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## CHAPTER 13

# Wetlands

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### 13.1 INTRODUCTION

Interpretation of aerial photographs is the conventional and most widely used method for inventorying and mapping wetlands. In the United States, several states, including New Jersey, New York, Delaware, and South Carolina have produced maps of coastal wetlands using large- or medium-scale aerial photographs (Klemas et al., 1973; Tiner, 1977; Brown, 1978). Coastal wetlands and some types of inland wetlands have been inventoried through aerial photointerpretation for land cover and land use mapping projects in Massachusetts and Rhode Island (MacConnell, 1974, 1975), and elsewhere. States have also mapped inland wetlands through use of large- or medium-scale aerial photographs, including Maine (McCall, 1972), New York (Cole and Fried, 1981), Wisconsin, and more recently, New Jersey, Maryland, and Massachusetts. The latter states are conducting detailed wetland inventories to assist in administering wetland protection statutes.

Table 13.1 lists photography used for some significant wetland mapping projects in the United States. Local studies involving wetland photointerpretation include Olson (1964), Stroud (1969), Anderson and Wobber (1972), Reimold et al. (1973), Seher and Tueller (1973), McEwen et al. (1976), Shima et al. (1976), Roller (1977), Carter et al. (1977, 1979), Bartlett and Klemas (1980), Cowardin and Myers (1974), and Lovvorn and Kirkpatrick (1982). Miller et al. (1976) described the use of aerial photography for riparian habitat evaluation. Carter (1982) provided a review of applications of remote sensing to wetlands, while Lampman (1993) prepared a bibliography of articles on remote sensing for wetland research. Kennard et al. (1980) discussed the use of color-infrared (CIR) aerial photography for identifying inland wetlands. Kiraly et al. (1990) presented a review of federal coastal wetland mapping programs in the United States.

In addition to these efforts, the Fish and Wildlife Service (FWS) of the U.S. Department of the Interior

began the National Wetlands Inventory (NWI) project in 1975. The NWI project was established to develop and disseminate scientifically-based information on the distribution, characteristics, and extent of United States wetlands. The NWI uses mid- to high-altitude aerial photographs to locate, classify, and map wetlands at a scale of 1:24,000 for most of the U.S. and at 1:63,360 for Alaska (Wilén and Tiner, 1989). The maps show the locations, sizes, shapes, and types of wetlands according to the FWS's official wetland classification system (Cowardin et al., 1979). By the end of 1996, about 88 percent of the conterminous United States, all of Hawaii, Guam, and the Northern Mariana Islands, and 30 percent of Alaska were mapped by the NWI. The Emergency Wetlands Resources Act called for completing NWI map coverage for the lower 48 states by 1998 and for Alaska by 2000, but recent budget cuts will cause a significant delay in this schedule.

The purpose of this chapter is to discuss photointerpretation of wetlands. Emphasis is placed on the NWI's use of high-altitude photographs for mapping United States wetlands, with the procedures outlined in section 13.7. The chapter also includes discussions of photointerpretation for monitoring or assessing wetland changes and of the potential application of satellite imagery for wetland detection. Although the chapter is not intended to be an exhaustive review of the literature, it should provide a solid foundation and references to better understand how photointerpretation has been and can be used for wetland identification. This is especially true when the material presented here is combined with other chapters of this *Manual*, particularly chapter 14.

### 13.2 WETLAND IDENTIFICATION CRITERIA

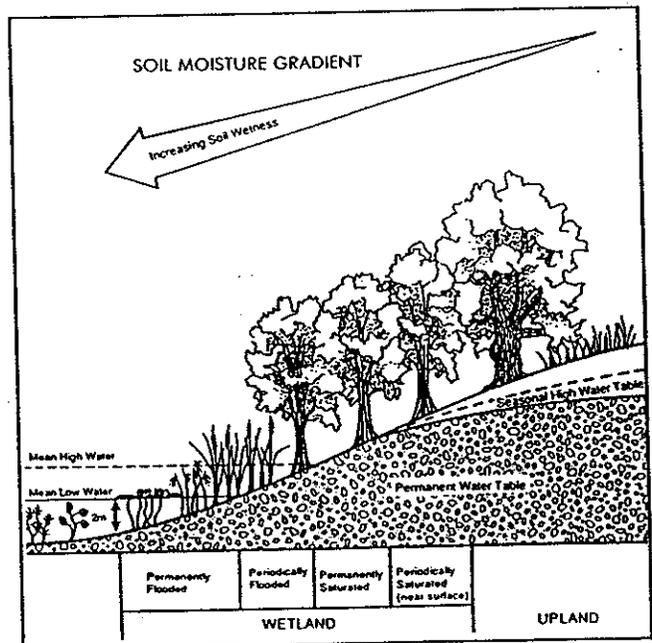
Wetlands include marshes, swamps, fens, prairie pot-holes, pocosins, playas, bottomland hardwood forests, wet

**Table 13.1. Summary of photography used for some major wetland mapping projects in the United States. R - color infrared, BW - black and white panchromatic, C - color; photographic scales are shown in thousands (e.g., 1:40 is 1:40,000).**

State or Region (Type of Wetland)	Photography		Project/Reference
	Emulsion	Scale	
Entire Country (All)	CIR	1:40	U.S. Fish & Wildlife Service National Wetlands Inventory Project
	CIR	1:58	
	BW	1:80	
	(see Table 4 for specifics)		
Delaware (Coastal)	CIR,C, & BW	1:12	Klemas et al. (1973)
Hawaii (All) (>2 ha)	C & CIR	1:130	Chime et al. (1978)
		1:65	
		1:32.5	
Maine (All) (>4 ha)	BW	1:1.32	McCall (1972)
Maryland (Coastal) (>0.1 ha)	C (mostly)	1:12	McCormick and Somes (1982)
Maryland (Nontidal)	CIR	1:40	Maryland Dept. Natural Resources
Massachusetts (All, except forested)	BW	1:20	MacConnell (1975)
Massachusetts (All)	CIR	1:12	Mass. Dept. Environ. Protection
New Jersey (Coastal)	CIR	1:12	Brown (1978)
New Jersey (Freshwater)	CIR		New Jersey Dept. Environ. Protection
New York (Inland)	BW	1:24	Cole & Fried (1981)
New York (Coastal)	CIR	1:12	Brown (1978)
Rhode Island (All, except forested)	BW	1:12	MacConnell (1974)
South Carolina (Coastal)	BW	1:40	Tiner (1977)
	CIR	1:12; 1:6	

tundra, mudflats, rocky shores, and other wet habitats (fig. 13.1 — see color section). Most wetlands occur in depressions or along rivers, lakes, coastal embayments or drainageways, where they are subject to periodic inundation. Other wetlands, however, develop on slopes in association with groundwater seepage, especially in hilly and mountainous areas. Wetlands are commonly viewed as transitional habitats, lying between permanent water bodies and well-drained terrestrial (upland) habitats, yet they are not restricted to this zone (Tiner, 1993c). Wetlands occur along the natural soil wetness gradient from areas with permanent shallow water to areas with a seasonally high water table near the surface for more than two weeks during the growing season in most years (fig. 13.2). Many wetlands are seasonally saturated depressional landscape features surrounded by upland and lacking an open water body. The wide range in hydrologic regimes associated with wetlands creates a diverse set of environmental conditions affecting plant growth and soil development.

Wetlands are characterized by permanent or periodic inundation and/or soil saturation, typically sufficient to cause prolonged anaerobic conditions in the substrate. All areas considered wetland must periodically have enough water during times of plant



**Figure 13.2. From a conceptual standpoint, wetlands occur near the wetter end of the soil moisture continuum. Wetlands are often found between deepwater habitats and rarely or never flooded uplands, but some wetlands occur in seasonally wet (flooded and/or saturated) depressions surrounded by upland.**

rowth to favor those plants that have adapted through various mechanisms (e.g., morphological, physiological, reproductive) for life in water or saturated soils. Although wetlands do include nonvegetated areas such as mudflats, most wetlands have hydrophytic vegetation and hydric soils.

The United States government developed a technically-based manual for identifying and delineating the boundaries of vegetated ("jurisdictional") wetlands (Federal Interagency Committee for Wetland Delineation, 1989). The manual includes technical criteria for identifying wetlands on the basis of hydrophytic vegetation, hydric soils, and hydrology. Several states, including Maine, New Hampshire, New Jersey, Oregon, Pennsylvania, and Vermont, have adopted the manual for identifying wetlands subject to state wetland protection statutes. The government used the manual for identifying wetlands subject to the Clean Water Act from 1989 to 1991. Its use was laden with political controversy. Because the Federal regulators had to use it, this established for the first time a national standard for wetland identification and delineation for the Clean Water Act Program. Misapplications of the manual coupled with changes in Federal policy regarding use of farmed wetlands caused considerable controversy, and eventually Congress forbid the use of the manual by the U.S. Army Corps of Engineers. The Federal government is now using the 1987 Corps manual for wetland delineation (Environmental Laboratory, 1987) for the Clean Water Act Program, until a new manual is produced based on technical recommendations from the National Research Council (1995).

### 13.3 WETLAND CLASSIFICATION

Once identified, wetlands can be further classified as different types. The FWS has developed a classification system for inventorying the nation's wetlands (Cowardin et al., 1979). It is a hierarchical system that groups wetlands according to ecologically similar char-

acteristics. It first divides wetlands and deepwater habitats into five ecological systems: (1) marine, (2) estuarine, (3) riverine, (4) lacustrine, and (5) palustrine (fig. 13.3).

The marine system generally consists of the open ocean and its associated coastline (fig. 13.4). It is most-

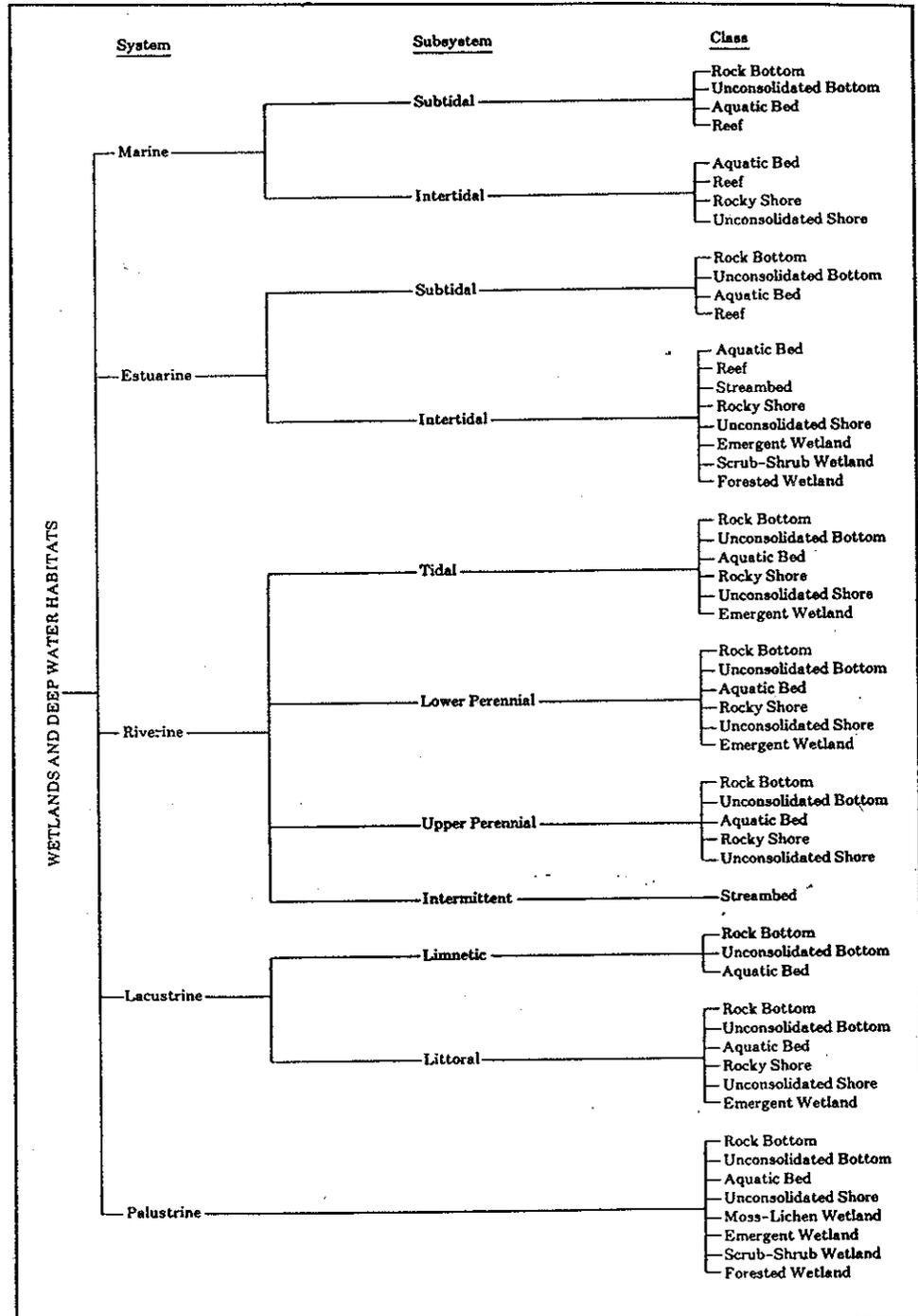


Figure 13.3. Classification hierarchy of wetlands and deepwater habitats, showing systems, subsystems and classes according to Cowardin et al. (1979). The palustrine system does not include any deepwater habitat.

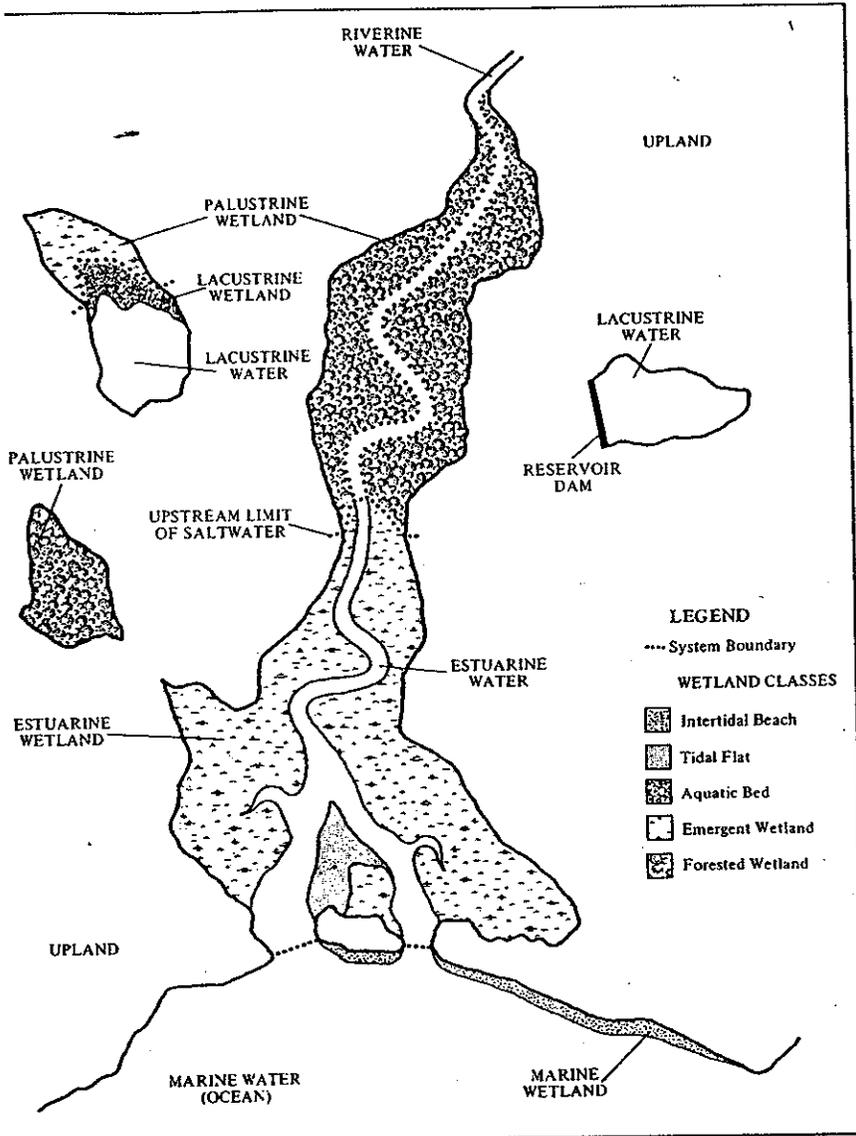


Figure 13.4. Diagram showing major wetland and deepwater habitat systems. (Note: Tidal flat and intertidal beach are now combined into the inconsolidated shore class.)

ly a deepwater habitat system with marine wetlands limited to intertidal areas, such as beaches, rocky shores, and some mollusk, worm, and coral reefs. The estuarine system includes coastal wetlands, such as salt and brackish tidal marshes, mangrove swamps, and intertidal flats, as well as deepwater bays, sounds, and coastal rivers. The riverine system is a system of flowing (lotic) waters and is limited to freshwater river and stream channels. It is mainly a deepwater habitat dominated system, but it includes marshes characterized by non-persistent vegetation along the banks and shallow-water wetlands. The lacustrine system is also largely a deepwater habitat system, represented by standing (lentic) waterbodies such as lakes, reservoirs, and deep ponds. Lacustrine wetlands are generally limited to marshes

with nonpersistent vegetation along the shores, aquatic beds, and shallow bottoms (less than 2.2 m deep at low water). The palustrine system encompasses the vast majority of the country's inland marshes, bogs, and swamps but does not include any deepwater habitat. Within the five systems, wetlands can be identified by various classes, based on the dominant vegetative life form or the composition of the substrate where vegetative cover is less than 30 percent. Stewart et al. (1980) found that this classification system was the easiest of the existing national wetland classification systems to use for wetland map preparation. Mader (1991) claims that this system is the national standard for wetland classification. The Federal Geographic Data Committee has also adopted this system as the standard to be included in the national spatial data transfer standards, which are currently under development. For a general overview of United States wetlands, consult Tiner (1984) and Wilen and Tiner (1993).

### 13.4 WETLAND PHOTOINTERPRETATION

Wetland photointerpretation is not a simple task for several reasons. First, because wetlands occur along a soil moisture continuum between permanently flooded deepwater habitats and drier habitats that are not wet enough to develop prolonged anaerobic soil conditions, most wetlands are not permanently inundated or saturated. Seasonal wetness makes many wetlands, especially those subject to only brief flooding and/or saturation, particularly difficult to identify on photographs or on the ground. Second, wetlands form not only in distinct basin-like depressions but also on broad flats and gently to moderately sloping areas. Third, while many wetlands are represented by distinct plant communities, the vegetation of drier wetlands often is not dramatically different from that of adjacent non-wetlands. This requires field investigators to rely heavily on hydric soil properties for delineation in many situations (Tiner, 1993a). Last, because wetland types vary widely from one region to another, wetland photointerpretation requires knowledge of the local ecology.

Photointerpretation of wetlands is limited by many factors, including

- the degree of wetness of the wetland type (the ease or difficulty of identifying such types on the ground as well as from aerial photographs)

- land use activities (e.g., drainage and haying)
- conditions at the time of photography (e.g., weather and state of vegetation)
- scale of the photography (affects detail and resolution of small wetlands)
- film type and photographic quality
- quantity and quality of available collateral data
- skill and knowledge of the photointerpreter.

The degree of wetness of the wetland type is both limiting and beyond the control of the photointerpreter. While the timing, scale, and quality of photography can be specified, the nature of wetlands establishes the bottom line in determining how and if photointerpretation or other remote sensing techniques can be effectively employed. A general rule is that, the more difficult a wetland type is to identify on the ground, the less likely it will be identified through photointerpretation. Therefore, many temporarily flooded wetlands and most seasonally saturated wetlands (those maintained by a periodically high water table) are virtually impossible to identify consistently through remote sensing techniques. These wetlands are best identified through extensive field inspections with examination of soil properties. Much fieldwork may aid photointerpretation if, in the absence of distinct photographic signatures, it is possible to establish a convention for mapping such wetlands by focusing on landscape positions. These conventions must be based on field observations that validate their reliability.

In any aerial photographic interpretation project, the quality and timing of the photography are prerequisites for accurate interpretation. Overexposed or underexposed film is of little value as are photographs with considerable cloud or snow cover or with extreme flooding. Seasonality of the coverage is a crucial factor in wetland photointerpretation because the hydrologic characteristics and, often, the predominant vegetation largely determine the relative ease or difficulty with which wetlands can be interpreted. The wettest wetlands are usually easiest to interpret from aerial photographs of any season. The drier wetlands are much more problematical, requiring wet season photography for best results. Leaf-off photography facilitates recognition of most forested wetlands (except evergreen swamps), because canopy foliage obscures the wetness of underlying soils. Antecedent weather conditions are important considerations (e.g., heavy rainfall or abnormal dryness prior to the photographic overflights). Extreme flooding as well as extreme droughts create obvious problems for accurate wetland photointerpretation.

In practice, when conducting a comprehensive inven-

tory of all wetland types and when budgetary constraints do not permit acquisition of multiseason photographs, the available photographs predetermine many of the problems to be encountered. If possible, photographs that facilitate detection of the most abundant and difficult-to-identify types should be selected.

Stereoscopic coverage with sufficient overlap is essential for assessing topographic relief and for cover-typing (e.g., separating trees from shrubs based on height). Stereoscopic photographs allow detection of depressional wetlands and facilitate identification of certain sloping wetlands. Stereoscopic coverage also aids in distinguishing shadows from ponded areas, which has posed a serious problem for satellite image processing and for the novice interpreter. Stereoscopic viewing also can help one look around scattered clouds which might otherwise obscure underlying areas (D. Peters, personal communication, 1993).

Photographic scale establishes limits on what can be interpreted (e.g., minimum mapping unit, degree of resolution between different wetland types, and the detail of wetland boundaries). Scales of 1:24,000 and larger are best for local and statewide mapping efforts where precise boundaries of wetlands and identification of small wetlands are required. Several states, including New Jersey, Delaware, and Maryland, have produced regulatory maps for tidal wetlands based on wetland interpretation of large-scale photographs (such as 1:12,000); the maps depict the official boundaries of regulated wetlands. Ongoing inland wetland inventories in Massachusetts and New Jersey are relying on large-scale photographs to produce highly detailed wetland maps for state wetland protection programs, whereas Maryland is using 1:40,000 scale aerial photographs for similar purposes. Large-scale photographs also facilitate identification of discrete plant communities. In contrast, small-scale photographs (e.g., the 1:58,000 NHAP series, app. B) are more useful for regional or national inventories, where less detail is required and where information will be displayed on maps of 1:24,000 scale or smaller. With photography of this scale, general wetland boundaries can be delineated for wetlands larger than 0.4 ha in size and even for smaller conspicuous wetlands (e.g., ponds or pothole wetlands in agricultural lands). Somewhat larger-scale photographs, the 1:40,000 scale NAPP series (app. B) represents a good compromise. Minimum mapping units of about 0.2 ha or less are possible (Tiner and Smith, 1992). While larger scale provides improved resolution and smaller minimum mapping sizes, it greatly increases the cost of the inventory by requiring more photographs (table 13.2) plus additional interpretation and handling time for map production (table 13.3). This level of detail is also better displayed on large-scale maps (e.g., digital orthophoto quarter quads at 1:12,000) than the 1:24,000 U.S. Geological Survey base maps used by the NWI (B. Wilen, personal communication, 1993).

Film type and processing may also create problems

**Table 13.2. Number of aerial photographs providing stereoscopic coverage for a 1:24,000 scale map area at various photographic scales (Tiner and Smith, 1992).**

Photograph Scale	No. Photographs	Photograph Costs(\$)/Map*
1:58,000	3	75
1:36,000	6	150
1:24,000	12	300
1:12,000	42	1050

\*Based on \$25 per color-infrared photograph.

**Table 13.3. Approximate time to produce preliminary wetland maps for interpretations of four different scales of aerial photographs for the Millington, Maryland/Delaware quadrangle (Tiner and Smith, 1992).**

Scale of Source Photos	Effort Required to Prepare Maps* (Hours)	Minimum Mapping Unit** (Acre)
1:58,000	24.2	1
1:36,000	40.25	0.5 - 1.0
1:24,000	87.6	0.25 - 0.5
1:12,000	150.5	0.1 - 0.25

\*Includes data preparation, photointerpretation, quality control, and cartographic transfer of data to base map.

\*\*Dot-sized wetlands may be mapped at each scale, but are not included in these figures. The minimum mapping unit size is based on the smallest mappable polygon at the specified photographic scale.

for wetland photointerpretation. CIR photography is best for identifying vegetated wetlands, such as marshes, swamps, and bogs. Although the optical transmission of water varies with the Secchi depth and other spectral properties, CIR photography generally provides less water penetration than color photography, which is preferred for mapping submerged aquatic beds. Processing also may introduce unexpected problems for wetland photointerpretation. For example, it is not uncommon to find photographs made at different times from the same originals to appear quite dissimilar. Ideally, the inter-

preter should have access to the original photographic transparencies or first-generation prints.

Collateral data and the amount of fieldwork performed may greatly affect the results of a photointerpretation project. Soil surveys are a primary aid in wetland mapping. The quality of soil surveys varies, however, and needs to be taken into account. The availability of any existing wetland maps should also be explored. In the United States, the FWS's NWI maps are the major national source of wetland data, while certain states and local governments have produced or are producing wetland maps to serve regulatory purposes. Any wetland map has limitations based on the methods employed and the nature of the wetlands. Fieldwork is essential to become familiar with the wetlands that occur in a geographic area and their photographic appearance. The time necessary to accomplish this in the field varies regionally and with the type of wetland, with the drier wetlands usually requiring more fieldwork for verification.

Lastly, the skills and knowledge of the photointerpreter are the final ingredient for successful wetland photointerpretation. Good stereovision is required because many wetlands occur in depressional landforms, and classification of wetlands usually requires separating forested wetlands from shrub wetlands by a height threshold. Since CIR and color films are perhaps the most frequently used, good color vision is also required. Wetland photointerpreters must have some knowledge of wetland ecology and wetland identification, and they must be knowledgeable about where wetlands occur in the landscape (not restricted to basins) and, through field inspection, be able to identify the variety of wetland types that occur in project areas. The latter requires basic knowledge of plant identification, hydric soil properties, and hydrology. Field verification is a critical step in any wetland inventory.

### 13.5 PHOTOINTERPRETATION OF SPECIFIC WETLAND TYPES

Given the variety of wetlands and seasonal changes, wetlands are represented by many different photographic signatures. Moreover, a single wetland type may look quite different seasonally, as well as on different photographs. Estuarine wetlands are mostly tidally influenced, salt and brackish marshes (emergent wetlands) dominated by herbaceous (nonwoody) plants, mainly grasses, rushes, and sedges, while inland wetlands are highly varied in terms of predominant vegetation. Inland wetlands are affected by a wider range of hydrologic regimes than coastal wetlands and often occur in less obvious landscape positions. Since these dissimilarities lead to different problems in photointerpretation, the discussion is divided into estuarine (coastal) and palustrine



Figure 13.5. Panchromatic aerial photograph (original scale 1:80,000) of estuarine marshes and barrier islands in southern New Jersey.

inland) sections. The following discussion is an overview and not an exhaustive treatment of the topic.

### 13.5.1 Estuarine (Coastal) Wetlands

Estuarine wetlands occur in low-lying, periodically flooded areas along coastal rivers and embayments, where tidally influenced waters are salty or brackish due to ocean-derived salts (fig. 13.5). Tidal flooding occurs daily in the lower portions of these coastal wetlands. This zone is often called the low marsh, intertidal marsh, or regularly flooded marsh when dominated by herbaceous vegetation. In Florida and other tropical areas, woody vegetation—mangroves, especially red mangrove (*Rhizophora mangle*)—occupy this zone (Tiner, 1993b). Higher portions of coastal marshes are flooded less often than daily and are usually exposed to air for longer periods. This zone is referred to as the high marsh or irregularly flooded marsh.

Since tidal water gradually moves upstream in the estuaries with the incoming rising tide, different marshes within a large estuarine system are in various stages of flooding at a single moment in time. For example, when marshes closest to the ocean are flooded, similar

marshes farthest upstream usually are not. This presents a basic problem for acquisition of low-tide aerial photographs for vast estuarine systems. Moreover, the tidal cycle requires 24 hours and 50 minutes to make a complete cycle (e.g., two high tides and two low tides on the Atlantic Coast), so low tide does not always fall within the optimal time of day for aerial photography. Low-tide photography is required for mapping submerged aquatic vegetation in coastal waters.

Acquiring low-tide photography for such systems requires considerable planning and expense as well as good fortune, because local weather conditions can pose additional problems. Consequently, aerial photographic missions that cover large areas, such as the NHAP and NAPP (app. B), are not synchronized with low tide. Depending on the time of photography, coastal marshes may be in various stages of flooding. If flooding is particularly deep, vegetation may be obscured, making the waterward boundary difficult to define. In some coastal areas with substantial tidal ranges, such as Maine, Oregon, Washington, and Alaska, there are extensive areas of nonvegetated tidal flats. When covered by deep water, these areas cannot be accurately delineated.

When exposed (not flooded), many estuarine wetlands are among the simplest to interpret, for several reasons:

- they may be large, expansive systems lying between conspicuous uplands and deepwater areas, often behind coastal barrier islands and beaches (e.g., between the mainland and the Atlantic Ocean or Gulf of Mexico)
- they are open systems usually dominated by herbaceous vegetation in the temperate regions and, in many cases, are bordered by trees intolerant of salt and brackish water flooding
- in many coastal wetlands, plant communities are relatively monospecific, dominated by conspicuous species such as smooth cordgrass (*Spartina alterniflora*), salt hay grass (*S. patens*), big cordgrass (*S. cynosuroides*), marsh spikegrass (*Distichlis spicata*), black needlerush (*Juncus roemerianus*), black mangrove (*Avicennia germinans*), red mangrove (*Rhizophora mangle*) (Tiner, 1987, 1993b), pickleweed (*Salicornia virginica*) and Lyngby's sedge (*Carex lyngbyei*), which give these wetlands characteristic photographic signatures
- many of the dominant plants grow only in these habitats and not in adjacent uplands
- most estuarine wetlands can be readily interpreted during virtually any season.

### 13.5.1.1 Estuarine Marshes

The waterward and landward limits of the estuarine marshes can often be readily established. It may be more difficult to separate low marsh from high marsh along the Atlantic and Gulf coasts on the high-altitude photographs because smooth cordgrass occurs in both zones. These zones may be separable on summer photographs at the peak of the growing season due to differences in plant height and vigor, but most aerial photographs used for comprehensive wetland inventories, including NHAP photographs, are not acquired at this time. Figure 13.5 shows an example of a northeastern coastal marsh. On the Pacific coast, the low marsh and high marsh are dominated by different species making it more easy to separate these zones through photointerpretation (D. Peters, personal communication, 1993).

Certain prominent plant communities can be recognized on aerial photographs, especially large-scale CIR. Black needlerush is a persistent emergent plant that has a characteristic appearance on CIR and color photographs during any season (fig. 13.6 — see color section). Larger scale photographs improve detection of black needlerush stands, with 1:40,000 scale photographs being significantly better than 1:58,000 scale photographs (J. Hefner, personal communication, 1993). Dense stands of common reed (*Phragmites australis*) or cattails (*Typha angustifolia*, *T. domingensis*) can be interpreted, especially on large-scale photographs. Common reed may have a distinct signature on both panchromatic and CIR films, while circular growth patterns of clonal (vegetatively reproduced) stands of cattail are often evident. Salt flats within the high marsh can be observed as barren sandy areas or as areas vegetated by glassworts, pickleweed (*Salicornia* spp.) or saltwort (*Batis maritima*), depending on plant density. The high reflectance of sand may dominate the reflectance of vegetation, thereby obscuring any vegetative signature.

### 13.5.1.2 Mangroves

Black mangrove can be separated from red mangrove on large-scale photographs owing to the observed morphological differences in growth forms. Patterson (1986) reported that 1:2000 to 1:12,000 scale CIR photography was best for separating various mangrove communities. The characteristic texture and deep-red signature of the fringing mangroves and the white-capped texture and pink signature of the mixed mangrove community could be easily recognized at the larger scale. On high-altitude photographs, these differences are not apparent, and it is not possible to separate the two species (J. Hefner, personal communication, 1988). Patterson (1986) noted that the fringing mangrove community could not be detected on 1:60,000 scale CIR photographs owing to its narrow width (about 22 m); it merged with the adjacent mixed mangrove community at this scale.

### 13.5.2 Palustrine (Inland) Wetlands

Palustrine or inland wetlands occur beyond the reach of saline ocean waters. They may be divided into four general types based on the dominant life form of the vegetation: (1) aquatic bed, (2) emergent (dominated by herbaceous plants), (3) scrub-shrub (dominated by woody plants less than 6.6 m high), and (4) forested (dominated by woody plants 6.6 m or taller).

Although the difference in vegetation is a prime factor in photointerpretation, in general, the wetter the wetland, the easier it is to identify, regardless of vegetative cover, provided the photographs are acquired during an optimal time period. The optimal time period varies among wetland types, however. For example, aquatic beds are best identified on photographs acquired at the peak of the growing season when vegetation can be observed floating on the surface or submerged (in clear waters). This is also true for many emergent wetlands although not all. The boundaries of prairie pothole marshes are best delineated when the basins are filled with water, yet this obscures the different vegetation zones comprising individual potholes. Deciduous forested wetlands are best observed on leaf-off photographs taken during the spring, when water tables are usually highest and saturated or flooded soils can be observed beneath the canopy. For dense, evergreen wetland forests, there is no optimal time, since leaves are not shed annually.

#### 13.5.2.1 Aquatic Beds

Aquatic beds, characterized by floating and floating-leaved species (e.g., water lilies, *Nymphaea* spp.), are obvious and readily identified on late spring, summer, and early fall photographs. They are usually missed when early spring photographs (including pre-growing season) are used, yet they are included within the boundaries of their associated open waterbodies, which are easily mapped. In some areas where there are strong correlations between the occurrence of aquatic beds and certain hydrologic regimes, it may be possible to establish mapping conventions to identify these beds without actually seeing them on the photographs. This has been done by the FWS's NWI in the Prairie Pothole region of the upper Midwest (C. Elliott, personal communication, 1993).

Submerged aquatic vegetation, especially that in deeper water, usually requires aerial photography with better water penetration than CIR. As noted, color film is preferred. Photographs acquired during the peak of the growing season, showing maximum bed size, are best for interpretation. In the Northeast, August to early October photographs are optimal, but in Florida, photographs taken at any time may be used (V. Carter, personal communication, 1993). Detecting different species is generally impossible (see chap. 17, sec. 17.6.1).

Knowledge of local systems gained through fieldwork is necessary to define species. Periods of high turbidity must be avoided when acquiring aerial photographs for mapping submerged aquatic vegetation.

### 3.5.2.2 Emergent Wetlands

Emergent wetlands include marshes, wet meadows, herbaceous fens, wet tundra, prairie potholes (in the upper Midwest), and certain playas (in the Southwest). Marshes are usually among the most easily recognized inland wetlands. Topographic position, the smooth texture of the vegetation, and the close relationship to water (i.e., many marshes are associated with a permanent water body) are the major interpretive elements (fig. 13.7). Beaver-influenced marshes are easily recog-

nized by the presence of beaver dams and/or lodges and dead trees in open water. Marshes affected by muskrats can also be interpreted: their lodges and eat-out areas are recognizable at scales as small as 1:40,000 and 1:58,000. Herbaceous fens occur in boreal regions, such as Minnesota and Maine, as well as in high-altitude temperate areas, such as the southern Appalachians. They are often observed as emergent wetland patches within larger shrub-bog wetland complexes.

Certain plant species may be best observed when flowering. Balogh and Bookhout (1989) obtained color photographs of purple loosestrife (*Lythrum salicaria*) when it was flowering in July and August. Using 35-mm color transparencies, they were able to locate 213 sites containing this undesirable invader of freshwater marshes and meadows in four Ohio counties. Frazier and Moore (1993) recommend using color slides at scales of 1:5000 or larger for detecting individual flowering plants of purple loosestrife when designing successful eradication programs. Other dominant flowering herbs that characterize certain marshes may also be detected following these or similar methods. These plants may include the spring-blooming marsh marigold (*Caltha palustris*), the summer-blooming rose mallows (*Hibiscus spp.*) and late-summer-blooming bur-marigold (*Bidens laevis*). Stands of wild rice (*Zizania aquatica*) may be similarly observed.

Wet meadows often occur in agricultural areas, including pastures and rangeland, and may be found in isolated depressions, on gentle groundwater seepage slopes, or along narrow streams. They are best observed on spring photographs that show saturated soils due to the seasonally high water table. Human impacts, such as mowing and irrigation, plus animal grazing, make identification of many wet meadows difficult. For example, distinguishing wet pastures (wetlands) from moist pastures (uplands) in irrigated regions, such as Montana, Nevada, Wyoming, and Utah, can be problematic (C. Elliott, personal communication, 1993; D. Peters, personal communication, 1988). In Alaska, distinguishing between moist tundra (wetland) and alpine tundra (non-wetland) can be very difficult. However, subtle tonal differences along the topographic gradient can be detected by a skilled interpreter (J. Hall, personal communication, 1988).

Temporarily flooded emergent wetlands may contain 0.3 m or 0.7 m of water for a week or more in the spring, but by

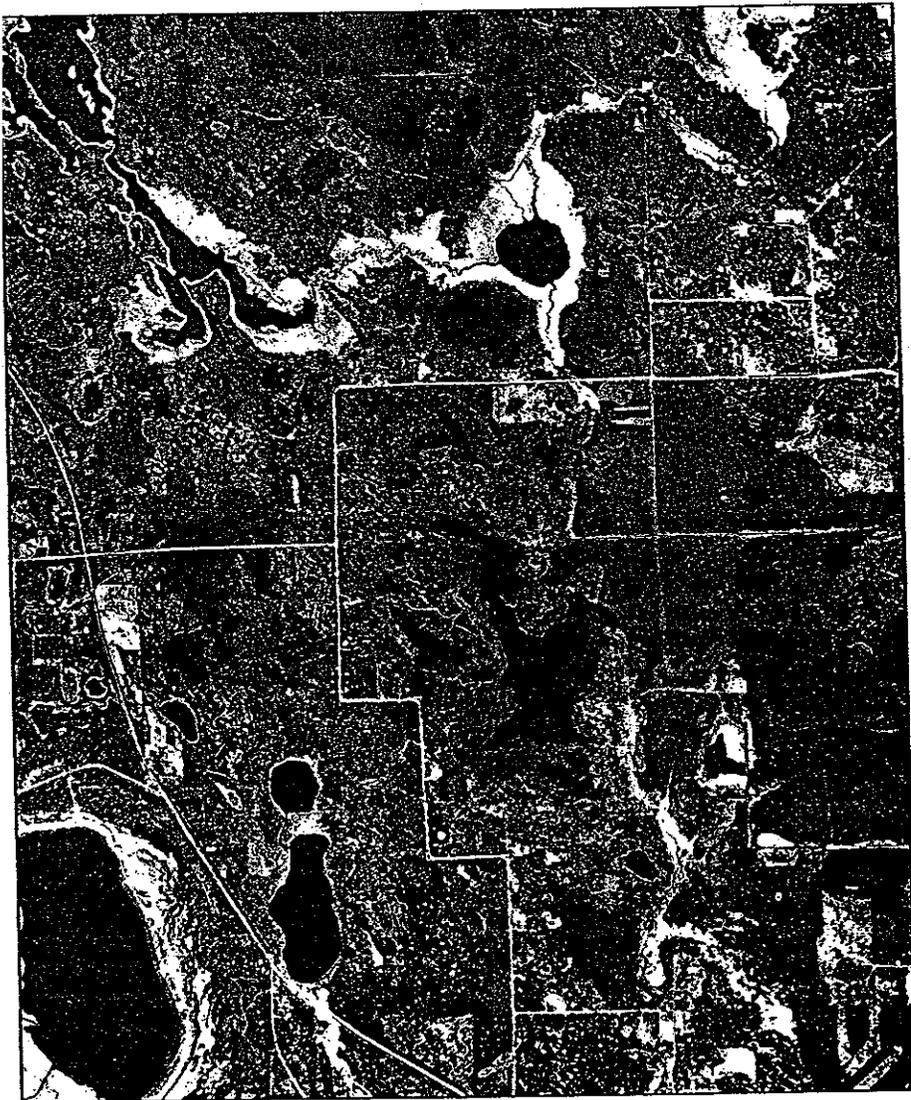


Figure 13.7. Panchromatic aerial photograph (scale 1:80,000) of palustrine marshes along streams and lakes (appear white) and palustrine forested bogs (smooth, dark gray) in Minnesota.

late summer, they are usually dry. Many of these wetlands are tilled earlier in the year and planted with crops. The absence of surface water for most of the year and the cultivation makes these wetlands extremely difficult to identify. Early spring photography may capture these wetlands in their flooded or saturated condition, which would facilitate their identification. Unfortunately, most available photography does not reflect these conditions. Considering landscape position and conducting sufficient fieldwork are necessary ingredients for successful photointerpretation of these wetlands. Collateral data, such as local soil surveys, may also help.

The presence of drainage structures (e.g., ditches and tile drains) confuses wetland identification on photographs as well as on the ground. In these cases, examination of photographs from several years—during normal, wet, and/or dry years—facilitates wetland detection. The USDA follows this approach for identifying farmed wetlands and prior-converted croplands (mostly former wetlands, now effectively drained).

Other difficult-to-identify emergent wetlands include pitcher-plant bogs of the southeastern United States. The bogs occupy varied positions on the landscape ranging from depressions to adjacent sloping hillsides. Because these wetlands lack standing water and a distinctive appearance, they look similar to adjacent uplands (J. Hefner, personal communications, 1988).

Prairie potholes are glacially formed depressional wetlands characteristic of the upper Midwest (the Dakotas and western Minnesota). The wetlands of this region, known for its wide-ranging rainfall patterns, can experience a marked change in plant species composition over a relatively short time period, sometimes from year to year and certainly within two or three years (C. Elliott, personal communication, 1993). For example, wetland basins can change from semipermanently flooded cattail marshes to tilled cropland. In dry years and seasons, the limits of the pothole basins are more difficult to identify, because the drier portions of these wetlands are often tilled and cultivated at these times. Consequently, delineation of the basins is best performed on photographs acquired when the basins are filled with water.

Prior to mapping prairie potholes for the NWI Project, the FWS had special photographic missions flown when the basins were filled. It took several years to acquire these photographs, but they proved most useful for wetlands mapping (fig. 13.8 — see color section). In the larger potholes, there is a distinct vegetation pattern associated with degrees of wetness or water regimes. In the center, the deeper potholes have a permanently flooded zone where aquatic beds may predominate. This zone is fringed by emergent vegetation and aquatic beds in a semipermanently flooded zone. In the larger basins, zones of seasonally flooded and temporarily flooded vegetation are also often present. These concentric bands of vegetation are most apparent during the growing season.

Smaller basins may be characterized by one or two types of emergent wetland (e.g., temporarily flooded marsh or meadow).

### 13.5.2.3 Scrub-Shrub Wetlands

Scrub-shrub wetlands include bogs and pocosins dominated by ericaceous shrubs and other wet areas dominated by true shrubs or tree saplings. Some of these wetlands have characteristic plant species that may be easily identified, such as leatherleaf (*Chamaedaphne calyculata*), alders (*Alnus* spp.), buttonbush (*Cephalanthus occidentalis*), willows (*Salix* spp.), swamp cyrilla (*Cyrilla racemiflora*), fetterbush (*Lyonia lucida*), shrubby St. John's-worts (*Hypericum* spp.), cranberries (*Vaccinium* spp.) and meadowsweets (*Spiraea* spp.). Leatherleaf bogs are particularly evident on spring CIR photographs, appearing as a smooth, orange tone (fig. 13.9 — see color section). Evergreen shrubs of the pocosins (coastal North Carolina) display a smooth, red tone on fall, winter, or early-spring CIR photographs (J. Hefner, personal communication, 1988).

Mixed shrub communities in temporarily flooded wetlands are difficult to interpret as are wet alder thickets in more northern areas. Speckled alder (*Alnus rugosa*) is fairly well restricted to wetlands in the southern part of its range, which facilitates identification of this wetland type; however, farther north (as in northern and eastern Maine), speckled alder becomes less wetland-specific. It can be found in large numbers on uplands, creating difficulty for wetland photointerpretation. Here topography and existing soils information from local soil surveys are often considered in separating alder wetlands from dry alder areas. The same situation applies to red alder (*Alnus rubra*) in the Pacific Northwest (D. Peters, personal communication, 1993).

In the southwestern United States, honey mesquite (*Prosopis juliflora*) dominates certain riparian habitats. It grows from the water's edge (on sand bars) to floodplain terraces and adjacent hillsides. To separate the wet sites from the dry sites, one must consider plant size, plant density, and topography. The wetter areas are usually covered by a dense growth of taller individuals (W. Hagenbuck, personal communication, 1988).

### 13.5.2.4 Forested Wetlands

Forested wetlands are dominated by deciduous and/or evergreen trees. Tiner (1990) describes the use of high-altitude aerial photography for inventorying forested wetlands in the United States. Much of the following discussion is based on this paper.

For most of the conterminous United States, early-spring photographs are best for mapping forested wetlands. At this time, the areas should be free of ice and snow, the water table should be closest to the surface, new leaves have not yet developed on deciduous trees,

and surface-saturated or inundated soils are visible from above (fig. 13.10 — see color section). Fall photography may also have deciduous trees in leaf-off condition, but it is normally not as useful as spring photography for forested wetland detection because water tables are usually rising and recently fallen leaf litter may obscure surface saturation. Nevertheless, fall photography acquired when tree leaves have changed colors may facilitate identification of certain forested wetland communities, such as larch (*Larix laricina*, *L. occidentalis*) wetlands in the boreal regions and bald cypress (*Taxodium distichum*) in the Southeast. Larch leaves, for example, turn yellow in the fall, so leaf color in combination with the tree's pyramid shape make it easy to identify on panchromatic as well as CIR photographs. Leaves of bald cypress turn an orange-like color that may give a unique spectral signature to the species in the fall. Red maple swamps in the Northeast may also be readily observed on early fall photographs when the leaves are red on the swamp trees and green on trees in adjacent uplands and other forested wetlands.

When leaf-off photographs are not available, even the wettest deciduous forested wetlands may be difficult to identify. This is especially a problem in regions where weather or sun angle favor the acquisition of summer coverage, such as the northwestern United States and Alaska. Frequent fog and rain in the Northwest (west of the Cascades) generally preclude acquiring leaf-off photographs for large areas. In Alaska, the low sun angle in spring and fall causes extensive shadows that complicate photointerpretation; the extended snow cover virtually prevents large-area acquisition of usable leaf-off photographs (J. Hall, personal communication, 1988). These conditions have posed a significant limitation on the use of national aerial photography programs and the Alaska High-Altitude Photography Program (AHAPP) for wetland mapping in affected areas. For smaller projects, however, it is possible to acquire leaf-off photographs.

When using leaf-on photographs, one must usually rely on features other than saturated or flooded soils to separate deciduous forested wetlands from deciduous forested uplands. Topography plays a particularly important role. Forested areas at low positions on floodplains may be identified as forested wetlands, especially if collateral information indicates hydric soils in the area. In all cases, fieldwork must be conducted to identify a general contour at which wetland ends and upland begins within a representative sample of drainage basins in the project area.

Recognizing that wetlands also occur on slopes with hillside seepage, one must also consider whether the forested slope is wetland. For example, along the Pacific Coast, west of the Cascade Mountains, forested wetlands of red alder (*Alnus rubra*) commonly occur on seepage slopes; in the Pacific Northwest, however, red alder dominates both wetland and upland slopes. Separating the wet alder from the dry alder on leaf-on photographs is

difficult. In some cases, there are canopy openings where wetland understory vegetation (e.g., sedges and willows) or beaver dams may be observed. In the absence of these openings, distinguishing the red alder wetlands from the red alder uplands remains problematic. As one moves south into southern Oregon and northern California (where the climate is much drier than in the Pacific Northwest), red alder is restricted to wetlands including hillside seeps. Thus, red alder communities are only wetland communities here and can be identified as such (D. Peters and B. Harrison, personal communication, 1988). This situation is similar to the speckled alder (*Alnus rugosa*) shrub wetlands on the East Coast, mentioned earlier in this chapter. In general, it is much more difficult to interpret all types of deciduous forested wetlands with leaf-on photographs than leaf-off photographs.

Temporarily flooded and seasonally saturated, forested wetlands are the most difficult type of deciduous forested wetlands to recognize, regardless of the photographs used. In fact, wetlands of these types are often difficult to identify on the ground, because many associated plants are also found in uplands. Temporarily flooded wetlands commonly occur on floodplains, where they are flooded for brief periods during the growing season (usually less than two weeks). They also occur in isolated depressions where they are subject to saturation from a seasonally high water table or to ponding from precipitation (fig. 13.11 — see color section). Seasonally saturated wetlands occur along the margins of many seasonally flooded wetlands in areas of low relief and in broad interstream divides typical of the Atlantic Coastal Plain. The latter sites may be characterized by hardwood and/or pine flatwoods, where loblolly pine (*Pinus taeda*) is a dominant species. Since saturated soils are not usually observed unless leaf-off photographs are acquired at a time of surface saturation or inundation, one must rely more on topographic position (e.g., low positions on the floodplain or interstream flats), drainage patterns, soil survey reports, and fieldwork. Specific field studies are conducted to demarcate wetland/nonwetland boundaries within representative floodplains and other positions on the landscape. These relationships may then be applied to a wider range of similar drainage basins. This is vital to the success of any photointerpretation project.

Temporarily flooded, forested wetlands are difficult enough to identify in their natural state, but the hydrology of many of these wetlands have been modified to varying degrees. This situation is particularly widespread in the Southeast and the West where dams, levees, channelization projects, and stream diversions often prevent seasonal flooding. In these cases, the interpreter must decide whether the hydrology has been altered to the extent that the area is no longer wetland.

In the western United States, cottonwoods (*Populus* spp.) are the dominant trees in temporarily flooded, riparian wetlands and former wetlands that are no longer flooded. The wetland cottonwood-community often

has a denser canopy and a thicker understory than the nonwetland (relict) cottonwood-community (C. Elliott, personal communication, 1988). Photointerpretation of the extremes is relatively easy, but there are many intergrades. Moreover, there is considerable debate over whether all or only part of the riparian habitat along the rivers and streams is wetland. The wooded riparian corridor is, however, relatively easy to identify in arid regions (fig. 13.12 — see color section), though separating the wetland from nonwetland components is often difficult, especially in hydrologically-altered systems.

Dense evergreen forested wetlands are among the most difficult to identify, although certain types, like Atlantic white cedar (*Chamaecyparis thuyoides*), have characteristic signatures and are easily identified (fig. 13.13 — see color section). Because evergreens do not lose their leaves each year, their foliage prevents observation of saturated soils, at least through dense stands which are extremely common. Where the canopy is more open, wetland detection is aided by observing saturated soils (fig. 13.10 — see color section) or characteristic understory vegetation. Along the coastal plain of North Carolina, pocosin forested wetlands, dominated by pond pine (*Pinus serotina*), may be recognized by their characteristic smooth-textured shrub understory (J. Hefner, personal communication, 1988). In the Pacific Northwest, lodgepole pine (*Pinus contorta*) wetlands have a dense understory of willows and sedges in contrast to the more sparse understory of lodgepole pine uplands (B. Harrison, personal communication, 1988). In the Northeast, black spruce (*Picea mariana*) wetlands may have openings of leatherleaf (an easily interpreted evergreen shrub on CIR photographs) or may occur contiguous with and at approximately the same elevation as leatherleaf, bogs, and other wetlands (fig. 13.9 — see color section).

The biggest problem in interpreting evergreen forested wetlands concerns dense, evergreen stands that occur both in wetlands and adjacent uplands. The height of the canopy may reflect a difference in wetness. In Alaska, for example, wetland evergreens, including lodgepole pine (*Pinus contorta*), are somewhat shorter than upland evergreens (about 20 m vs. 35 m tall) in certain areas (J. Hall, personal communication, 1988). Evergreens growing in seasonally flooded wetlands may also show signs of water stress, as evidenced by the yellowing (chlorosis) of some of their leaves. In other cases, evergreen forested wetlands may be dominated by a species that actually looks different from evergreens on the adjacent uplands, such as Atlantic white cedar which occurs only in wetlands, or by species that occur in both wetlands and adjacent upland, such as pitch pine (*Pinus rigida*) in the Pine Barrens of southern New Jersey (fig. 13.13 — see color section). Here, it is relatively easy to separate the white cedar stands from the pitch pine forests, but separating pitch pine wetlands from pitch pine uplands is more difficult. The saturated soils of the wetter pines may be evident in canopy openings, but

many pitch pine wetlands are only temporarily flooded or seasonally saturated, and their soils are not usually saturated at the surface. Again, landscape position and available soils information must be considered and field studies conducted. This approach is also taken in the southern Appalachians, where red spruce (*Picea rubens*) and rose-bay rhododendron (*Rhododendron maximum*) extend from wetlands into adjacent uplands (J. Hefner, personal communication, 1993). A similar problem is encountered where the dominant life form of the upland forest resembles the dominant life form of the wetland forest, such as white spruce (*Picea glauca*) and black spruce, respectively, in the Northeast and Alaska.

In the southern United States, many wetlands are used for silviculture, and pines are planted in wetlands. Some of these wetlands are drained while others are not. These pines look much like upland pines in that they form dense well-ordered stands (J. Hefner, personal communication, 1988). Consequently, the photointerpreter must again consider topographic position, consult available soils information, and perform field checks. This approach provides a useful, generalized wetland boundary for planning purposes, but one must recognize that the boundaries are not exact. Also, one must be aware that some types of evergreen forested wetlands are difficult to identify even in the field, and that extensive soil sampling is required to determine the limits of hydric soil. This is true as well for both temporarily flooded and seasonally saturated wetlands in general.

In some parts of the United States (e.g., southeastern Alaska and Hawaii), rainforests make photointerpretation of forested wetlands extremely difficult. In southeastern Alaska, topographic features such as drainage ways, depressions, and level terrain can be used to assist in identifying evergreen forested wetlands (J. Hall, personal communication, 1988). In Hawaii, the NWI Project used leaf-on panchromatic photographs. At higher elevations, areas were identified as mixes or complexes of forested wetland and forested upland, depending on the recognition of a saturated emergent wetland appearance within the forests and reconnaissance level soil surveys (D. Peters, personal communication, 1988, 1993). Consequently, photointerpretation of forested wetlands in rain forest regions is usually conservative.

## 13.6 MONITORING WETLAND CHANGES

Losses and gains in wetlands can also be detected on aerial photographs. Aerial photographic interpretation has provided a convenient and cost-effective means of analyzing wetland changes. This information is useful for assessing wetland status and the effectiveness of government wetland programs and policies.

Many wetland trend studies have utilized aerial pho-

tography. The FWS is using aerial photographic interpretation to produce data for periodic reports to Congress on the status and trends of the nation's wetlands, as required by the Emergency Wetlands Resources Act of 1986. To date, two national trends studies have been completed: one covering the mid-1950s to mid-1970s (Frayer et al., 1983; Tiner, 1984) and the other covering the mid-1970s to the mid-1980s (Dahl and Johnson, 1991; Frayer, 1991; Tiner, 1991). The next update was scheduled for the year 2000, but will be postponed due to budget cuts. National estimates of wetland area by major type (estuarine emergent, estuarine scrub-shrub, palustrine forested, palustrine emergent, and palustrine scrub-shrub) were generated along with estimated changes (losses/gains) during the intervening period by interpreting wetland status and changes in several thousand 10.35 sq km plots. Following similar procedures, intensified regional wetland trend studies have been conducted for the following areas: Middle Atlantic States (Tiner and Finn, 1986), Chesapeake Bay watershed (Tiner et al., 1994), Central Valley of California (Frayer et al., 1989), and Florida (Frayer and Hefner, 1991). Hefner and Brown (1984) used data from the 1950s to 1970s national trends study to report on wetland trends in the Southeast. In the FWS's Northeast region, numerous wetland trends studies have been completed for particular geographic areas including Maryland's Anne Arundel and Prince Georges counties (Tiner and Foulis, 1991, 1992), southeastern Massachusetts (Tiner and Zinni, 1988), central Connecticut (Tiner et al., 1989) and New Jersey's Cape May County (Smith and Tiner, 1993). These studies analyzed wetland trends on a 7.5-minute quadrangle-map basis, rather than statistically estimating trends from 10.35 sq km sample plots.

The FWS has worked with Pennsylvania's Coastal Zone Management Program to establish an operational monitoring program for assessing trends in Pennsylvania coastal wetlands along Lake Erie and the Delaware River. Interpretation of periodically acquired, 1:36,000 scale aerial photographs has proved to be an invaluable tool for investigating potentially illegal filling and other alterations of wetlands within the state's coastal zone.

Conventional photointerpretation techniques have also been successfully employed to monitor changes in sea grass beds. In Chesapeake Bay, researchers used 1:24,000 scale panchromatic and color photographs to detect changes in estuarine aquatic beds from 1978 to 1987 (Orth et al., 1990). NOAA's National Marine Fisheries Service is using similar techniques to identify submerged aquatic beds in North Carolina's estuaries and in other coastal states (Ferguson and Wood, 1990).

With larger scale photographs, smaller wetland changes can be detected and delineated more accurately. In a trend analysis of tidal wetlands within a coastal embayment on Long Island, New York, Tiner (1987b) identified wetland changes smaller than 0.04 ha on 1:12,000 scale CIR photographs. Conspicuous changes of

this size could be detected on 1:36,000 scale CIR photographs, which were available for the study, but these changes could only be mapped as dots on a photographic overlay. More importantly, many of these small changes might have been overlooked if the 1:12,000 scale photographs had not been examined.

## 13.7 THE NATIONAL WETLANDS INVENTORY PROJECT

The FWS, through its NWI Project, is the United States leader in wetland photointerpretation and mapping. As described, in producing NWI maps, the FWS employs conventional photointerpretation techniques, using photographs at scales from 1:40,000 to 1:80,000, and for the earliest maps, at 1:133,000.

Prior to 1980 the best available, high-altitude photographs were 1:80,000 scale panchromatic, acquired by the U.S. Geological Survey (USGS) for orthophotoquad mapping (figs. 13.5 and 13.7). NWI relied on these photographs for most early inventories (table 13.4). The minimum mapping unit for wetlands was 1.2 ha to 2.0 ha.

In 1980 the USGS and other agencies established NHAP, which until 1987, acquired 1:58,000 CIR photographs for much of the country (app. B). These photographs served as the primary data source for most of the NWI work completed to date (figs. 13.9, 13.12, and 13.13; table 13.2). In 1978, state and federal agencies formed the AHAPP to acquire photography for Alaska. The NWI has used this 1:60,000 scale photography for most of its mapping activities in Alaska. In some areas (e.g., the Prairie Pothole region), NWI had the National Aeronautics and Space Administration (NASA) fly 1:65,000 scale CIR photography for special wetland mapping projects (fig. 13.8). The larger scale and CIR emulsion allowed for better detection of smaller wetlands as well as improved mapping of wetland boundaries.

With NHAP photography, the minimum mapping unit for polygons ranges between 0.4 ha and 2.0 ha or smaller in the case of conspicuous wetlands such as ponds and potholes which may be consistently mapped down to 0.1 ha. Conspicuous, dot-sized wetlands below this size are mappable. For example, in the Devils Lake region of North Dakota, NWI maps have identified an average of more than 460 individual dot-sized wetland basins (prairie potholes) per 1:24,000 scale map, with some inventoried potholes being as small as about 8 m in diameter (C. Elliott, personal communication, 1993). The 1:58,000 scale photography was practical and cost-effective for the national inventory, since, on average, only two photographs plus stereopairs were required to cover the working unit, a 1:24,000 scale map. The main limitation of this scale, however, is the minimum mapping unit, which is considered too large by some users, notably regulatory personnel and highway planners.

**Table 13.4. Source photographs for the NWI work completed as of 1988. CIR - color infrared, BW - black-and-white panchromatic, and C - color; photographic scales are shown in thousands (e.g., 1:58 is 1:58,000). Photograph types are listed in approximate order of significance for mapping wetlands to date.**

STATE	PHOTOGRAPHS USED FOR NWI	STATE	PHOTOGRAPHS USED FOR NWI
ALABAMA	1:58 CIR, 1:65 CIR, 1:80 CIR, 1:60 CIR, and 1:80 BW	MISSOURI	1:58 CIR, 1:80 BW, 1:130 CIR, and 1:120 CIR
ALASKA	1:65 CIR, 1:60 CIR, 1:120 CIR, 1:62 CIR, 1:110 CIR, and 1:63 CIR	MONTANA	1:58 CIR
ARIZONA	1:120 BW and 1:58 CIR	NEBRASKA	1:58 CIR, 1:65 CIR, 1:80 BW, 1:130 CIR, 1:111 CIR, 1:45 CIR, and 1:65 BW
ARKANSAS	1:58 CIR, 1:80 BW, 1:120 CIR, 1:65 CIR, 1:130 CIR, and 1:123 CIR	NEVADA	1:58 CIR
CALIFORNIA	1:58 CIR, 1:80 BW, 1:130 CIR, 1:65 CIR, and 1:120 CIR	NEW HAMPSHIRE	1:58 CIR and 1:80 BW
COLORADO	1:80 BW	NEW JERSEY	1:80 BW
CONNECTICUT	1:80 BW	NEW MEXICO	1:58 CIR, 1:80 BW, 1:120 CIR, 1:110 CIR, and 1:120 BW
DELAWARE	1:58 CIR and 1:80 BW	NEW YORK	1:58 CIR, 1:80 BW, 1:80 CIR, and 1:120 CIR
FLORIDA	1:58 CIR, 1:80 CIR, 1:65 CIR, 1:69 CIR, 1:80 C, 1:50 CIR, 1:20 BW, 1:24 C, 1:76 CIR, 1:6 CIR, and 1:132 CIR	NORTH CAROLINA	1:58 CIR, 1:80 BW, and 1:120 CIR
GEORGIA	1:58 CIR, 1:80 CIR, 1:65 CIR, 1:80 BW, 1:130 CIR, 1:76 CIR, 1:132 CIR, and 1:120 CIR	NORTH DAKOTA	1:65 CIR
HAWAII	1:48 BW, 1:50 BW, 1:55 BW, 1:40 BW, and 1:41 BW	OHIO	1:80 BW, 1:58 CIR, and 1:120 C
IDAHO	1:58 CIR and 1:24 C	OKLAHOMA	1:58 CIR, 1:65 CIR, and 1:50 CIR
ILLINOIS	1:58 CIR	OREGON	1:58 CIR, 1:80 BW, 1:45 BW, 1:130 CIR, and 1:124 CIR
INDIANA	1:58 CIR, 1:80 BW, and 1:120 CIR	PENNSYLVANIA	1:58 CIR, 1:80 BW, and 1:36 CIR
IOWA	1:58 CIR	RHODE ISLAND	1:80 BW
KANSAS	1:80 BW and 1:58 CIR	SOUTH CAROLINA	1:58 CIR, 1:80 BW, 1:120 CIR, 1:129 CIR, 1:132 CIR, 1:125 CIR, 1:126 CIR, 1:128 CIR, 1:133 CIR, and 1:67 CIR
KENTUCKY	1:58 CIR	SOUTH DAKOTA	1:65 CIR
LOUISIANA	1:58 CIR, 1:65 CIR, 1:130 CIR, 1:60 CIR, 1:120 CIR, 1:123 CIR, and 1:24 CIR	TENNESSEE	1:58 CIR, 1:80 BW, 1:120 CIR, and 1:120 C
MAINE	1:80 BW, 1:127 CIR, and 1:58 CIR	TEXAS	1:65 CIR, 1:58 CIR, 1:80 CIR, 1:80 BW, 1:123 CIR, and 1:110 CIR
MARYLAND	1:58 CIR and 1:80 BW	UTAH	1:58 CIR, 1:65 CIR, 1:80 CIR, and 1:80 BW
MASSACHUSETTS	1:80 BW and 1:58 CIR	VERMONT	1:80 CIR
MICHIGAN	1:80 BW, 1:58 CIR, and 1:120 CIR	VIRGINIA	1:58 CIR and 1:80 BW
MINNESOTA	1:80 BW, 1:58 CIR, and 1:65 CIR	WASHINGTON	1:58 CIR, 1:80 BW, 1:130 CIR, 1:60 CIR, 1:120 BW, and 1:45 BW
MISSISSIPPI	1:58 CIR, 1:130 CIR, and 1:120 CIR	WEST VIRGINIA	1:58 CIR and 1:80 BW
		WISCONSIN	No work to date
		WYOMING	1:58 CIR, 1:65 CIR, and 1:80 BW

In 1987, NHAP was replaced by NAPP, which is providing 1:40,000 scale CIR photographs or black-and-white photographs made from the CIR photographs (app. B). Although the increased number of photographs per map sheet will increase wetland mapping costs, NAPP photographs are now the best available source of recent wetland data and are the primary data source for the NWI (fig. 13.6). With this photography, especially the CIR photographs, wetlands smaller than 0.4 ha are usually mapped. Unfortunately, much of the coverage was acquired during the leaf-on season. This greatly limits its use for wetland mapping, especially for shrub and forested wetlands. Updated NWI maps have been prepared for several areas, including Cape May County, New Jersey (Smith and Tiner, 1993), southeastern Virginia, and coastal South Carolina, where the NAPP photographs served as the primary data source. In some cases, the NAPP photographs were used to update NWI maps without required detailed delineations on the 1:40,000 photographs. NAPP photographs were interpreted on a Stereo Zoom Transfer Scope (chap. 2), and changes in wetland boundaries, types and improved linework were transferred directly to the existing NWI map. This significantly reduced the photointerpretation effort and associated costs for updating and improving the quality of NWI maps.

In conducting the inventory and preparing the maps, the NWI undertakes the following steps:

1. Review aerial photographs to identify obvious wetland types, typical wetlands, and problematical areas (i.e., wetland vs. upland, disturbed areas, and classification questions—cover types, water regimes, etc).
2. Select sites and a route for field checking representative wetlands, obvious wetland types and, especially, problematical areas.
3. Visit field sites (usually one or two 1:100,000 scale map sheets per week of fieldwork, depending on wetland density and complexity) and collect site-specific data to resolve photointerpretation questions.
4. Review field trip results by stereoscopically viewing inspected sites on aerial photographs to become more familiar with the appearance and diversity of wetlands in the study area.
5. Perform stereoscopic photointerpretation of the study area following NWI standard conventions (U.S. Fish and Wildlife Service, 1987a), delineate wetland boundaries on photographic overlays, classify each wetland polygon according to the official wetland classification system (Cowardin et al., 1979), and consult

existing collateral information (such as soil survey reports) as needed.

6. If necessary, before finalizing the photographic overlays, conduct a follow-up field trip to resolve new problems that arose during photointerpretation.
7. Perform quality control of interpretations at regional and national levels. (Regional quality control involves reviewing every interpreted photograph for possible additions, deletions and misclassifications. This step is performed at the FWS Regional Offices. National consistency quality control includes random checking of interpreted photographs to insure compliance with standards for classification and delineation. This work is performed at the NWI National Headquarters in St. Petersburg, Florida.)
8. Prepare draft 1:24,000 scale wetland maps (or 1:63,360 scale maps for Alaska) following NWI cartographic conventions (U.S. Fish and Wildlife Service, 1987b).
9. Coordinate interagency (federal and state) review of draft maps and conduct field checking (depending on available funding) to ensure overall map accuracy.
10. Prepare edited draft map for final map production.
11. Produce final NWI maps (fig. 13.14). (NWI maps can be ordered by calling 1-800-USA-MAPS; maps are also available from NWI map distribution centers in 39 states. Digital map data are also available for many areas through the Internet.)

These procedures have generally permitted the NWI to achieve a high level of mapping accuracy. For example, evaluations in Massachusetts and Vermont showed map accuracies (wetland vs. upland) of 95 percent and 91 percent, respectively, while the accuracy of classifications of individual types was somewhat lower (Swartwout et al., 1981; Crowley et al., 1988). These accuracies, however, may not be valid for other areas or for certain types of wetlands. For evergreen forested and seasonally saturated wetlands in the Northeast, the NWI maps may be expected to have lower accuracies, especially where field checking was not extensive. Lower accuracies may also be likely for forested wetlands in the Pacific Northwest (D. Peters, personal communication, 1993). More intensive fieldwork during photointerpretation and draft map review should increase mapping accuracy.

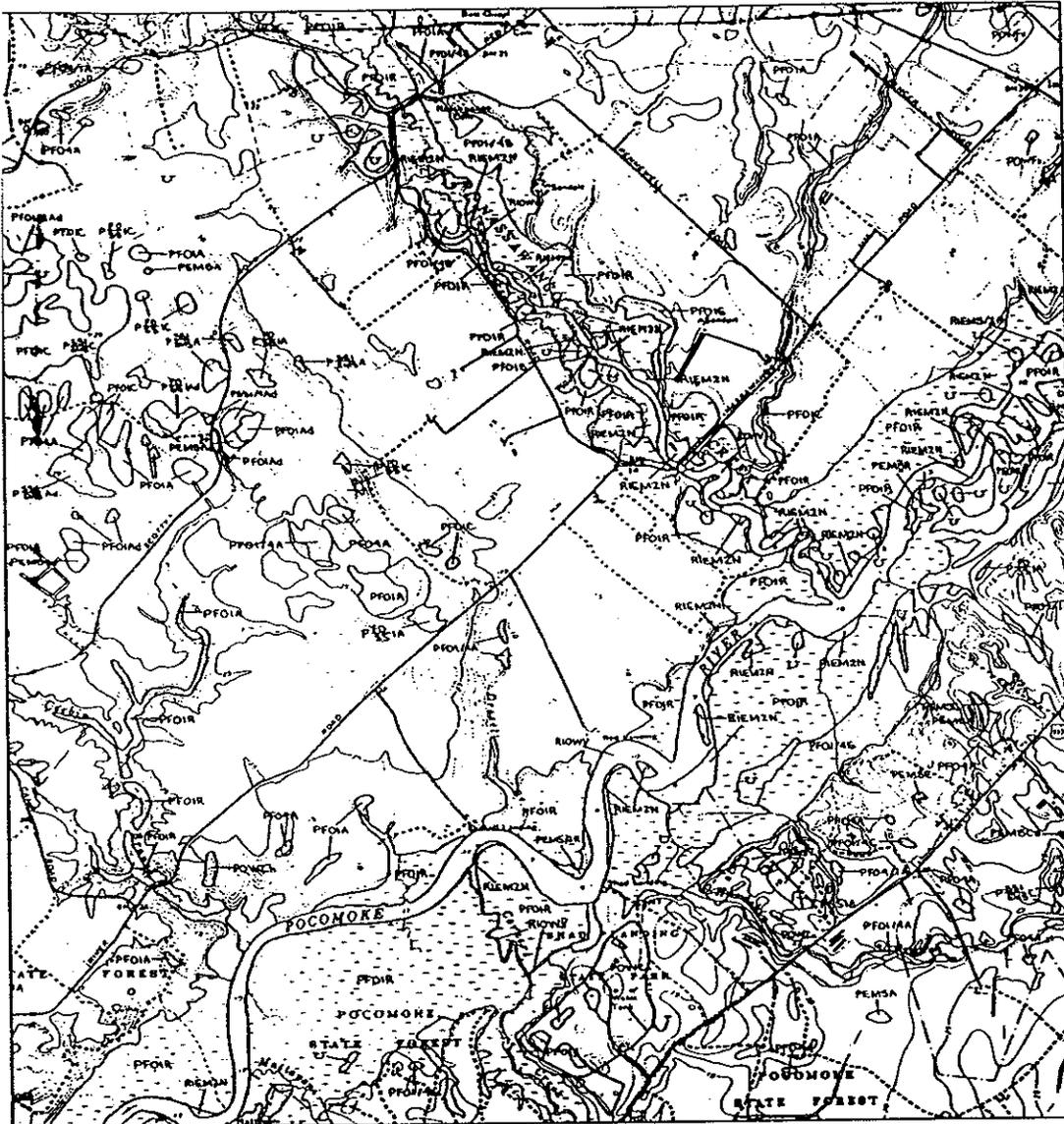


Figure 13.14. Example of a National Wetlands Inventory map (reduced scale). Wetlands are identified with alpha-numeric codes. Examples on this map are PFO1E (palustrine forested wetland, broad-leaved deciduous, seasonally flooded/saturated), PFO1R (as previous but seasonally flooded-tidal), PFO1A (temporarily flooded forested wetland), PEM5A (palustrine emergent wetland) and R1EM2N (riverine tidal emergent wetland, regularly flooded).

not meet the accuracy requirements for classification detail and wetness determinations. This was confirmed in further testing which showed that Landsat MSS data could not be used reliably to conduct initial inventories, update existing NWI maps, or detect wetland changes.

In July 1982, however, the Landsat Thematic Mapper (TM) was launched, providing higher resolution (30 m vs. 79 m) data in seven spectral bands, with improved radiometric sensitivity. Ducks Unlimited (Jacobson et al., 1987) compared TM data against NWI maps for monitoring wetlands in the Prairie Pothole Region of Canada and the United States. The results indicated that TM data have utility for inventorying and monitoring some wetland types. TM data achieved an accuracy of greater than 90 percent for water bodies more than 8 ha in size but only 25 percent for seasonally and temporarily flooded emergent wetlands. Moreover, only 25 percent of the wetlands under 0.8 ha were identified. In the Prairie Pothole Region, most of the wetlands are smaller than 0.8 ha. TM data should, however, be useful for identifying

## 13.8 SATELLITE IMAGES FOR WETLAND DETECTION

### 13.8.1 Potential NWI Use of Satellite Images

Owing to the magnitude of the NWI Project, remote sensing was the obvious approach. When the inventory was initiated in 1975, the basic choice was between high-altitude aerial photography and Landsat Multispectral Scanner (MSS) data (app. B). After comparing information that could be derived from MSS data with the needs of the NWI, it was evident that the satellite data could

water bodies, including flooded marshes and deciduous shrub swamps.

Although TM data cannot be used to produce wetland maps that meet NWI standards, the NWI is testing the feasibility of using TM data to detect changes in wetlands on existing NWI maps, and to gauge the need for map updates.

Ducks Unlimited has also evaluated data from SPOT 1, the French satellite. Early results indicated that, because of the lack of a middle-infrared band (cf., TM band 5), SPOT data failed to recognize as many wetlands as TM data, despite better ground resolution (10 m or 20 m vs. 30 m).

The FWS (NWI representative), as a member of the U.S. Department of the Interior Remote Sensing Task Force, has made recommendations for improvements needed to advance commercial remote sensing satellite systems. Based on a decade of experience with Landsat, the NWI remains skeptical about the feasibility of building an operational system that is sufficiently advanced to be competitive with commercially available aerial photography and still be economically viable for producing detailed wetland maps (B. Wilen, personal communication, 1992).

### 13.8.2 Applications for Wetland Detection

Despite its failure to meet NWI map specifications, potential applications of satellite imagery include

- regional wetland mapping (1:100,000 and smaller)
- identifying certain dominance types (using multirate scenes to maximize discrimination of plant species)
- mapping flooded farmed wetlands
- identifying large-scale changes in wetlands, such as submergence of Louisiana's coastal marshes and bottomland hardwood or pocosin conversion to cropland or silviculture, and monitoring these changes on a regular basis. This use requires detection of small-scale changes in wetland boundaries and precise discrimination between major wetland types.

Merging conventional photointerpretation and satellite image processing may provide the best means for monitoring wetland trends in the future (Haddad and Harris, 1985; Lade et al., 1988). It may be possible to combine detailed wetland maps prepared by photointerpretation with satellite imagery to detect changes in mapped wetlands. This would maximize the advantages of both types of remotely sensed data: use aerial photographs for accurate delineation and classification of wetlands, and use satellite imagery for making annual observations of wetland trends. NOAA's CoastWatch change analysis project and the FWS's NWI project are attempting to do this. A classification system that groups wetlands according to types potentially detectable by satellite image processing has been proposed (Klemas et al., 1993). In general, this scheme separates estuarine wetlands from palustrine wetlands and emergent wetlands from woody wetlands. If satellite data can be merged successfully with existing NWI data and existing aerial photographs, rapid, repeated, and potentially cost-effective analysis of wetland trends may be possible for

broad geographic areas. It must be emphasized, however, that despite twenty years of research with satellite imagery, it has not proved useful for operational wetland mapping for broad geographic regions. Researchers using satellite imagery still acknowledge that aerial photography is superior for producing detailed wetland maps (Klemas et al., 1993; Burgess et al., 1992). In fact, the Federal Geographic Data Committee concluded that aerial photographic interpretation used by the FWS's NWI project provides the best technique for initial wetland habitat and inventory mapping, while merging digital NWI data with satellite data provides improved monitoring capabilities over what can be offered by either data type individually (Federal Geographic Data Committee, 1992).

## 13.9 CONCLUSION

Interpretation of aerial photographs has been applied successfully throughout the United States for identifying wetlands. While the available photographs have been used to produce reliable wetland maps, the results may not be perfect due mainly to limitations in the quality and timing of the aerial photographs and to the difficulty of interpreting certain wetland types. The more difficult it is to identify a wetland on the ground, the more problematic will be its identification on photographs. In difficult cases, landscape position must be considered, subtle photographic features examined, available collateral information reviewed, and more fieldwork conducted to produce a reliable map product. In these more perplexing cases, photointerpretation can only provide general wetland boundaries regardless of the quality of the photographs and the interpreter's expertise. Overall, however, interpretation of aerial photographs provides an efficient, cost-effective, practical and reliable means of locating and inventorying wetlands.

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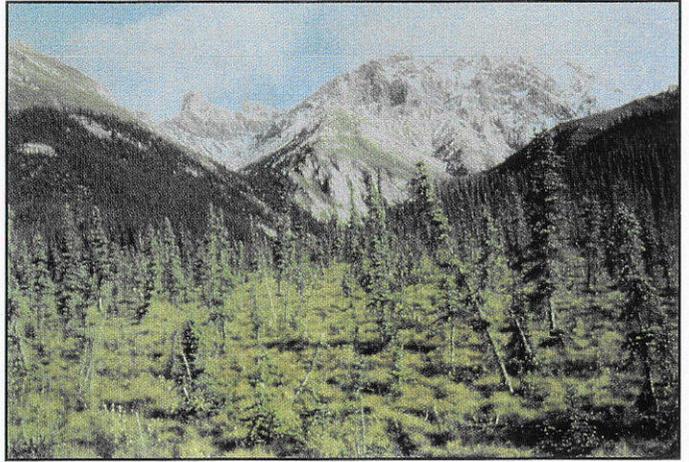
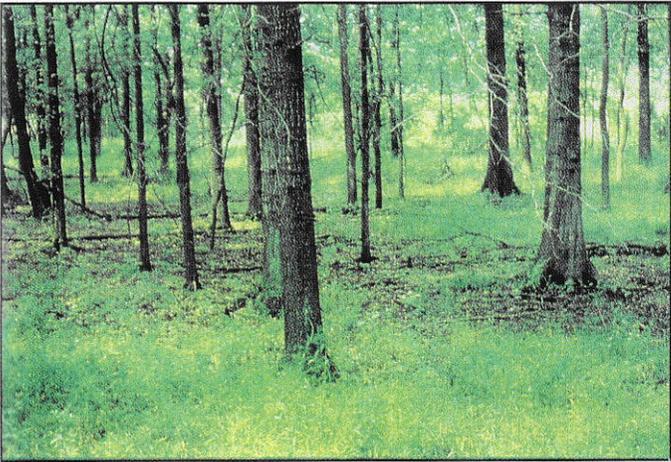
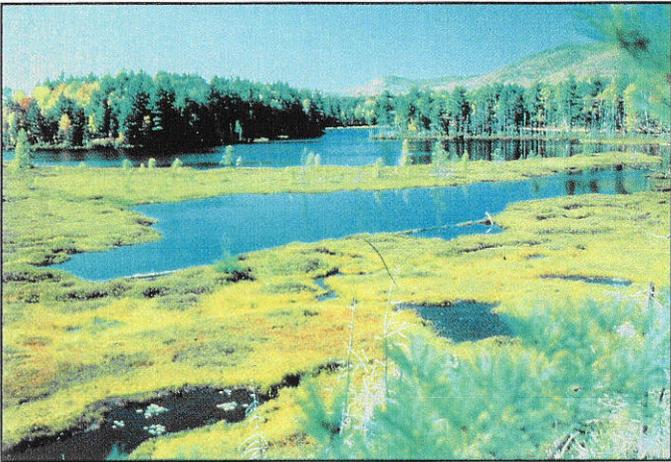
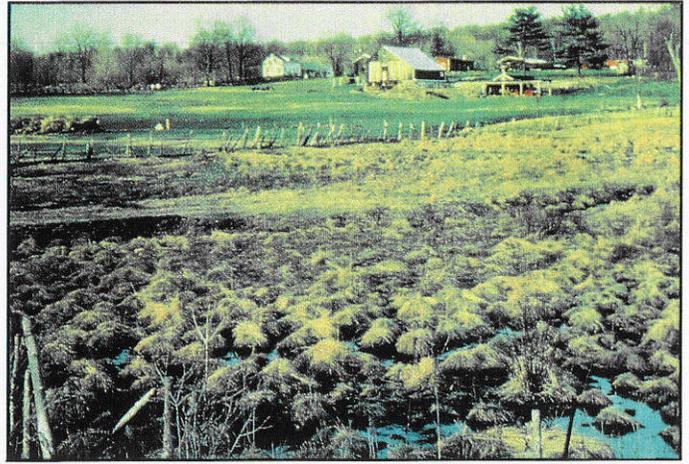
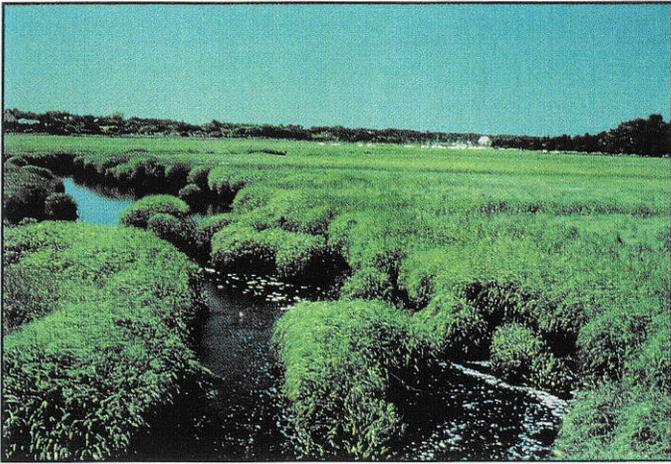


Figure 13.1. Ground-based color photographs of examples of United States wetlands:

- (a) estuarine emergent wetland (salt marsh) (R. Tiner)
- (b) palustrine emergent wetland (wet meadow) (photograph courtesy B. Zinni)
- (c) palustrine scrub-shrub wetland (floating bog) (photograph courtesy B. Zinni)
- (d) palustrine forested wetland (southern swamp) (R. Tiner)
- (e) palustrine forested wetland (temporarily flooded swamp) (R. Tiner)
- (f) palustrine scrub-shrub wetland (Alaskan muskeg) (U.S. Fish & Wildlife Service photograph)





Figure 13.6. Color-infrared aerial photograph (scale 1:40,000) of Maryland brackish marshes dominated by black needlerush (*Juncus roemaerianus*; appears medium brown) and salt-hay cordgrass (*Spartina patens*; appears whitish green).

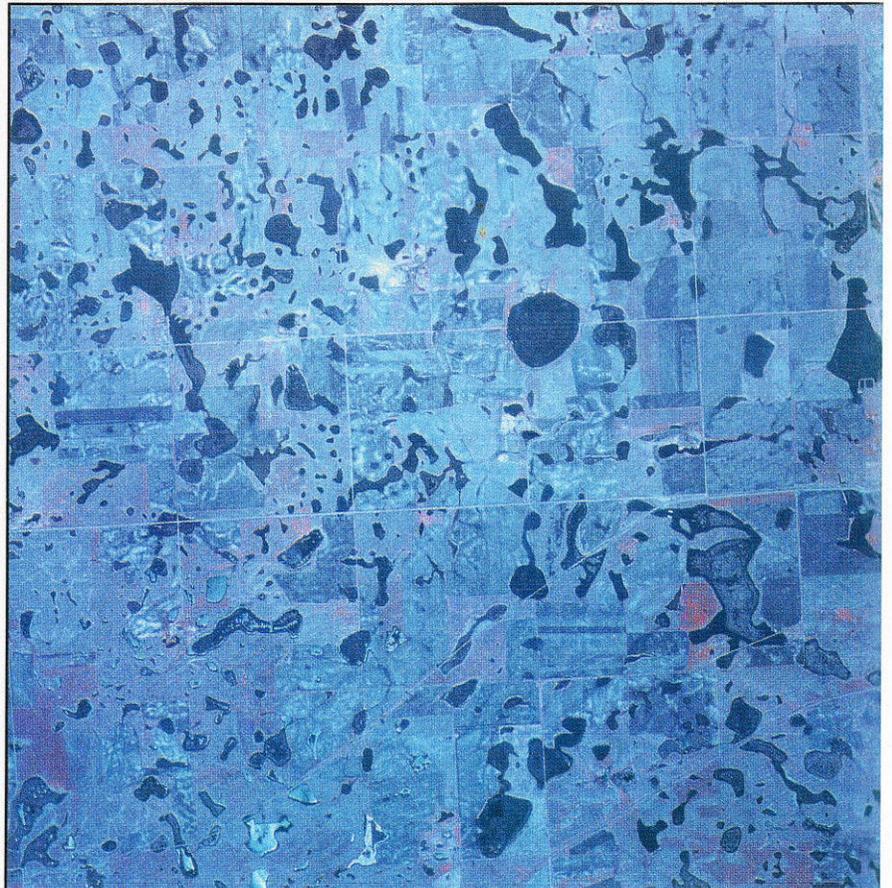


Figure 13.8. Color-infrared aerial photograph (original scale 1:65,000) of prairie pothole wetlands in North Dakota. Emergent vegetation can be seen in many potholes.





Figure 13.9. Color-infrared aerial photograph (original scale 1:58,000) of leatherleaf bogs (*Chamaedaphne calyculata*; appear smooth, orange) in Maine. Flooded marshes (dark) can be seen along streams, while nonflooded marshes (whitish) are also present. Vast evergreen forested wetlands, dominated by black spruce (*Picea mariana*) and/or balsam fir (*Abies balsamea*) (appear red/reddish brown, coarse textured), lie between these marshes and the adjacent upland forests (evergreen appear coarse, bright red; deciduous appear tan) and evergreen regrowth areas (smooth, bright red).

Figure 13.10. Color-infrared aerial photograph (original scale 1:12,000) of seasonally flooded forested wetlands in southeastern Massachusetts. Deciduous forested wetlands dominated by red maple (*Acer rubrum*) appear dark bluish-gray and coarse textured, while evergreen swamps of white pine (*Pinus strobus*) appear as reddish patches within or contiguous with the red maple swamps.







Figure 13.11. Color-infrared aerial photograph (original scale 1:12,000) of deciduous forested wetlands on the Eastern Shore of Maryland. Temporarily flooded swamps appear light medium gray and coarse textured, while seasonally flooded swamps appear darker gray and coarse textured. Pothole-like ponds appear dark blue.

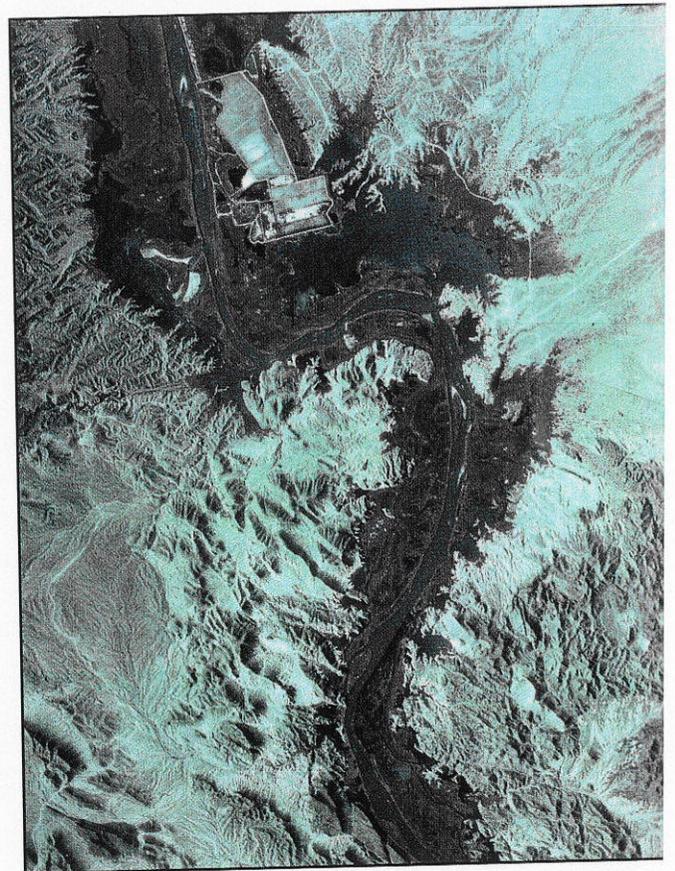


Figure 13.12. Color-infrared aerial photograph (original scale 1:58,000) of woody riparian habitat (appears reddish) along the Colorado River, between California (left) and Arizona (right).





Figure 13.13. Color-infrared aerial photograph (scale 1:58,000) of Atlantic white cedar swamps (*Chamaecyparis thyoides*; appear deep maroon), bottomland hardwood swamps with an understory of American holly (*Ilex opaca*; appear blue and red, coarse textured), and pitch pine forests (*Pinus rigida*; appear medium red, coarse textured). Pitch pine swamps occur along headwater streams, in depressions or in drainageways. They may appear slightly brighter red than adjacent upland pine forests.

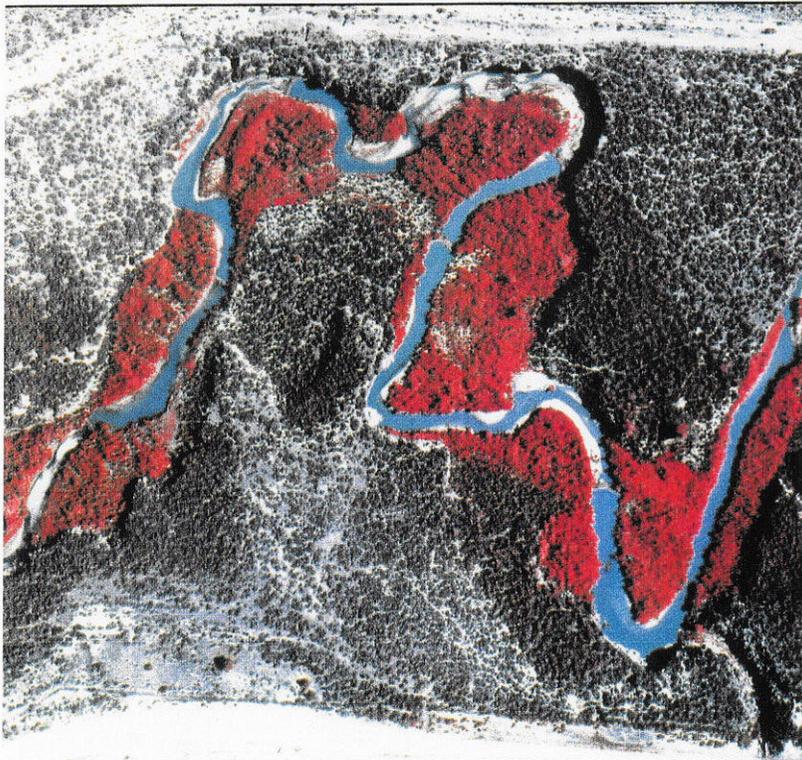


Figure 14.1. Color-infrared aerial photograph of beaver dams (D20-D27), beaver lodges (L10, L13, L15), and associated riparian habitat on East Douglas Creek in northwestern Colorado (Baker et al., 1992b). Habitat codes are O - water, M - channel substrate, W - willow, S - sagebrush, DS - dead sagebrush, G - greasewood, R - rabbitbrush and H - herbaceous. Photograph was taken at a scale of 1:2660 in September 1989. Photointerpretation and ground-truthing were completed in July 1991. Differences between the 1989 photograph and 1991 mapping document the dynamic nature of this beaver-dominated riparian system (e.g., beaver dam 21 was not present, and water and channel substrate locations changed).

