Method To Identify, Inventory, and Map Wetlands Using Aerial Photography and Geographic Information Systems

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The Washington State Department of Transportation (WSDOT) has a need to inventory wetlands along highway rights-of-way. Aerial photo interpretation was determined to provide a reasonable compromise between accuracy and cost, so several forms of aerial photography were tested. Two test areas were photographed with both true color and color infrared film in three scales. Photo interpreters classified wetlands and delineated their boundaries, and these interpretations were compared with data from field delineations performed by a wetland biologist. A method using aerial videography was also analyzed. On the basis of the test results and other factors, the preferred inventory method will use color infrared film at a 1:12,000 scale. WSDOT devised techniques to plot wetland boundaries on existing base maps and developed an Oracle data base that will be linked with the map files. When this is completed, it will be possible to print maps that depict wetland boundaries and classifications. A variety of modeling tasks and data analyses will also be possible. The inventory will cost approximately $658,000 for 7,030 mi of WSDOT right-of-way. The end product should improve early project planning, eliminate problems resulting from late discovery of wetlands within project boundaries, and reduce biologist field time.

In recent years, the state of Washington, along with other regional and national governments, has begun to realize the value of wetlands. Washington's wetlands benefit the state in many ways: they desynchronize peak runoff events, moderating surface flows and groundwater supplies; they detain floodwaters, helping to reduce flood damage; they trap sediments and pollutants, improving water quality in associated watersheds; and they provide vegetation diversity and crucial fish and wildlife habitat.

Recognizing the value of wetlands, state and federal legislatures have established regulations to preserve them. The state of Washington Governor's Executive Order EO 89-10 proclaimed a state goal of "no overall net loss" of wetlands. To meet this goal, development projects must avoid wetland impacts, or, if unavoidable, replace any lost wetlands. This effort has been hampered by a lack of information about the locations, types, and sizes of all the state's wetland resources.

RESEARCH APPROACH

Washington State is working toward better understanding and management of these resources. The Washington State Department of Transportation (WSDOT) has a particularly pressing need for wetland management because state and federal regulations demand that highway projects must avoid wetlands when possible, or mitigate when impacts are unavoidable. The WSDOT Protection of Wetlands Action Plan D31-12 (August 1990) directs that WSDOT shall complete a statewide inventory of wetlands within highway rights-of-way. This pioneering project will identify, classify, and map wetlands along all 7,030 mi of paved state highway.

Such an inventory will allow more precision and fewer false starts during initial planning stages. During project scoping and in early stages of project planning, this inventory will provide valuable information to aid in those processes. Field study time will be reduced. And long-term planning exercises could, for the first time, include reasonable estimates of impact on the state's wetland resources.

It is hoped that data from a WSDOT inventory can be linked with data from other state agencies to compile a detailed and comprehensive inventory of all of Washington's wetlands. Such information will provide an important management tool and will allow tracking of the state's resources over many years. Also, WSDOT will be better able to evaluate its own contributions to the goal of no net loss and consider remedial action if necessary.

This research is an attempt to determine the best method to inventory wetlands along all state transportation corridors. The study includes an overview of current methodology along with pilot projects to test the most promising methods. The final report, with appendexes, is available from WSDOT in Olympia (*1*).

State of the Art

Regional mapping of wetlands is being done on national and local scales. Interpretation of aerial photography is the most commonly used method because it can be employed over large areas with reasonable speed and accuracy. Brown, Howland, and others have found aerial photo interpretation to be a very effective method, provided that the interpreters are skilled in aerial photo interpretation and have a sound understanding of wetland ecology (*2,3*). Several types of film have been used, including normal black and white, black and white infrared, true color, and color infrared. Carter stated that color infrared was the best overall choice for wetland identification but added that true color was a good second choice (*4*). Austin et al. found that color infrared was best for surface vegetation, whereas true color was best for submerged vegetation (*5*). At

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present, color infrared is most frequently used for regional wetland inventories.

In large regions, small-scale (high-altitude) photos are generally used as the only feasible way to cover large areas in a reasonable amount of time. The best-known work has been done nationally as part of the U.S. Fish and Wildlife Service National Wetland Inventory (NWI). This survey has mostly used 1:80,000 (1 in. = 6,666 ft) and 1:58,000 (1 in. = 4,833 ft) color infrared photos. After the photos are interpreted by experienced persons, wetlands are plotted on 1:24,000 (1 in. = 2,000 ft) U.S. Geological Survey (USGS) topographic quadrangles, and these are made available to the public. The NWI maps work well to define large wetlands, but the scale is not well-suited to handling small areas such as those WSDOT deals with on highway rights-of-way. The NWI also purposely omitted agricultural land from the mapping exercise.

Several states have conducted, or are now working on, statewide wetland inventories. These are generally on a scale similar to the NWI work, although the resolution is often much lower. For example, the inventory in Michigan includes only wetlands that are at least 10 acres, whereas New York maps freshwater wetlands only larger than 12 acres. On the other end of the spectrum, some local governments have inventoried wetlands very precisely using a combination of large-scale (low-altitude) aerial photos and ground checks by wetland biologists. Unfortunately, these time-intensive and expensive surveys are not practicable for large areas.

To determine the experience and current thinking of other state departments of transportation (DOTs) in the subject of wetland inventories, wetland specialists from 15 state DOTs were contacted. States selected for the survey were those that seemed the most likely to be pursuing wetland inventories of their own. However, as of January 1991, none of the DOTs of surveyed states had endeavored to develop wetland inventories. Maine has come closer than any other state surveyed. The Maine DOT is working in cooperation with the Maine Department of Natural Resources to inventory the state's wetlands. The Maine DOT has funded some of the aerial photography, and the two agencies are sharing the photos and the results of their interpretations.

In several states, wetland regulation has prompted statewide wetland inventories by one or more state environmental agencies. The resulting information is generally made available to other state agencies, including the state DOT. However, this information is usually at a smaller scale than that required for highway planning, so the information may be useful only as a general guideline. When better data are unavailable, most DOT environmental sections use NWI maps for initial predictions about the presence of wetlands, although these maps are generally considered to be rough indicators. In later planning stages, field biologists are deployed to find wetlands and delineate the boundaries. The field work is very time-consuming and is probably part of the reason that most state DOT biologists profess that they are always struggling to keep up with the workload.

Research Goals

Given the usefulness of an inventory of wetlands along WSDOT rights-of-way, it remained for WSDOT to choose a method of performing such a task. There are no established procedures for inventorying wetlands along transportation corridors, although aerial photo interpretation can be considered as a starting point. The purpose of this study, then, was to determine the best method of using aerial photos to identify, classify, and map wetlands. Along with standard aerial photo techniques, a new method of computer-enhanced aerial videography was also evaluated.

Selection of the best method was based on a combination of factors, especially accuracy and cost. Once the best method was established, techniques were explored for entering data into a geographical information system (GIS). It is hoped that such a data base will make wetland data easily accessible in a variety of formats, including maps and summary reports. It will also allow WSDOT to share data with other state agencies to produce a more comprehensive picture of the state's wetland resources, thereby providing better management opportunities.

Research Approach

Aerial Photo Interpretation

Literature review and discussions with experts provided an understanding of the current state of the art in performing regional wetland inventories. This understanding led to a choice of techniques to be tested during the pilot study. Moderate-scale color aerial photography was deemed the most promising for WSDOT needs. Two small study areas were selected: 1.7 mi of SR-395, an agricultural area in the Colville River valley, and 3.7 mi along SR-18, a forested region with several stream crossings (Figure 1).

Aerial photos were taken in true color and color infrared using three scales: 1:24,000, 1:12,000 (1 in. = 1,000 ft), and 1:6,000 (1 in. = 500 ft). The photography was completed during the first week of April 1990. Two sets of prints were made so that two interpreters, working independently, could identify the wetlands. The two interpreters had very different background experience, which allowed some comparison of accuracy. Interpreter 1 had 4 years of photo interpretation experience, all of which focused on wetland delineation and included considerable field work in various wetland types. Interpreter 2 had more years of experience in photo interpretation, including 4 years interpreting hydrologic features, but no actual wetland delineation experience.

The interpreters used magnifying stereo lenses with stereo photo pairs to identify wetlands. Interpretation standards were set as follows:

1. NWI maps and USGS soil maps could be used for collateral data.
2. Wetlands within 250 ft of the road edge were to be classified according to the Cowardin et al. system and their boundaries drawn on mylar overlays (*6*).
3. All wetlands of at least 0.25 acres were to be included.

To determine the accuracy of the various interpretations, the study areas were assessed in detail in the field by a WSDOT wetland biologist. The field biologist produced a list of wetlands bordering the highway, documenting the Cowardin clas-

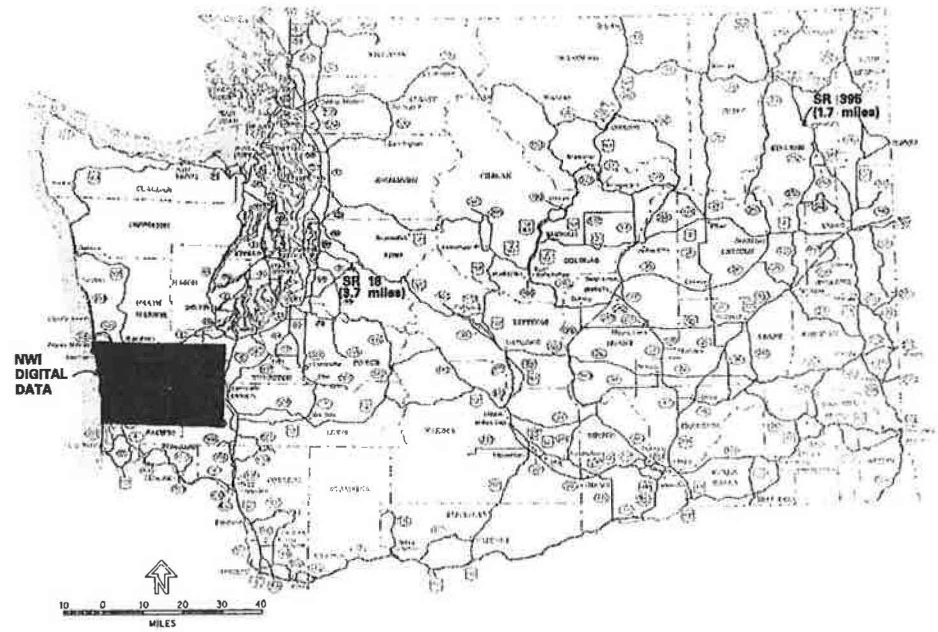

FIGURE 1 Location map of test areas.

sification of each wetland and its linear extent along the highway (*6*). These data are called the ground-truth in the discussion that follows.

A different WSDOT biologist compared the photo interpretations with the ground-truth. The biologist who did the comparisons checked some of the discrepancies in the field. In all cases that were checked, the ground-truth was found to be correct and the aerial photo delineation was in error. This supports the premise that the ground-truth accurately represents reality.

Comparison Methods

To evaluate the accuracy of the aerial photo interpretations, a WSDOT biologist compared the photo interpretations with the ground-truth. The first step was to record the extent and classification of wetlands on the aerial photo interpretations. Then the amount of overlap with ground-truth wetlands was determined at a rough level of comparison. There was no expectation of 100 percent agreement because geographic referencing was not accurate enough to translate wetland positions with complete precision. However, all photo interpretations received the same treatment, so different interpretations could be compared with one another.

The comparison between aerial and ground-truth wetlands determined the number of aerial-mapped wetlands that reasonably matched ground-truth wetlands. Wetlands that were incorrectly classified as to type and those more than 50 percent underestimated or overestimated were considered partially correct, as long as the general location had been correctly identified. Upland areas incorrectly classified as wetlands were counted as errors. Ground-truth wetlands that were missed in the photo interpretation were rated as worst-case errors.

Once these rough comparisons were completed, the results were used to produce a weighted score for each photo type. The scoring formula was based on the following criteria:

1. It is most important that existing wetlands be found by the aerial interpretation, so this criterion was most heavily weighted.
2. It is also important, though less so, that the interpretations should not show wetlands where there are none.
3. Errors in determining the vegetation type or size of a wetland will have a negative effect on the usefulness of the data, so such inaccuracies reduced the score, although these errors carried the least weight.

Computer-Enhanced Videography

As a demonstration project, WSDOT engaged EnviroScan, Inc., to use its aerial video imaging technique to delineate wetlands in the same two test areas that were used for the aerial photo study. Aerial videotapes were produced using four spectral filters: narrow-band chlorophyll a, narrow-band carotene, wide-band infrared, and wide-band ultraviolet. Approximately 1,000 ft along one side of the road was taped on each pass. In addition, one lower-altitude pass was flown to tape a strip 250 ft wide. A computer program was used to find and color-code regions on the videotape that had similar reflectance values (as represented by 256 shades of gray), supposedly areas of similar vegetation. The videos were interpreted by a wetland expert just as aerial photos would be.

The WSDOT research biologist intended to compare the EnviroScan wetland delineations with the ground-truth data in the same way that the aerial photo interpretations were compared. However, the EnviroScan report lacked the information required to do a detailed comparison. Therefore, this method was evaluated on the basis of a live demonstration of the product along with the written report.

Cartography and GIS

WSDOT Geographic Services installed new computer equipment and software shortly before beginning this research project. The new system consisted of an Intergraph 6240 Series Modular GIS Environment (MGE). Before any attempts to handle the data produced by the aerial photo interpreters, a sample data set of NWI maps in digitized form were obtained from the U.S. Fish and Wildlife Service (Figure 1). Techniques and software were developed to input the NWI data, in DLG-3 format on 8-mm tape, into the Intergraph system.

After the NWI data were successfully entered and test maps were printed, the cartographers moved on to processing the wetland information produced by the WSDOT interpreters. Aerial photo overlays for the true color photos in all three scales were used in the trial. The work of only one interpreter was used.

There were several steps in processing the wetland data. First, an existing 1:24,000 base map in digital form was scaled to fit the scale of the aerial photography, then printed. Second, wetland boundaries and labels were traced onto the fitted base map. Third, the annotated paper map was attached to a digitizing table, and standard techniques were used to fit the paper map mathematically to the digital base map and to trace the wetland boundaries. This produced a new digital layer for the base map.

Once the spatial data were entered, maps could be printed in a variety of scales, regardless of the original scale of the aerial photography. To deal with the wetland classification data, additional work is required to set up an Oracle data base to be linked with the base map files. The data base portion of the system will allow data analysis and modeling using the wetland data. For example, users will be able to find out how many acres of palustrine forested wetland are present along a specified milepost range on a given highway. As of this writing, WSDOT Management Information Services and Geographic Services are working together to develop this data base application.

FINDINGS

Aerial Photography

Accuracy

The calculated scores for each of six photo types are shown in Table 1. In theory, the higher the score, the more accurate the aerial photo interpretation. A perfect match between the ground-truth and an aerial interpretation would score 200. A negative score results from a large percentage of errors. Although these scores provide some method of comparison, they are the result of a highly subjective rating system. Therefore, it is not possible to use statistical methods to determine a percentage error or a significant difference between scores.

Two photo interpreters worked independently to delineate and classify wetlands on the aerial photos. Interpreter 1 was experienced in wetland delineation, but Interpreter 2 was not. Despite several years of experience with photo interpretation and acknowledged expertise, Interpreter 2's lack of actual wetland experience was probably responsible for the lower level of accuracy of those interpretations. All scores were considered when selecting the best method, but the scores of Interpreter 1 were probably more representative of photo interpretation work that would be done by trained and experienced wetland biologists.

Scores for both test sections are combined here, although the scores for the eastern Washington section were notably lower than those for the section west of the Cascades. The agricultural land in the eastern test area was particularly difficult to delineate, both in the field and by photo interpretation.

The aerial photos at 1:12,000 produced the most accurate results. At the larger scale of 1:6,000, there were more errors in which upland areas were incorrectly designated as wetlands. At the smaller scale of 1:24,000, accuracy was only slightly less than at 1:12,000, but the interpreters expressed a high level of uncertainty in defining very small wetlands on these photos. Because the goal of the inventory is to find wetlands as small as 0.25 acre, the 1:24,000 scale was rejected.

Although the 1:6,000 scale provides the most detail, both interpreters believed that the 1:12,000 photos had a definite advantage over the 1:6,000—the broader scope of the photos

TABLE 1 Wetland Interpretation Scores for Two Interpreters and Six Combinations of Scale and Film Type

	Scores		
Scale and Film Type	Interpreter One	Interpreter Two	Combined Data
1:6,000			
True Color	72	10	34
1:6,000			
Color Infrared	18	8	-26
1:12,000			
True Color	103	38	54
1:12,000			
Color Infrared	104	72	86
1:24,000			
True Color	98	43	63
1:24,000			
Color Infrared	61	15	35

made overall drainage patterns and ecological relationships more visible. The 1:12,000 scale seemed to provide the best compromise between a detail view (as in 1:6,000) and an overview (as in 1:24,000). The middle scale provided a reasonable level of resolution: quarter-acre wetlands were barely distinguishable without magnification, although magnification was used in the interpretation process.

There was no definite trend showing one film type, true color or color infrared, to be better than another. The higher-scoring film varied with the interpreter, the scale, and the test area. When asked about their preferences in working with true color versus color infrared, both interpreters marginally preferred the true color. These results are surprising, because historically, most wetland photo interpretation has used infrared photography. However, the test photos were taken in early April, somewhat early in the growing season for good plant definition on infrared film.

Estimated Costs

A comparison of costs is presented in Table 2. Aerial photo costs are for 7,030 mi of highway and are the same for color and color infrared. The number of photos required at each scale, and thus the cost for materials, doubles with each increase in scale. In our limited trial, the interpretation and mapping costs were roughly the same for each scale, despite the difference in the number of photos, because the lower resolution at smaller scales made some aspects of the work more difficult and time-consuming.

Computer-Enhanced Videography

For our pilot study, the consultants presented a demonstration of computer-enhanced images of the SR-395 study area, followed by a written report with a more detailed analysis of the wetlands in the area. The SR-18 study area was not analyzed because the aerial videotaping produced inadequate images.

After careful consideration, this method was rejected because of several shortcomings. The videotapes provided black and white images with relatively low resolution. The low-altitude trial showed more detail but also exhibited severe vertical distortion, making the landscape appear to undulate and obscuring the actual topography. When the videos were digitized for computer enhancement, even more resolution was lost.

Although the computer enhancement could highlight areas of similar reflectance, the demonstration showed that these areas were not necessarily areas of similar vegetation. And not all areas of similar vegetation would always have the same reflectance, since reflectance depended on several factors, including phenology and environmental conditions. Therefore, despite the computer enhancement of the images, an interpreter was still required to look carefully through the entire tape. Overall, the computer enhancement required a significant amount of manipulation and interpretation by the operator, and this interpretation appeared to be more difficult than what could be done using color stereo photographs. Reflectance signatures are just one of many clues used in aerial photo interpretation, and with the EnviroScan method the other clues, such as texture and topography, were more obscure than with color aerial photography. The two aerial photo interpreters involved in this study attended the EnviroScan demonstration, and both indicated that they could do much better with standard aerial photos.

Other factors also reduced the feasibility of this alternative. Selecting the best spectral filter would be very difficult because none of the filters was perfectly suited to discriminate a wide variety of wetland vegetation such as we expect to encounter in a statewide inventory. Problems with geographic referencing and map production may be dealt with in future implementations of the system, but at present the techniques are untried. The EnviroScan system may have some potential for wetland inventory use, but the system has never been used for regional wetland identification and mapping, and it seems that several bugs remain.

Cartography and GIS

Techniques were developed to enter interpreted wetland boundaries and classifications as a separate layer of the WSDOT Intergraph system. Some additional work will be needed to quantify and attempt to minimize inaccuracies inherent in the techniques. The available base maps are at 1:24,000 scale, and when these are enlarged to fit the larger aerial photo scales of 1:12,000 and 1:6,000, any errors are magnified. The errors would be greater using the 1:6,000 than the 1:12,000 photo scales. Some additional error may be introduced when the annotated paper maps are fit to the digital base maps. Nonetheless, the maps produced in this trial were deemed to be accurate enough for their intended purpose.

Costs for this portion of the project were almost entirely labor expenses. It was determined that computer costs were insignificant because this project used equipment and materials already in-house for other WSDOT needs. Labor costs did not vary significantly with the different aerial photo scales

TABLE 2 Estimated Costs of Wetland Inventory of 7,030 mi of State Highway

	Estimated Costs[a]			
Method	Materials	Salaries	Travel	Total
Aerial photos, 1:6,000	$428,000	$420,000	$24,000	$872,000
Aerial photos, 1:12,000	$214,000	$420,000	$24,000	$658,000
Aerial photos, 1:24,000	$107,000	$420,000	$24,000	$551,000

[a] Costs include aerial photography, wetland delineation, and entry of wetland boundaries and associated data into the GIS computer system.

used. The task of entering wetland inventory data for the entire state highway system would require one full-time Cartographer 2 working over a 4-year period.

CONCLUSIONS AND RECOMMENDATIONS

The WSDOT statewide inventory of highway rights-of-way should use color infrared aerial photography at 1:12,000. Results of the pilot project and other considerations show that the moderate scale of 1:12,000 is at least as accurate as 1:6,000 and is much less expensive. Although the timing of photography was not evaluated, all consulted experts agreed that the optimum time would be early in the growing season when water levels are high and when differences in vegetative reflectance are maximized.

The pilot project did not clearly distinguish between the accuracy of true color and color infrared photos. The costs are the same, so other factors must be considered. Color infrared has traditionally been the film of choice in the field of wetland delineation from aerial photos. There are some disadvantages to using color infrared photos. Infrared film requires special shipping and storage procedures that make it harder to supply on short notice. Accurate evaluation of color infrared photos requires that the interpreter be experienced in reading infrared photos for the particular area under consideration, since certain reflectance signatures are relied on to distinguish wetland vegetation.

Despite these drawbacks, there is strong support for color infrared from the community of professionals who have been interpreting aerial photos over the years. Virginia Carter, photo interpretation expert with USGS, and Dennis Peters, Northwest Regional Coordinator of the NWI, both claimed to have had very good results delineating wetlands from color infrared photos and recommended that WSDOT should use that film type (personal communications). Considering the close results of our pilot study, these recommendations provide sufficient evidence to suggest that we select color infrared film as the preferred medium.

The selected method will cost approximately $93/highway-mi, including the GIS implementation. This investment will give WSDOT a valuable planning tool. Designers will be able to refer to the inventory and note the presence of wetlands during the development of a project prospectus. Biologists, planners, and maintenance personnel are expected to make frequent use of the maps and other wetland data that will ultimately be available. Field delineations will still be required for projects that affect wetlands, but these will take less time with the inventory data available as a starting place. It will also be easier to find suitable mitigation sites. Finally, by sharing data with other state and local agencies, the WSDOT wetland inventory will contribute to a better understanding of Washington's invaluable wetland resources.

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