Lessons Learned.” In summary, they are:

- The best plans have clear visions, goals, and action items.
- Good leaders are committed and empower others.
- Having a coordinator at the watershed level is desirable.
- Environmental, economic, and social values are compatible.
- Plans only succeed if implemented.
- Partnerships equal power.
- Good tools are available.
- Measure, communicate, and account for progress.
- Education and involvement drive action.
- Build on small successes.

1.5 SUMMARY

The watershed is the framework from which the web of life is structured, from the microbe to the mouth of the watershed, with the common element being water, its lifeblood (Figure 1.5). Affecting even a small component, such as microorganisms or soil particles, causes a chain of events that could affect other components in the watershed. This text therefore reviews even

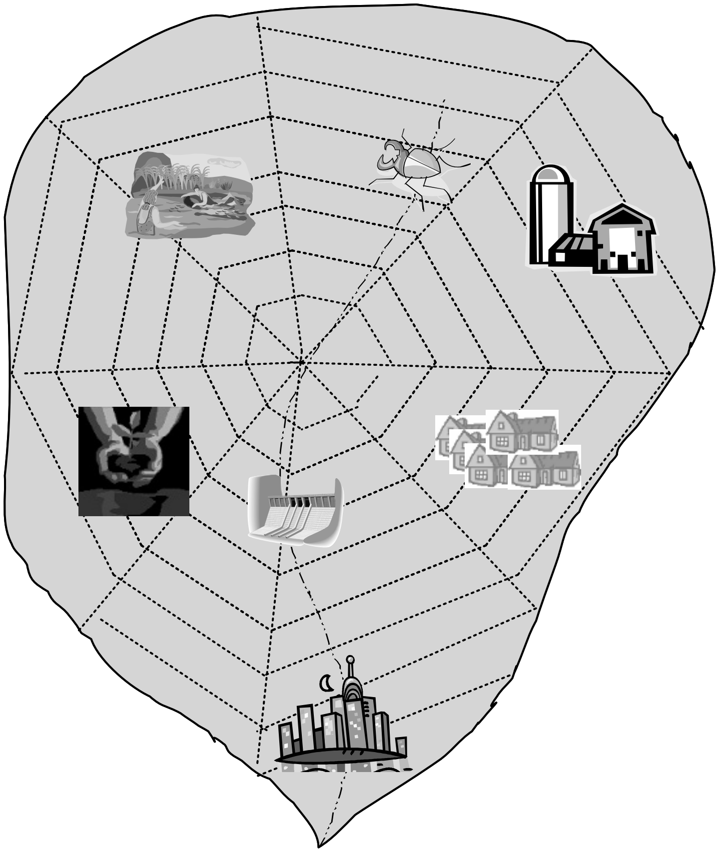

Figure 1.5 The watershed is the framework from which the web of life is supported.

the smallest component of the watershed, and the reader should keep in mind when reading those sections how these relate to the processes in one. The text concerns things as small as soil particles to things as large as the Mississippi River watershed.

Except in rare instances, for instance where a water company owns all the watershed land to their reservoir, a watershed cannot be managed by a single entity. However, one can manage the various parts that comprise the watershed: land use, lakes, stream banks, water withdrawals, and so on. Of these, land use change has the greatest impact on the watershed.

In order to develop a truly comprehensive watershed management plan, all facets of the watershed, including physical features and socioeconomic and political factors, must be considered. All of these factors should be analyzed individually and then combined to determine goals and objectives unique to the particular watershed being studied. This will allow watershed managers to better and more efficiently manage watersheds to address their particular concerns, whether it is stormwater management, floodplain management, water quality control, or conservation planning. Each factor will be mentioned in more detail in the following chapters.

The watershed should be divided into "management districts" based upon similar biological, chemical, hydrologic, hydraulic, land use, geologic, soils, and political and regulatory characteristics. Therefore, evaluating the ecosystem, physiographic provinces and other classification systems aids in developing these districts. GIS provides an efficient tool to aid in watershed planning and management. This book will expand upon the items described in this chapter and will discuss in detail the requirements for a successful, comprehensive watershed management plan.

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