William MacConnell
Department of Forestry & Wildlife Management
University of Massachusetts
Amherst, MA 01003
William Niedzwiedz
Division of Environmental and Urban Systems
Virginia Polytechnic Institute
Blacksburg, VA 24061

Remote Sensing the White River in Vermont

Aerial photographs provide a data base for wildlife and fisheries biology studies of the effects of stream channelization on an excellent trout stream which was once a prime spawning ground for the Atlantic salmon.

Abstract: *Torrential rains and severe flooding in the White River Watershed in Vermont in June 1973 resulted in the issuance of a Declaration of Disaster, which led to channelization in the river and its tributaries. Conventional springtime panchromatic aerial photography at a scale of 1:12,000 was taken the following year in order to establish a data base for wildlife and fisheries biology studies of the effect of the channelization on the river. The aerial photographs were used to assess the impact of stream channelization on the White River and its tributaries, measure vegetation and land use of value to wildlife along the river, determine stream bank characteristics, and delineate and measure water characteristics of value to fish in the river. Springtime photography without leaves on vegetation or snow on the ground proved very useful in delineating channelized sections of the river; and in identifying vegetation, land use, and river bank types of importance to wildlife as well as water characteristics of importance to fish.*

Introduction

Torrential flooding in the White River Watershed of Vermont during the period June 26 to July 6, 1973 led to a Declaration of Disaster (FDAA #397-DR, dtd. July 6, 1973) issued under P.L. 91-606. All Vermont general laws relating to wetlands, stream protection, and water quality were nullified for a 60-day period by a gubernatorial declaration. Under the authority of P.L. 91-606 and with Federal Disaster Assistance Administration funding, the White River among other rivers in Vermont was channelized to reduce future flooding threats to public health, safety, and property. The White River and its tributaries is known as an excellent trout stream, in the past as a prime spawning stream of the Atlantic salmon (*Salmo salar*), and as the site of a National Fish Hatchery devoted to Atlantic salmon culture and rearing. Additional stream alteration was implemented by the Agricultural Stabilization and Conservation Service under P.L. 85-58 and by the U.S. Soil Conservation Service under P.L. 81-516.

This paper describes a study initiated to document by aerial photographs the ecological changes resulting from channelization of the White River and its major tributaries. It also measured the characteristics of the

Photogrammetric Engineering and Remote Sensing,
Vol. 45, No. 10, October 1979, pp. 1393-1399.

river, its banks and vegetation, and land use adjacent to the river which would have an effect on wildlife and fish.

Research objectives were first to provide a habitat data base of the White River and vegetation and land use adjacent to it for fisheries biologists studying benthos and fish habitat and wildlife biologists studying wildlife and wildlife habitat. The second objective was to document the extent and nature of stream channelization. The third objective was to develop a fish and wildlife habitat classification system to include vegetation, land use, stream bank parameters, stream-water characteristics, and channelizing activity.

Flood damage assessment and flood prediction are necessary components to any successful land-use planning process that covers flood-prone rivers and shorelines. Many flood-prone areas are highly populated, heavily industrialized, or prized for agricultural uses. Flood-plain development in flood-prone areas has increased the need for careful planning and management by local, state, and federal agencies. Accurate, rapid, and economical methods are required to provide data necessary for water resources assessment for planning-management functions (Meyers and Welch 1975). Remote sensing techniques have been utilized for many years to aid the process of studying floods and flood-caused damage. However, the thrust of Remote Sensing applications has been toward flood inundation mapping and property damage assessment (Hoyes *et al.*, 1973; Piech and Walker, 1972).

Aerial photographs at scales ranging from 1:10,000 to 1:15,000 can be used directly to obtain information for quantitative description of drainage systems (Meyer and Welch, 1975). As outlined by Bunik and Turner (1971) black-and-white photography at these scales can be utilized to produce a data base defining stream-drainage basins to their lowest orders. Meyer and Welch (1975) indicate that cross-sectional information is possible for streams where photography penetrates to the streambed or with ground truth data.

Panchromatic, infrared, color infrared, and color photography as well as thermal imagery techniques have been used successfully to assess water patterns related to changes in channel conditions. Coleman (1969) and Coleman and McIntire (1971) have demonstrated that water surface turbulence can be correlated with channel topography. Their studies show that relatively calm water normally overlies shallow bars, while highly turbulent water areas are captured as mottled, patchy areas on aerial photography.

The White River study attempts to classify on aerial photographs river and stream water as habitat for fish, and land adjacent to the water as habitat for wildlife. The product produced was used in research by wildlife and fisheries biologists making on-ground and in-water studies of wildlife and fish. It is expected that annotated negatives showing conditions on the White River in the spring of 1974 will be printed for use by biologists in the future, if the White River once again becomes important for Atlantic salmon spawning.

Study Area

The White River Watershed is located in central Vermont and consists of a drainage area of 1844 km^2 (712 mi^2). Headwaters of the White River and its tributaries are located on the slopes of the Green Mountains, and it joins the Connecticut River at White River Junction. Included in this study are the White River; the First, Second and Third Branches of the White River; Stony Brook; Gilead Brook; and the West Branch of the Tweed River. Most of these tributaries have clear water with a rock and gravel stream bed. Agriculture and urban land uses dominate the lowlands adjacent to the river while a mixed hardwood-conifer forest (*Tsuga canadensis*, *Picea* spp., *Acer* spp., and *Betula* spp.) borders the tributaries on the uplands. The river and strips of riparian land to a distance of 305 m (1000 feet) on both sides of the river make up the study area.

Materials and Methods

Standard panchromatic aerial photographs at a scale of 1:12,000 were taken of the study area on May 2, 1974 when snow was gone and trees were without leaves. The Zeiss RMK-A camera used had a 15 cm (6 in.) focal length and a 23 by 23 cm (9 by 9 in.) contact film format. Specifications for photography were those defined by the U.S. Department of Agriculture (1969). To capture maximum photographic detail of streambanks and water characteristics, photographs were exposed during the brief period between loss of snowcover and budding of deciduous vegetation. Four power pocket stereoscopes were used for interpretation and .000 diameter technical ink fountain pens were used to annotate both the photographic prints and corresponding negatives (Figure 1). Dot grids were used to measure area types, map measures were used to measure line types, and point types were counted for tabulation.

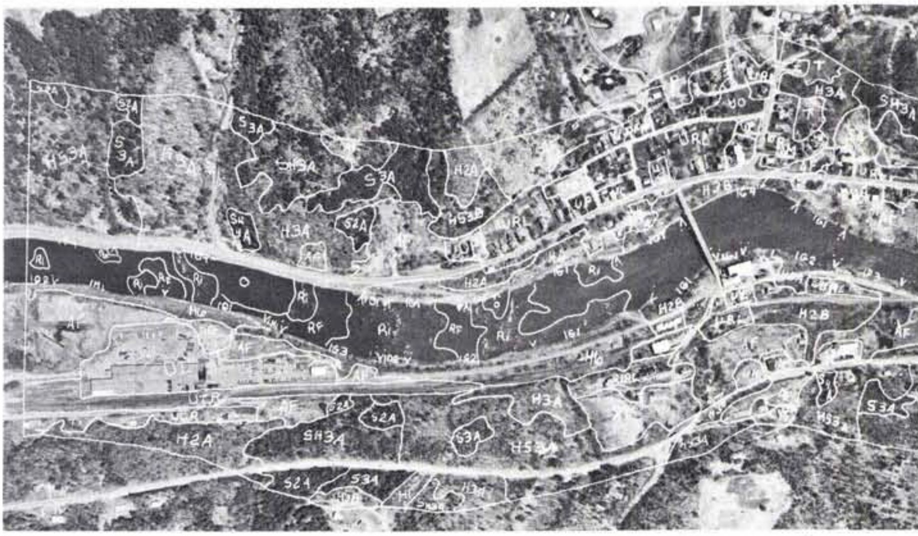

FIG. 1. Reproduction of a photo copy of a 1:12,000 scale annotated negative showing water characteristics, stream bank types, and vegetative and land-use types near the mouth of the White River in Vermont. Boundaries of the stream bank types are marked with Vs and the type symbols are shown on the water adjacent to the stream banks. Water and stream bank type symbols are described in this paper while vegetative and land-use types on the bank of the river are described in a bulletin by the authors cited in the references. (Photo by J. W. Sewall Co., Old Town, Maine)

CLASSIFICATION SYSTEM

A water and river bank classification systems for use with 1:12,000 scale leaves-off panchromatic photographs was devised to provide biologists with needed information about fish and wildlife habitat in and near the water. Water in the river, the character of its banks, and land adjacent to the river were all classified and measured employing the following system.

STREAMBANK CHARACTERISTICS ARE LINE TYPES FOR BOTH BANKS

Channelization

C — Evidence of stream channelization on the banks

Shade Provided by Streambank Vegetation

1 — Little shade on the water, 0-30 percent
2 — Light shade, 31-50 percent
3 — Medium shade, 51-80 percent
4 — Heavy shade, 81-100 percent

Composition of the Bank

M — Mud, clay, or soil other than sand or gravel
L — Ledge or bedrock
G — Sand, gravel, and stones less than 13 cm (5 in.) in diameter
R — Rock materials from 13 to 38 cm (5 to 15 in.) in diameter
B — Large boulders with diameters greater than 38 cm in diameter
D — Dead woody debris piled along the streambank from past floods
E — Eroded streambank
P — Rip-rap
W — Retaining wall

Elevation of Streambank

1 — A beach-like situation with no abrupt drop to the water
2 — An abrupt drop to the water which is less than 3 m (10 feet)
3 — An abrupt drop to the water of 3 to 6 m (10 to 20 ft.)
4 — An abrupt drop to the water which is more than 6 m

The C1G1 type would be a channelized stream with little shade, and gravel banks which have a beach-like character.

WATER CHARACTERISTICS MAY BE AREA, LINE, OR POINT TYPES

O — Pools over 30 m (100 ft) in diameter with fish holding capacity are outlined. Pools less than 30 m in diameter with fish holding capacity are marked as a point type.
X — Exposed streambeds over 30 m in diameter during low water in the summer are outlined. Exposed streambed less than 30 m in diameter are marked as a point type.

Ri — Rills with white water and some exposed rocks with diameters greater than 38 cm on streams over 30 m wide are outlined. Rills on streams less than 30 m wide are dashed lines with the Ri symbol.

Rf — Riffles have no white water but the water is fast moving and rough with rocks of unknown size beneath the water. Riffles are outlined on streams over 30 m wide. Riffles on streams less than 30 m wide are solid lines with the Rf symbol.

S — Mountain stream less than 3 m wide with fast moving, highly aerated water under complete shade. This is a line type marked periodically with the letter S and it is not assigned streambank or water characteristics.

⍋ — Trees down in the water providing cover for fish are marked as a point type with symbol shown.

The classification system has three subclasses: vegetation and land use as area types for 305 m (1000 ft) strips adjacent to the river, streambank characteristics as linear types for both banks, and water characteristics shown as area, linear, or point types. The land-use and vegetation classification subsystem used on the 305 m strips (MacConnell, 1975) was devised for New England and has been applied to towns and counties (MacConnell and Niedzwiedz, 1975), and on a statewide basis for Massachusetts (MacConnell, 1975) and Rhode Island (MacConnell, 1974). No interpretation problems occurred with the well tested land-use and vegetation types on the 1:12,000 scale aerial photographs used. This classification system that describes the nature of the land, vegetation on the landscape, and land use is so similar to other systems in use that there is no need to describe the 104 types here.

The streambank and water classification developed for this study contains characteristics of value to biologists making fish and wildlife habitat studies. The streambank classification sub-system is similar to one devised by MacConnell and Archey (1969) for classifying the banks of the Connecticut River in a recreation study. Streambanks are described by four characteristics indicated by a letter or number: evidence of channelization on the banks, amount of shade provided to water by trees on the streambank, composition of the bank, and elevation of the streambank above the water. Eighty-six streambank types were found on the river by combining one channelization type, four shade types, nine river bank composition types, and four bank elevation types. Streambanks were classified as a linear type on both sides for streams that maintain a minimum width of 3 m. Smaller streams were classified as mountain streams, and no streambank or water characteristics information was added to that stream type. Land-use and vegetation types on 305 m strips were, however, added to both sides of mountain streams.

The water sub-system consisted of three water characteristics of known value to fish. Pools over 30 m in diameter were outlined and measured for area on the photographs. Rocky rills with white water and rocky riffles without white water were also outlined and measured for area on streams over 30 m in width. On streams less than 30 m riffles and rills were shown as line types—riffles shown as solid lines and rills as dashed lines. Both area and line types were recorded by towns, river tributary, and for the entire river system. Pools less than 30 m in diameter were shown as point types without a boundary and were tabulated by count. Other point types included partially submerged fallen trees and streambed that would be exposed during low-water periods.

Interpretation and Annotation of Aerial Photographs

The boundaries of 305-m strips of land on each side of the river were marked on 112 alternate aerial photographs in the 32 flight strips with a segment of the river or tributary centered in each flight line. Photo interpreters then spent several weeks in Vermont to reconnoiter the river, verify the classification system, and establish thousands of ground truth points so that the classification system could be consistently and accurately applied under all conditions. Interpreters, all experienced with the vegetation and land-use part of the classification system, concentrated on the more difficult water and river bank types. During the interpretation work several more trips were made to the White River watershed to ground check work completed and to reconnoiter and establish more ground truth points in new areas to be typed. Subsequent summertime trips were valuable in checking exposed river bottom.

One of the interpreters had experience with a streambank classification system but the water classification, developed for use in this study, was new to everyone. Interpretation of streambank composition posed few problems after the extensive reconnaissance.

For example, sand and gravel bank areas are consistently displayed in light tone and fine texture on the photographs while other Vermont soils encountered were dark-toned. Channelized areas were easily identified because of their light tone, fine texture, smooth surface, and gentle gradient. A feature common in channelized areas was presence of bulldozer blade deposits that appear as linear mounds of light-toned gravel located along the outer reaches of the streambank. Man-made structures, such as rip-rap and retaining walls, were easily identified from their consistent linear or curvilinear nature. Ledge, large and smaller jumbled rock, eroded streambank, and piles of woody debris left from the flood all had a consistent signature on the photographs. Determination of streambank elevation required simple height measurements and abundant field checks. All these interpretations were most difficult to make where the streambank was partially masked with coniferous forest growth, but additional field work in coniferous areas prevented errors.

Identifying stream water characteristics proved to be the most challenging interpretive problem. Light penetration into water is often the limiting factor in water related studies (Geary, 1967; Polcyn, 1969). Light penetration is a function of water depth, water clarity, suspended particles in the water, and surface disturbance on the water that is in turn caused by wind or water velocities. Disturbance of moving water is controlled by water depth and composition of the bottom. Since the water characteristics classification was designed to measure fish habitat, many factors limiting light penetration that have been a hindrance in other studies aided accurate identification of water characteristics in the classification used here. For example, pools with fish holding capacity are large, relatively smooth-surfaced, and deep. Because little light was reflected from these deep pools, they were displayed as dark toned areas on the photographs. Rills with white water were easily identified by the presence of large rocks above the water line, and light-toned white water on the downstream side of the rocks caused by turbulent surface water. Rills have a generally light-tonal appearance caused by stream bottom reflectance through the shallow water.

Riffles are similar to rills except that increased water depths cover the rocks. Since stream bottom materials do not penetrate the surface water, no white water is present but the water is swift, and the rocky bottom caused turbulence or riffle areas that appear mottled in tone on aerial photographs. Increased water depths of riffles increased light absorption, causing them to register in generally darker tones than rill areas. Rocks in riffles and rills provide good cover for fish.

The mountain stream designation was assigned to those streams that averaged less than 3 m in width. This designation was used because the streams were too small to apply stream bank or the water character identifications. Mountain stream courses on this rugged terrain could be determined, but trees on the streambanks usually masked water characteristic information. Field reconnaissance indicated mountain streams were characterized by fast moving, highly aerated water with low temperatures. These streams had small pools, and gravel bottoms and banks. Any stream less than 3 m in width, covered by vegetation and located in moderate to steeply sloping terrain, was classified as mountain stream.

Pools, riffles, and rills were shown as area types where sufficiently large and as line or point types where small. Trees down in the water, available as cover for fish, were marked as point types. Bottom exposed during low water periods was also annotated as a point type.

Reproduction of Annotated Aerial Photographs

An extensive search was made for good large-scale base maps of the White River so that land-use and water characteristics maps at a scale of 1:12,000 could be made in quantity. Most suitable were USGS maps at 1:24,000 and 1:62,000 scales. The latter scale was blown up 6.25 diameters and tested for cartographic accuracy. Enlarged 1:62,000 scale maps proved too coarse and inaccurate for use as a base map at the 1:12,000 scale chosen for this study. Next, some of the annotated aerial photos were produced as Mylar transparencies with a resolution of 60 lines/cm (150 lines/per in.) that could be reproduced by Diazo process. Mylar photocopies did not show the detail required by researchers and this technique was abandoned. Land-use and water types were added to the original photo negatives by tracing from the annotated photographs. On printing, the photographs show type boundaries (Figure 1) in white while all original detail of the photograph is preserved. Four copies of the annotated negatives were printed for use by various White River channelization research teams. The U.S. Fish and Wildlife Service owns the negatives and uses copies of them as a tool to train wildlife and fisheries biologists in aerial photointerpretation.

Tabulations

Since no maps were made from the aerial photographs, areas of land use and water types were measured directly on annotated aerial photographs by dot grid. A dot grid with 100 dots per square inch was used, and each dot counted in a type represented 0.57 ha (0.23 ac). Linear distances of the line types were determined with a map measure, and point types were counted. Tabulations were separated by water course and towns and were summarized for counties and the White River study area. One hundred four land use types were measured in 305 m strips along the river, and 86 bank types, 5 water types, and 3 point types were also measured or counted and tabulated.

Results

The White River and its tributary streams in this study totaled 287 km (167 mi). Of this, 19.3 km (12.1 mi) or 7 percent of total river length in the study area were classified as channelized on aerial photographs. A severe storm after channelization scoured away much of the channelization evidence before aerial photographs were taken. Consequently, channelization data are conservative.

The total drainage system in the study area included 4356 ha (1764 ac) of open water in that part of the river system over 3 m wide. Of this, 257 ha (104 ac) were in pools over 30 m in diameter, 788 ha (319 ac) were in riffles, and 526 ha (213 ac) were in rills. There were also 16.6 km (10.3 mi) of riffles and 11.4 km (7.1 mi) of rills on streams less than 30 m wide. There were 174 pools less than 30 m in diameter, 148 trees down in the water, and 220 areas where the bottom would be exposed in the low water period during the summer.

Vegetation land-use data on the 305 m strips bordering the river and its tributaries in the study area included 104 types from the Massachusetts Classification System. There were a total of 96,910 ha (39,235 ac) in these strips. 47,550 ha (19,251 ac) or 49 percent is forest; 46 percent of the forest is hardwood, 31 percent mixed wood, 22 percent softwood, and 1 percent was forest plantation. Forty-one percent or 39,357 ha (15,934 ac) in the strips was in agricultural use. Of this, 34 percent was tilled, 65 percent was in pasture or abandoned fields, and 1 percent was in power line right-of-way. There were 6825 ha (2763 ac) of urban land that accounted for 7 percent of the total land area within 305 m of the river or its tributaries. Forty-six percent of the urban land was single family dwellings, 12 percent industrial or commercial, and 35 percent was in divided highway, an urban type in the system used. Seven percent of the urban land was in public use. Approximately 1.5 percent of the total study area was used for mining and waste disposal and about one-third of one percent was in outdoor recreation use.

Conclusions

Standard panchromatic aerial photographs at a scale of 1:12,000 can be used successfully to study stream alteration activities, and to identify and annotate streambank and stream water characteristics as well as to identify vegetation types and land use. Successful analysis of a river system in northern climates requires photography taken in the spring after snowmelt and before the buds on deciduous vegetation begin to swell. Photography should be flown as soon as possible after stream alteration activities have been completed in order to reduce risk of losing alteration evidence due to additional flooding and erosion after original stream alterations have been completed. The photographs used in this study were taken one year after stream alteration and after a second severe flood had erased much of the channelization evidence, making measurement of channelization uncertain on either the photographs or on the ground. Vegetation, land-use, and streambank types proved useful to wildlife biologists studying the impact of channelizing on songbird and small mammal populations adjacent to the river (Possardt and Dodge, 1978). Fisheries biologists have also found streambank and water characteristics of value in studying fish habitat (Dodge *et al.*, 1976).

Acknowledgments

Research reported herein was funded by USDI, Fish and Wildlife Service Contract 14-16-0008-1149. This is a contribution of the Massachusetts Agricultural Experiment Station and the Massachusetts Cooperative Wildlife Research Unit jointly supported by the U.S. Fish and Wildlife Service, Massachusetts Division of Fisheries and Wildlife, University of Massachusetts, and the Wildlife Management Institute.

REFERENCES

Bunik, J. A., and K. A. Turner, 1971. Remote sensing applications to the quantitative analysis of drainage networks. *Proc. Fall Mtg. Am. Soc. Photogrammetry*, Falls Church, Va. 71-313.

Coleman, J. M., 1969. Brahmaputra River: channel processes and sedimentation. *Sedimentary Geology*. 3:131-239.

Coleman, J. M., and W. G. McIntire, 1971. Transiting coastal river channels. *International Hydrographic Review* 48:13-43.

Dodge, W. E., E. E. Possardt, R. J. Reed, and W. P. MacConnell, 1976. *Channelization Assessment, White River, Vermont: Remote sensing, benthos, and wildlife*. Bordeaux Co., West Springfield, Mass. 74 pp.

Geary, E. L., 1967. Coastal hydrography. *Photogrammetric Engineering*. 34:44-50.

Hoyer, B. E., G. R. Hallberg, and J. V. Taranik, 1973. Seasonal multispectral flood inundation mapping in Iowa. *Proc. Symposium Management and Utilization of Remote Sensing Data*. Am. Soc. Photogrammetry, Falls Church, Va., 130-141.

MacConnell, W. P., 1974. *Remote sensing land-use and vegetative cover in Rhode Island*. Bull. 200, Coop. Ext. Service, University of Rhode Island, Kingston, 93 pp.

———, 1975. *Remote sensing 20 years of change in Massachusetts*. Bull. 630, Mass. Agr. Expt. Sta., Univ. of Massachusetts, Amherst, 79 pp.

MacConnell, W. P., and W. Archey, 1969. *The use of aerial photographs to evaluate the recreational resources of the Connecticut River in Vermont*. Bull. 575, Mass. Agr. Expt. Sta., Univ. Massachusetts, Amherst, 85 pp.

MacConnell, W. P., and W. R. Niedzwiedz, 1975. *Remote sensing 20 years of change in Worcester County Massachusetts, 1951-1971*. Bull. 625, Mass. Agr. Expt. Sta., Univ. Massachusetts, Amherst, 173 pp.

Meyer, W., and R. I. Welch, 1975. Water resources assessment. *Manual Remote Sensing*, Am. Soc. Photogrammetry, Falls Church, Va., 1479-1551.

Piech, K. R., and J. E. Walker, 1972. Thematic mapping of flooded acreage. *Photogrammetric Engineering* 38:1081-1090.

Polcyn, F. C., 1969. *Depth determination by measuring wave surface effects*. NASA Ann. Earth Resources Program Review.

Possardt, E. E., and W. E. Dodge, 1978. Stream channelization impacts on songbirds and small mammals in Vermont. *Wildlife Soc. Bull.* 6:18-24.

USDA, ASCS, 1969. *Aerial photography specifications*, (ASCS-AP-201 Revision 4), USDA, ASCS Washington, D.C. 43 pp.

(Received October 18, 1978; revised and accepted June 25, 1979)