Second Edition

Wetland Landscape Characterization

Practical Tools, Methods, and Approaches for Landscape Ecology

Ricardo D. Lopez
John G. Lyon
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CRC Press
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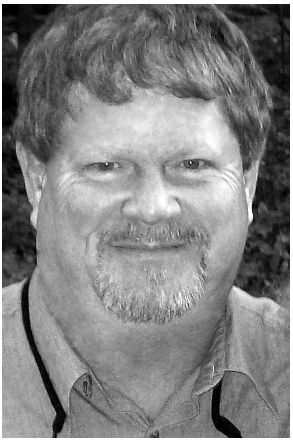
Preface

Decision makers of all types are increasingly called upon to determine the details of the complex and transitional ecosystem called "wetlands." Because wetlands are, by their very nature, ephemeral and transitional, their complexity makes the task of capturing their essence, that is, characterization, very challenging. The need for characterizing wetlands is growing every day to meet scientific and societal needs, and this need is on the increase as we better understand the wealth of ecosystem services wetlands provide us. For those continuing their quest for wetland knowledge, this second edition of *Wetland Landscape Characterization* is designed to enhance their knowledge base, providing them with a pathway to understanding how wetland characterization tools, methods, and approaches can be integrated to address twenty-first century wetland issues.

Authors

Ricardo "Ric" Daniel Lopez is a leader in the field of wetlands ecology and landscape ecology. During his tenure in academia and public service, he has lead in geographically diverse applications of field-based and geospatial approaches to theoretical and applied environmental topics. This body of work includes monitoring and assessing of wetlands and streams, invasive plant species, broad-scale indicators of sustainability, and solutions to risk-based issues. A native of coastal California, Lopez spent his youth knee-deep (or deeper) in the many wetlands and tide pools of the region. Lopez earned his BS in ecology, behavior, and evolution at the University of California, San Diego, and his master's and doctoral degrees in environmental sciences at The Ohio State University, with an emphasis on wetland ecology and landscape ecology.



John Grimson Lyon was interested early on in wetlands as places of native vegetation. This interest was honed during youthful wanderings in the mountains and river valleys of the Pacific Northwest, California, Nevada, and Alaska. Systematic study at the undergraduate, graduate, and professional levels has yielded a body of work on remote sensing, mapping, identification, and characterization of processes in wetlands, and related ecosystems in the Great Lake states and western United States.

Lynn Krise Lyon is a lifelong educator, writer, and artist. She spent a good portion of her youth playing in creeks and streams. As an adult, she has visited wetlands all over the United States with her husband, John. She abhors black flies and snakes, loves cranberry bogs, and fervently believes Michigan has the best wetlands in the world.

Debra Kim Lopez has dedicated her existence to the appreciation of literature and writing, global sustainability issues, and the social sciences. She values the importance of global initiatives for improving communities around the world; she has traveled extensively. Lopez has partnered with her husband, Ric, on a plethora of wetland and other environmental issues, ever since they first encountered one another on a common travel adventure twenty-two years ago.

1

Introduction: The Challenge

One ponders the imponderable. What are the future challenges for landscape characterization particularly related to wetlands? You may have encountered these challenges in your professional life and observed them in your personal life too. Many of these challenges are related to the big issues in the news and are on the public's mind regarding adequate and safe water, sufficient and affordable food supplies, and infrastructural development. All have something to do with landscapes and wetlands.

Wetland landscape characterization is an important component of determining the degree to which wetlands improve environmental conditions in a particular location. Similarly, the type of wetland, the characteristics of particular types of wetlands, and a wetland's position in the landscape has a tremendous influence on water-quality benefits of aquatic resources. In essence, wetlands provide critical linkages between water and land, people and creatures, and their food and water as well as shelter. It is important to understand these critical linkages, and functions and services that wetlands provide.

The challenges and dialogue specifically focus on critical needs and linkages that are inextricably part of wetlands. The safety and security of water, which is a matter of survival, have linkages both on the issues of *water quality* and *water quantity*. Specifically, water sustains life and without it humans perish in a few days. Due to water's unique properties, water can convey pollutants directly to organs and cells. However, wetlands can store water and delay or reduce the flow of drainage or subsurface water flow from developed areas, consequently removing or reducing the amount and form of pollutants to improve water quality (i.e., chemistry), and thus improving water quality of streams, lakes, and seas. These linkages and societal benefits are intertwined, yet must be understood for thoughtful decision making.

Another critical linkage between society and wetlands is food safety and food security, particularly involving crop and grazing productivity, the availability of wild foods, and the security of the public's food supply (Thenkabail et al. 2009). Food supply and the security of the food supply is critical because without minimum caloric need being met, humans die in a matter of weeks, and reduced nutritional intake is a serious threat to individual and community health. Also because food is another primary conveyance of chemical constituents into organs, any chemical, biological, viral, or radiological contamination of food is a direct threat to individual and community health and longevity. Wetlands are therefore a critical link to food supplies and security, directly providing food; including hunted animals (e.g., goose and duck), wild and cropped foods (e.g., rice, fish, crustacean, and seaweeds) and pollination, and wetlands also directly improve water quality of source water to cropped areas.

A third critical linkage between society and wetlands is generally described as *infrastructure*, which is to say the interconnected framework that supports the development of humans' everyday physical environment, from personal dwellings, roads, and bridges to the Internet and other global communications networks. An emerging way of understanding this infrastructural linkage is by way of the concepts of ecological goods and services. These can include water supply regulation and filtration; protection from flood waters and storm surges; habitat provisioning for terrestrial and aquatic species; and recreational, spiritual, and aesthetic benefits to society, supporting the structure of communities and cultures.

Of course this infrastructural support varies tremendously throughout the world, both societal and geographic, depending on the traditions and values of people. In addition, local, regional, and global policies and decisions that involve wetlands or allied natural resources require social scientists, along with other scientists, economists, and others to provide decision makers with current and accurate information about wetland conditions and the risks to wetlands (that could lead to wetland degradation or outright loss).

This edition provides the methods and approaches necessary for informed decision making on wetland resource issues of all types. It provides several new examples and case studies that describe detailed and general lessons for all applications. This also integrates well with an emerging infrastructural, ecosystem goods and services perspective to better assist readers who may encounter these concepts and challenges during the assessment and characterization of wetlands, within the context of the larger landscape. And, importantly, supplies pithy scientific analyses to drive the dialogue.

Accordingly, this book increases the knowledge, skills, and abilities of professionals and apprentices, and provides for continued growth in their careers. It brings the reader the concepts and skills necessary to achieve a better understanding of how project goals can be best achieved in the rapidly changing disciplines of landscape sciences and wetland ecology and management, by providing explicit examples that illustrate a variety of encountered situations and solutions. Each of these examples offers more depth and breadth of information, particularly in terms of utilizing current techniques in assessment, inventory, and monitoring of natural resources under conditions that are ever-changing over space and time.

The discerning reader will find many opportunities to combine the conceptual and operational linkages described here, which outlines the integration of wetland landscape characterization, inventorying, monitoring, assessment, and restoration techniques. The inventive reader will also find several opportunities to make connections between their specific natural resource management issues and goals, and the specific examples, techniques, and approaches provided in subsequent chapters.

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Key Themes Driving Landscape Characterization

Wetlands are all about linkages. As a mixture of phenomena juxtaposed between terrestrial and aquatic landscapes, they have challenged methods and approaches for their analyses. To inform the public and decision makers it is necessary to use technologies to probe the landscape and linkages. Any number of questions can be addressed using these approaches with the wide-ranging variety of tools, techniques, and approaches available to the practitioner.

Wetland Principles

Wetlands are land areas that are periodically flooded or covered with water (Figure 2.1). It is the presence of water at or near the soil surface for more than a few weeks during the growing season that may help to create many wetland conditions. The water slows diffusion of oxygen into the soil and to plant roots. Lack of oxygen or anaerobic conditions causes major changes in the soil chemistry. Only certain *wetland plants* are adapted to live in these harsh conditions. Their adaptations allow them to use available soil nutrients, and they exhibit a variety of physical and physiological adaptations to grow in the absence of available oxygen.

The combination of anaerobic and waterlogged soils, the presence of wetland plants, low-lying topography, and other conditions help to create a different land cover type called wetlands. These characteristics and conditions are also used to define and identify wetlands.

Different types of wetlands have been created by hydrological and topographical conditions. This has a lot to do with the variety of water bodies or sources of water associated with the wetland. For example, wetlands adjacent to rivers take on the characteristics of the riparian and riverine conditions. Wetlands on the shore of lakes have many hydrological characteristics that are driven by the lake system. Wetland areas on marine coasts have coastal characteristics and are also influenced by the varying salinity concentrations from open ocean, coastal ocean, and neighboring estuarine waters. Hence,

FIGURE 2.1
The combination of water and vegetation and standing water over soils make a wetland, such as this coastal wetland area of northern Lake Michigan.

the hydrology of a given area is important to the characteristics, conditions, the functions of wetlands, and ultimately to their identification.

As another example, the variability of temporary or ephemeral wetlands makes them particularly hard to distinguish. These areas may only display wetland function for a little over two weeks during the growing season. Yet they are vital to the ecology of most ecosystems, such as the desert or semidesert ecosystems in the western United States, Canada, and Mexico.

One central priority of the wetland issue is the definition of a wetland. In particular, we are interested in the definition of a jurisdictional wetland (Lyon 1993; Lyon and Lyon 2011). A wetland is defined in the U.S. Army Corps of Engineers (USACE) 1987 wetland manual as "areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs and similar areas."

A jurisdictional wetland is defined in the field. It must exhibit a predominance of wetland plants, soils subject to waterlogging or hydric soils, and indicators of wetland hydrology. These three individual criteria must be addressed, and areas exhibiting all three indicators are deemed jurisdictional wetlands (Lyon 1993; Lyon and Lyon 2011).

Trends in Wetland Inventory, Monitoring, and Assessment

Wetland science and landscape ecology has undergone tremendous change in the past decade, and the melding of the two disciplines has yielded new and exciting trends in inventory, monitoring, and assessment. New issues, new results, the advance of techniques, and decisive applications in wetland sciences and landscape ecology all have a bright future because of their increased applicability to fundamental societal needs, in terms of assessment and associated decision making. Simultaneously with this increased need for compelling information about wetlands and their status or conditions, the last ten years has witnessed important new developments and refinements of earlier paradigms, enhancing areas or landscapes, and the combination of biological, physical, and chemical processes (Figure 2.2). The emergent paradigm of the landscape sciences encompasses the disciplines and subdisciplines necessary to address the characteristics and ecology of wetlands at a landscape scale. Landscape science incorporates both the concepts of landscape ecology and landscape characterization.

Landscape characterization is the combination of methods and approaches that allows the characterization of earth and water resources, and the processes that drive the systems. Landscape ecology is the mix of biological, chemical, and physical processes, and characterizes the earth and water at the landscape scale (Figure 2.3). Together, wetland landscape characterization

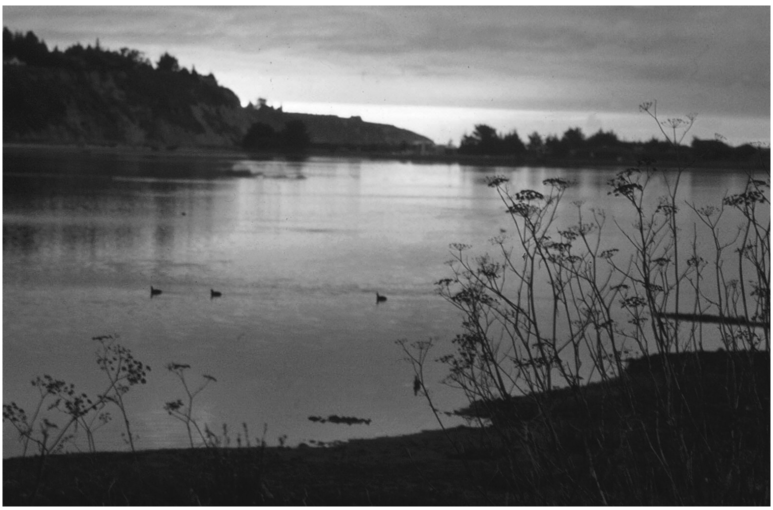

FIGURE 2.2
Movement of water, such as this tidal flow, causes areas to exhibit partial wetland characteristics during the day and perhaps less clear characteristics at other times in coastal Oregon.

FIGURE 2.3
Ebb and flow of water on the surface of soils across a broad landscape often is enough to keep soils saturated beneath the surface in the absence of standing water in some areas of the back barrier marshes and wet soils of Galveston Island, Texas.

and wetland landscape ecology allows for the integration of theoretical and practical characterization, evaluation and prediction of landscape resources, and the dynamics of their processes as they relate to wetland ecosystems. Importantly, the relatively new *landscape approach* makes possible the incorporation of all processes, both sociological and ecological, for improved wetland analyses and decision making. The landscape sciences represent the culmination of years of study and theoretical development and practical geospatial technologies. The result is a set of concepts that can be used to formulate the problems, execute their study in nature, help in the parameterization and simulation of real processes in a mathematical manner, and the prediction of future trends and the risk that is posed by natural and anthropogenic stresses.

An approach that is currently used in the landscape sciences is that of environmental risk assessment. Risk assessment involves the characterization of specific risks and how those risks may influence or expose natural resources, such as a wetland, or receptors of the risk, such as organisms within a wetland. The exposure of a wetland (resource) or organism (receptor) to a natural or human-induced stress may often define the problem that is necessary (or desired) to address through decisions and actions. Risk can be determined by the characterization of exposures and ecological effects to receptors, by stressors.

Once determined, it becomes important to evaluate the concern through risk characterization and address the correction of the problems through

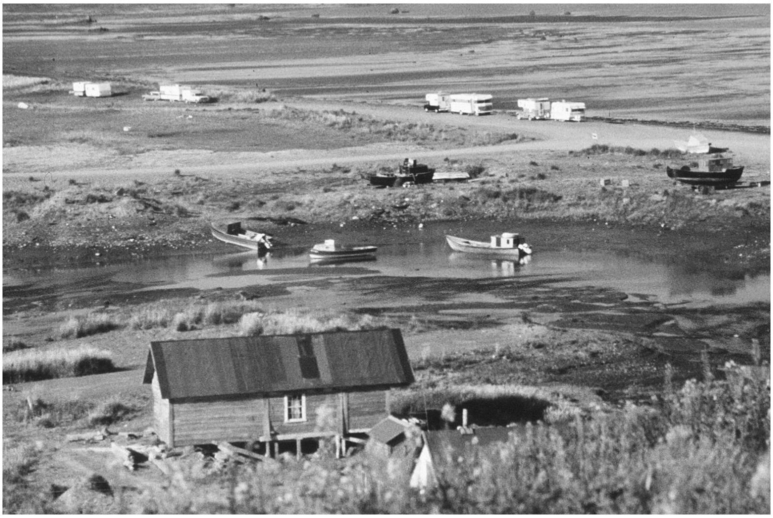

FIGURE 2.4
Many wetland areas appear problematic as compared to most people's ideal (such as in Figure 2.3). Areas with minimal plants but with anaerobic soils fit the definition of a wetland such as these areas on the coastal shore of Alaska.

risk management. To evaluate the potential risk or conduct risk assessment involves the determination of endpoints or assessment criteria. Endpoints come in two forms: either an assessment endpoint or a measureable endpoint. Often, endpoints of interest are difficult to evaluate, so that surrogate variables or measurable endpoints are used. Numerous examples of endpoints are provided in subsequent chapters.

Two important considerations in utilizing the risk assessment approach in landscape evaluations are spatial and temporal characteristics of the problem (Figure 2.4). Ecosystems vary over space and time, so the risk assessment paradigm should incorporate both of these dimensions and variables, particularly when utilizing *geospatial technologies* such as remote sensor data and geographic information systems (GIS).

Wetland landscape characterization (Figure 2.5) and wetland landscape ecology need to both encompass the risk assessment and characterization concepts necessary to measure, model, and predict the current, historical, and future status of wetlands and related ecosystems. Within this edition the concepts necessary to characterize (Figure 2.6) and evaluate the wetlands and related habitats, with examples, are demonstrated, including the methods and interpretations necessary to conduct similar efforts.

FIGURE 2.5
Presence of obligate wetland plants such as cattail often help identify the presence of wetlands even in a winter scene populated with plant residue in Ohio.

FIGURE 2.6
Wetlands and ponds supply recreation and learning opportunities that many people take advantage of including summer research programs in Michigan.

Wetland–Landscape Paradigm

In the United States and abroad there is burgeoning interest in maintaining the wetlands that are currently present in the landscape through a variety of means. This would include creating them in areas not previously found as well as restoring them in areas where they were previously found. This expansive interest is in addition to calls from public interest groups and regulations from resource management agencies. Numerous national and international consortia and interests also have influenced the burgeoning emphases on wetland protection and restoration. The powerful drivers of public need and governmental oversight and regulation make for a bright future for wetland analyses as well as management programs and projects.

Wetlands are very unique, and in some cases extremely rare, in that they are an unusual transitional ecological zone, sharing and mixing ecological components and functions from purely aquatic and purely terrestrial habitats. What one observes is often a mixture, or transitional gradient, of these upland or terrestrial conditions and aquatic conditions, which may be an added difficulty for interpretation due to the complex interspersion of soils, hydrologic conditions, and flora. Because of this mixture of terrestrial and aquatic characteristics, wetlands provide many functions and mixtures of functions of both aquatic and terrestrial ecosystems, creating the unique and rare environment that makes wetlands so special and treasured for their functional characteristics.

Most common or large wetland areas can be recognized by many people, however, the transitional character of wetlands and their potential impact on the larger watershed, or landscape, can be difficult to identify and to quantify. This sort of information is necessary for those who need to characterize wetlands and their beneficial impact on the larger landscape. This information quest is further complicated by the sometimes fleeting nature of wetlands, such as where wetlands are only temporary features in the landscape (e.g., only flooded part of the year), are directly adjacent to terrestrial ecosystems (e.g., an upland forest), or are directly adjacent to aquatic ecosystems (e.g., a stream) (Figure 2.7).

Although some people have a high comfort level about their knowledge of wetlands and believe they know how a given type of wetland should appear (Figure 2.8), others may need to utilize additional information to secure their decision about the existence of a wetland. A major concern is the lack of adequate understanding of wetland characteristics and functions in the face of a need to make land management decisions (Figure 2.9). A poor understanding of all the different wetland characteristics and functions can lead to nonsustainable land management decisions in a particular locale.

An important distinction is that landowners often identify wetland areas in a different manner than do regulators or other wetland delineation experts. Such regulators or experts are experienced at identifying less-than-apparent

FIGURE 2.7
Many areas experience floods or periods of standing water and saturated soils, and may have wetland functions for short periods of time, such as these rain-flooded areas of a farm field in South Dakota.

FIGURE 2.8
The riparian areas of the stream channel are often just that, but wetland plants abound and wetland soils are patchy in distribution dictated by historic meandering of water in interior Alaska.

FIGURE 2.9
These typical wetlands are understood by the layperson and include wetland-loving moose, illustrating the linkages of wetland landscapes to wetland functions and ecological services.

wetland characteristics and types. Wherever land areas have the potential to be waterlogged or flooded, there is potential for wetland presence (Figure 2.10). Depending on local and regional interests, activities in and around these potential wetlands may create harm and therefore may come under additional scrutiny.

The widespread distribution of wetlands holds the promise of the resource being found on many lands, including those lands that are slated for change in land cover or new management practices. Where such ecosystem risks may occur, personnel are working and naturally they will encounter wetlands in the course of practicing their profession. Where development and wetlands coexist, there are often potential or actual risks of loss of the physical wetland or loss of wetland functions (i.e., degradation of wetland processes). These losses are addressed by federal, state, and local regulations and oversight. Hence, interested parties must pay close attention to the potential for risks to wetlands, and it is extremely critical to know the location and variety of wetland ecosystems found in the landscape.

There are many opportunities to work with wetland ecosystems in such a way as to avoid or minimize disturbances, and make the improvement in the numbers and functions of wetlands to develop a more integrated and coordinated plan for land and water management using the landscape approach. The distributed nature of wetlands requires that their locations be identified for thoughtful management, preservation, and evaluation of risks. There are several ways to locate and inventory wetlands, and assess the risks imposed by stressors. It is necessary to accomplish these goals related to wetland

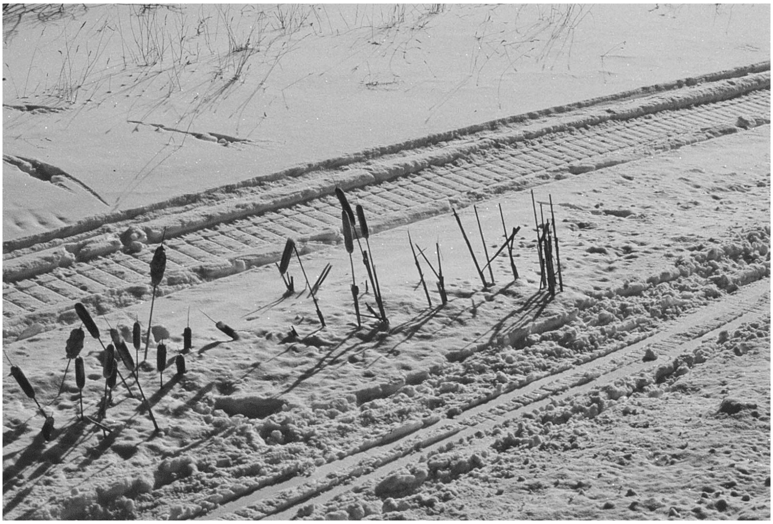

FIGURE 2.10
Spring runoff of snowmelt creates many wetland areas that may or may not be present later in the summer. Use of wetland indicators such as wetland plant residue can help locate resources across the landscape. Snow partially covering wetland vegetation is depicted in this image.

inventory and to do so in a manner that matches the needs of a particular community, paying particular attention to the financial resources human resources and skills that are available. There are also several different levels of details that can be collected about wetland areas to fully evaluate risks associated with human activities. These activities are all part of wetland landscape characterization and risk assessment.

Wetland landscape characterizations are particularly needed, and indeed required, for a number of reasons. Water quality and water quantity are naturally a unifying concern, with wetlands at the heart of the amalgam of physical hydrologic and chemical processes involved in these two important aspects. The mix of physiochemical processes, which are often mediated by wetland biogeochemistry, yields an amazing variety of functional properties that all life forms depend upon. To bring together the processes, functions, and uses of wetlands necessitates approaches and methods that are inherently spatial, and that incorporate concepts of environmental risk and environmental health.

The desire to better understand and manage wetland landscapes may create excellent opportunities to examine current capabilities for measurements, inventory, and modeling. Subjective judgments and anecdotal information no longer suffice to address the pressing issues of wetland characterization and associated decision making. In their place are new tools and approaches for providing more quantitative data and rigorous interpretations, including both conceptual and technological approaches.

FIGURE 2.11
The use of a variety of images, sensor types, and time of the year of seasons facilitates interpretation and leads to a convergence of evidence to support a hypothesis. Winter period images or low sun angle images can reveal additional information. Note the ice covering lakes helps to distinguish them from the surrounding land covers and displays their surface area. Dead plants and plant residue can be distinguished from forested areas by pattern and texture as well as gray tone.

We can now measure wetland and related ecosystems with a tremendous number of sample locations and at vast scales, relying on computing power to process and store this wealth of empirical data (Figure 2.11). Value-added processing of these data with simple or complex algorithms, based on theory and practice, allows for a quantitative and accurate view of a much larger extent of the landscape, with improved accuracy and precision as well. Empirical and simulation modeled results tested by assessments of accuracy now pace the dialogue in wetland landscape characterization. The power of these wetland-related decisions, along with facts and predictions behind them, is evidenced by the growing sophistication of publically available information on the Internet and elsewhere. Accordingly, this edition brings you several of these key examples where the power of new tools is evident and instructive.

To measure wetlands, and related landscapes, for this now expanded breadth of characteristics, the difficulty lies in developing novel and ingenious methods for collecting data as well as interpreting the data. Most research efforts conducted in a laboratory or in experimental plots seek to control all variables but one, and study different levels of the selected variable of interest or the large forcing function or stressors (Figure 2.12). Alternatively, landscape scale analyses focus on control of a given variable or a few variables, which can otherwise be difficult and potentially expensive.

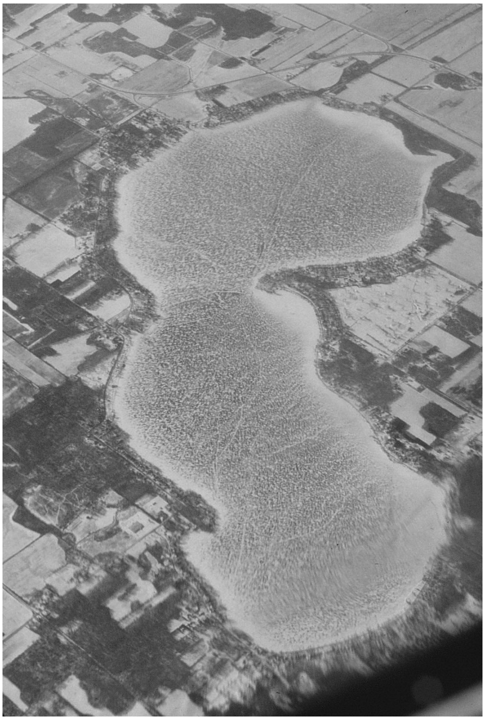

FIGURE 2.12
A low-altitude look at a pothole lake in the glaciated Midwest. The surrounding land cover can be distinguished as can plant residue and their shadow along the northwestern shore of the lake.

Therefore landscape scale studies have a key advantage in that they often utilize survey sampling techniques (Congalton and Green 1998, 2009) where large sample sizes address a number of potentially associated variables. This can be a successful approach where the typical empirical approach may not be feasible. This edition will demonstrate the advantages to using multiple factors to develop correlative analyses, allowing for the postulation of relationships between ecological and other physical parameters in the landscape.

Although the new wetland landscape characterization paradigm involves the use of advanced technology and methods, tremendous value also resides in the more traditional approaches. In this edition, we meld the two schools of thought, respecting the traditions of prior techniques and complimenting those techniques with the newer methods. To obtain the best quality and variety of data with a landscape scale often means using traditional survey sampling and other appropriate measurements and data organization technologies.

Collection of data from a distance is *remote sensing*, which has demonstrated its value for a number of applications. The variables of interest may be directly measured over large areas using uniform data collection methodologies, and may involve airborne or orbiting platforms, or other types of sensors located in the field and linked by telemetry such as a flux tower. Indirect variable or surrogate variables may also be measured to take advantage of the capabilities of remote sensing. Examples of direct measurements would be the inventory of general wetland types. Indirect measurements would be the location of different general wetland types, their presence and absence, their interspersion, their juxtaposition and perhaps fragmentation (Robinson et al. 1992) as compared to the known habitat requirements of biota too small to resolve given a remote sensor.

Because copious amounts of data are typically utilized in landscape scale evaluations, such data collections must be organized with tremendous human interpretation or augmented by computer analyses. The advent of spatial databases and GIS techniques make possible the storage of data in such quantities. The spatially based storage of data as feature locations (i.e., point coordinates) or boundaries (i.e., vectors), or other feature characteristics in raster formats (i.e., grid cells) makes implicit the spatial location of features and their associated characteristics. GIS allows retrievable storage and maintains spatial fidelity and quality assurance, and can accommodate as much data as are necessary to solve any wetland-related problems.

Current and future efforts are devoted to geospatial modeling of processes using GIS and remote sensor imagery systems, and thus a good understanding of the capabilities of these technologies is a critical component for the wetland landscape professional, which this edition brings to the reader in the form of projects and data examples.

Current Global Perspectives and Systems Approaches

The diversity of technology and infrastructure to monitor environmental systems (Figure 2.13), from global to local scales, is growing rapidly as public and private organizations increase their investment in them. Resource planning, decision making, and management requires environmental data that specifically answers the operational details of new real-world problems, which are now more routinely discovered and understood by the public, partly due to developments in visual media for conveying these data (i.e., imagery from maps, models, and processed airborne or satellite remote sensing data). Therefore good environmental planning and management requires excellent data to ensure compliance and to monitor for project or program successes. Remote sensing products (including aerial photography, and airborne and satellite sensor imagery) are increasingly useful for monitoring and reporting these requirements, established by national policies and international treaties, conventions, and agreements (Backaus and Beule 2005),

FIGURE 2.13
Wetlands can be found in the most unusual places where water and land meet. Here is a discharge channel into a river with an abundance of new sediment deposits as yet uncolonized by vegetation. The juxtaposition of light toned sands or sediment, and darker toned examples show the quenching or darkening influences of water and sediments.

and are indeed now common tools shared worldwide. With the advent of Google Maps, Bing Maps, Google Earth, and other easily accessible and user-friendly geospatial data viewers, the public at large now expects these data to be of high caliber and available to them for day-to-day decisions.

Remote sensing is used at regional scales to improve land management policies and associated decision making processes, especially in areas that are highly agricultural and that are urbanized (Miller and Small 2003; Bryan et al. 2009). For example, data from AVHRR (Advanced Very High Resolution Radiometer), MODIS (Moderate Resolution Imaging Spectroradiometer), and MISR (Multiangle Imaging Spectroradiometer) satellite sensors have been used to monitor biomass burning in Brazil (Koren et al. 2007), which has a global impact on all of society. A combination of historical aerial photography and satellite imagery can also be used to establish historic baseline maps for land cover, and to project the impacts of different land management policies through the application of different possible alternative futures scenarios designed by local decision makers and community members (Baker et al. 2004; de Leeuw et al. 2010) worldwide. Satellite sensors can also be used to monitor and assess important and incremental ambient or diffuse globally significant environmental conditions, such those related to air pollution (Engel-Cox and Hoff 2005) and urbanization, and the risks associated with those conditions (i.e., human health, or the potential for impacts to people and built structures from flooding or fires) (Miller and Small 2003). Satellite