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

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Based on test results and other factors, the preferred inventory method will use color infrared film at 1:12,000 scale. WSDOT devised techniques to plot wetland boundaries on existing base maps and is developing an Oracle database 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 miles 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.

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A METHOD TO IDENTIFY, INVENTORY, AND MAP WETLANDS USING AERIAL PHOTOGRAPHY AND GEOGRAPHIC INFORMATION SYSTEMS

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DISCLAIMER

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SUMMARY

This study will propose the best available method to find, classify, and map wetlands along Washington State Department of Transportation (WSDOT) highway rights of way. Such a statewide inventory is already planned to take place over a four year period. This work is needed to comply with state and WSDOT objectives to compile an inventory of all of Washington's wetlands. It is also hoped that the WSDOT inventory will improve early project planning, reduce conflicts resulting from late discovery of wetlands within project boundaries, and reduce biologist field time. The wetland data will be stored in a Geographical Information System (GIS) database which may then be used to produce maps and reports for any section of the state highway system.

Elsewhere within Washington, and throughout the rest of the country, wetlands are being inventoried on both local and regional scales. Interpretation of aerial photographs is the most commonly used method. 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 U. S. Fish and Wildlife Service (USFWS) has used this method to inventory the entire United States. The resulting National Wetland Inventory (NWI) maps work well to define large wetlands, but do not fulfill the needs of WSDOT where small roadside wetlands need to be identified and mapped.

At the local level, large-scale (low altitude) aerial photography has been used quite successfully by some cities and counties. This has generally been supplemented by extensive field work to precisely identify wetlands. The problem with this method is that it is too costly and time-consuming to apply to a large area.

In the hope of finding a reasonable compromise in terms of accuracy and cost, several methods of aerial photography were tested on two study areas, one in western Washington and one in the eastern part of the state. Photos were taken in true color and color infrared using three scales, 1:24,000 (1"=2000'), 1:12,000 (1"=1000'), and 1:6,000

(1"=500'). Duplicate sets of prints were made, and two people worked independently to interpret a full set of photos. The photo interpretations were compared with data from field delineations performed by a WSDOT wetland biologist.

A method utilizing aerial videography was also analyzed. The system, developed by EnviroScan Inc., uses a variety of spectral filters to produce aerial videotapes. A computer program is then used to select regions on the videotape which have similar reflectance values, supposedly areas of similar vegetation. The enhanced video is interpreted by an expert just as an aerial photo would be. After careful consideration, this method was rejected because of several shortcomings, as described in the Findings section elsewhere in this report.

Based on the comparisons and several other factors, the preferred method of performing a WSDOT inventory would use color infrared film at 1:12,000 scale. This technique does not produce perfect accuracy, but neither does any method now known, short of time-intensive field delineation. The 1:12,000 scale photo interpretation does provide a reasonable level of resolution, with 0.25 acre wetlands barely distinguishable. In our pilot project, this scale apparently provided more accuracy than 1:6,000 photos in which upland areas were often erroneously mapped as wetlands.

The WSDOT Geographic Services Branch devised methods to plot the delineated wetland boundaries on existing base maps. In cooperation with WSDOT Management Information Services (MIS), they are developing an Oracle database that will be linked with the map files. The end result will provide the capability to print maps annotated with wetland boundaries and classifications. In addition, a variety of data analyses and modeling tasks will be possible.

When estimating time and cost of a complete inventory, several additional factors must be considered. The best results would be obtained if aerial interpreters could do cursory field overviews before interpreting areas they aren't familiar with. Also, some areas should be ground-checked when the photos alone do not provide a reasonable level of certainty. After the interpreters produce photo overlays with wetland boundaries, Geographic Services will trace the wetland boundaries onto digitized base maps and enter wetland classification into the GIS database. Since WSDOT already owns the necessary computer equipment and software, these items are not included in cost estimates.

Considering salaries, materials, and services, the inventory would cost approximately $658,000 for all WSDOT rights of way over 7030 miles of paved state highway. This amounts to about $94 per highway mile. Since the resulting wetland information base would speed the planning process, reduce costly errors, and reduce biologist field time, this should prove to be a worthwhile investment for WSDOT.

INTRODUCTION AND RESEARCH APPROACH

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. 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 made more difficult by a lack of information about the locations, types, and sizes of all the state's wetland resources.

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 replace wetlands lost to unavoidable impacts. 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 7030 miles of paved state highway.

Such an inventory will allow more precision and fewer false starts during initial phases of project development. It will provide valuable information to aid in project scoping and the early stages of project planning. 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 to 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 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 (*1*), Howland (*2*), 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. Several film types have been used, including normal black & white, black & white infrared, true color, and color infrared. Carter (*3*) stated that color infrared was the best overall choice for wetland identification, but added that true color was a good second choice. Austin et. al. (*4*) found that color infrared was best for surface vegetation, whereas true color was best for submerged vegetation. At present, color infrared is most frequently used for regional wetland inventories.

In large regions, small-scale (high altitude) photos are generally utilized 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"=6666') and 1:58,000

(1"=4833') color infrared photos. After the photos are interpreted by experienced persons, wetlands are plotted on 1:24,000 (1"=2000') 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. Also, the National Wetland Inventory 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, while 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 feasible 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 which 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 DOT. However, this information is usually at a smaller scale than that required for highway planning, and may therefore be useful only as a general guideline. When better data is unavailable, most DOT environmental sections make use of 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 why 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 were no established procedures for inventorying wetlands along transportation corridors, although aerial photo interpretation could 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 database 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 our state's wetland resources, thereby providing better management opportunities.

Research Approach

Aerial Photo Interpretation

Details of research methodology are presented in Appendix A. 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 miles of SR 395, an agricultural area in the Colville River valley; and 3.7 miles 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"=2000'), 1:12,000 (1"=1000'), and 1:6,000 (1"=500'). 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 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 feet of the road edge were to be classified according to the Cowardin et. al. system (5) and their boundaries drawn on mylar overlays. 3) All wetlands at least 0.25 acres large 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 et. al. (5) classification of each wetland and its linear extent along the highway. This data is called the ground-truth in the discussion that follows.

A different WSDOT biologist compared the photo interpretations with the ground-truth (see next section). 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

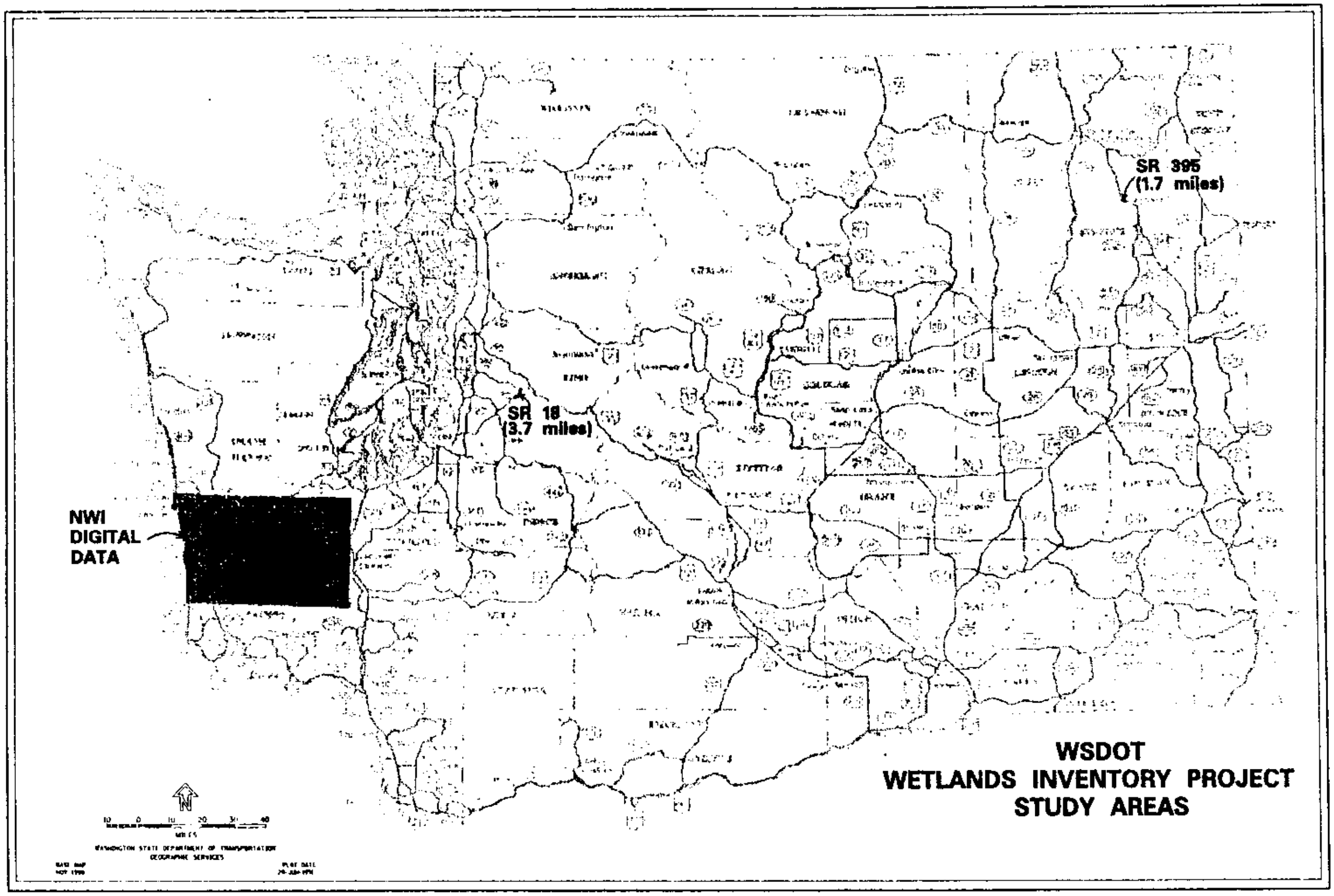

FIGURE 1. LOCATION MAP OF TEST AREAS.

correct while 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% 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 which reasonably matched ground-truth wetlands. Wetlands that were incorrectly classified as to type and those more than 50% 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 which 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 their aerial video imaging technique to delineate wetlands in the same two test areas as were used for the aerial photo study. Aerial videotapes were produced using four different spectral filters: narrow-band chlorophyll a, narrow-band carotene, wide-band infrared, and wide-band ultraviolet. Approximately 1000 feet along one side of the road was taped on each pass. In addition, one lower-altitude pass was flown to tape a strip 250 feet wide. A computer program was used to find and color-code regions on the videotape which had similar reflectance values (as represented by 256 possible shades of gray), supposedly areas of similar vegetation. The videos were interpreted by a wetland expert just as aerial photos would be.

It was the intention of the WSDOT research biologist to compare the EnviroScan wetland delineations with the ground-truth data in the same way as 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

Details of this portion of the project are presented in Appendix B. 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 attempting to handle the data produced by the aerial photo interpreters, a sample data set of NWI maps in digitized form was 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 involved 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 digitizing setup routines were used to mathematically fit the paper map 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 was 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 database to be linked with the base map files. The database 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 (MIS) and Geographic Services are working together to develop this new database application. When this development is completed, there will be a wetland "layer" in the new WSDOT GIS, consisting of a combination of spatial and attribute data.

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 have a score of 200. A negative score results from a large percentage of errors. While 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 percent error or a significant difference between scores.

Two photo interpreters worked independently to delineate and classify wetlands on the aerial photos. Interpreter One was experienced in wetland delineation, whereas Interpreter Two was not. Despite several years of experience with photo interpretation and acknowledged expertise, Interpreter Two'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 One were probably more representative of photo interpretation work that would be done by 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 (1"=1000') 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

TABLE 1. WETLAND INTERPRETATION SCORES FOR TWO INTERPRETERS AND SIX COMBINATIONS OF SCALE AND FILM TYPE.

Scale and Film Type		Scores		
		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

than at 1:12,000, but the interpreters expressed a high level of uncertainty in defining very small wetlands on these photos. Since the goal of the inventory is to find wetlands as small as 0.25 acres, the 1:24,000 scale was rejected.

Although the 1:6,000 scale provides the most detail, both interpreters felt that the 1:12,000 photos had one definite advantage over the 1:6,000 — the broader scope of the photos 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, with quarter-acre wetlands barely distinguishable without magnification, (although magnification was used in the interpretation process).

There was no overall 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. At the 1:12,000 scale, color infrared scored better than true color. When asked about their preferences in working with true color versus color infrared, both interpreters marginally preferred the true color. This was surprising, since, 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 7030 miles 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 lesser resolution at smaller scales made some aspects of the work more difficult and time-consuming.

TABLE 2. ESTIMATED COSTS OF WETLAND INVENTORY OF 7030 MILES OF STATE HIGHWAY.

	Estimated Costs*			
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

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

Computer-enhanced Videography

For our pilot study, EnviroScan Inc. 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 seemed 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. Selection of 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 to be worked out.

Cartography and GIS

Techniques were developed to enter interpreted wetland boundaries and classifications as a separate layer of the WSDOT Intergraph system. Details are presented in Appendix B. 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 photos than with the 1:12,000 scale. Also, 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 since 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 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 utilize color infrared aerial photography at 1:12,000 (1"=1000'). 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.

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 which 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 upon 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 the USGS, and Dennis Peters, Northwest Regional Coordinator of the National Wetland Inventory, both claimed to have had very good results delineating wetlands from color infrared photos and recommended that WSDOT should employ 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 per highway mile, including the GIS implementation. This investment will provide WSDOT with 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 impact wetlands, but these will take less time with the inventory data available as a starting place. It will also be easier to locate 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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Professionals from several agencies served on an advisory committee which helped to guide this research project. Represented agencies included the U.S. Fish and Wildlife Service, U.S. Soil Conservation Service, Washington Department of Ecology, Washington Departments of Wildlife and Fisheries, and the Washington Department of Natural Resources. The authors wish to thank all those who contributed their time and expertise.

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APPENDIX A: METHODS OF PHOTO INTERPRETATION, GROUND-TRUTH, AND COMPARISONS

Aerial Photo Interpretation

The study areas were photographed during the first week of April 1990. Each area was photographed six times, each time with a different combination of the three scales and two film types under consideration. Photos were taken with 60% overlap, resulting in stereo pairs which could be viewed as three-dimensional images with the aid of magnifying stereo lenses.

Duplicate sets of photos were given to two interpreters working independently. The two interpreters had very different backgrounds, which allowed some comparison of accuracy. Interpreter One had four years of photo interpretation experience, all of which focused on wetland delineation and included considerable field work in various wetland types. Interpreter Two had more years of experience in photo interpretation, including interpretation of hydrologic features, but no actual wetland delineation experience.

With the aid of magnifying stereo lenses, the interpreters identified and mapped wetlands which were 0.25 acre or larger. Only those wetlands within 250 feet of the road edge were considered. When an interpreter was 85% certain that an area was a wetland, the wetland boundaries were drawn as an enclosed area called a polygon. Wetland boundaries were drawn on mylar overlays attached to every other photo. Each polygon was labeled with the perceived wetland classification, following the Cowardin et. al. system (*5*).

Ground-truth Delineations

Wetland types and locations were determined in the field by an experienced WSDOT wetland biologist. Each wetland was classified according to the Cowardin et. al. classification system (5). The location of each wetland was presented as a linear range along the highway, using highway construction stations (1 CS = 100 feet) as reference points. For example, the data for one wetland might be: "Palustrine Forest (PFO1), west side, CS 1500 to 1507." This data is called the ground-truth in the following discussions.

A different WSDOT biologist compared the photo interpretations with the ground-truth (see next section). 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 while the aerial photo delineation was in error. This supports the premise that the ground-truth accurately represents reality.

Comparison

In order to compare the polygons mapped on the aerial photos with linear ground-truth data, the polygons were converted into linear data during the comparison. The starting and ending points of each polygon along the highway were considered without attention to the width or distance from the highway. (Only wetlands within 250 feet of the road edge were included.) The amount of overlap between ground-truth and aerial photo wetlands was estimated and each aerial photo wetland was assigned a rating based on this comparison. The rating criteria are listed in Table A1.

TABLE A1. RATING SYSTEM USED TO COMPARE WETLANDS DRAWN ON AERIAL PHOTOS WITH WETLANDS DELINEATED IN THE FIELD.

Rating	Meaning	Criterion
OK	Comparison Correct	Intersection of aerial* and ground-truth* included ≥ 50% of the aerial and ≥ 50% of the ground-truth.
IC	Incorrect Classification	Same as OK, except the wetland classifications did not match.
UE	Underestimated	Intersection of aerial and ground-truth included ≥ 50% of the aerial and < 50% of the ground-truth.
OE	Overestimated	Intersection of aerial and ground-truth included < 50% of the aerial and ≥ 50% of the ground-truth.
IN	Insufficient Match	Intersection of aerial and ground-truth included < 50% of the aerial and < 50% of the ground-truth.
FW	False Wetland	The aerial depicted a wetland not present according to the ground-truth.
WM	Wetland Missed	The ground-truth listed a wetland not depicted by the aerial.

* *Aerial* means the linear extent of an aerial photo polygon, and *ground-truth* means the linear extent of a wetland delineated in the field.

Each polygon on a photo interpretation was assigned a rating according to these criteria. Sometimes several polygons were considered as one if they were very close together and seemed to represent the same general wetland area. When a ground-truth wetland did not have any matching aerial polygon, an additional rating was generated, namely WM (Wetland Missed).

After all comparisons were completed, ratings were tallied to determine the total number of polygons with each rating. For example, the interpretation of true color photos at 1:6,000 produced 32 OK, 21 IC, 4 OE, 2 UE, 1 IN, 22 FW, and 0 WM. Although subjective, some method was needed to compare ratings, so a scoring system was devised. The tally numbers were converted to percents of the total number of polygons, and then a weighting formula was applied to produce a numerical score for each combination of scale and film type. The weighting equation was:

$$2 \times \%OK - 2 \times \%WM - \%FW - (\%IC + \%OE + \%UE + \%INS)/2 \qquad \text{(Equation 1)}$$

The scoring formula was based on the following criteria: 1) It is most important that existing wetlands be found by the aerial interpretation, so the OK classification is most heavily weighted as a positive factor, and the WM is most heavily weighted as a negative factor. 2) It is also important, though less so, that the interpretations should not show wetland polygons where there are no wetlands, so the FW rating is a negative factor. 3) Errors in determining the vegetation type or size of a wetland will have a negative effect on the usefulness of the data, so these items reduce the score, although to a lesser extent than either WM or FW.

The calculated scores for each of six photo types are shown in Table 1 (page 14). 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 have a score of 200. A negative score results from a large percentage of errors. While 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 percent error or a significant difference between scores.

APPENDIX B: MAPPING AND GIS

This section details the mapping and Geographic Information System (GIS) activities associated with the wetland inventory research project. First, the goals and objectives of this phase of the project are presented. Second, the technical details and results of constructing the base maps are discussed. And third, an automated mapping and GIS developmental framework for WSDOT is briefly described. This framework demonstrates how wetland data will be incorporated into the overall Departmental GIS activities.

Goals and Objectives

An automated mapping and GIS tool can effectively help manage wetlands information as part of an overall goal to protect wetland environments. The wetland mapping and GIS must be timely and accurate in order to provide managers, policy makers, planners, and engineers with sufficient information to carry out their assigned activities. The overall goal of the mapping and GIS portion of this project was to make available through maps and reports all of the available wetland inventory information that was needed by WSDOT personnel in order to make quick, reliable and inexpensive decisions concerning wetland environments.

Additionally, a basic intent was to develop an inventory system that could be used not only within WSDOT, but also as part of a larger state or federal effort. To meet this broadly stated goal, and to build a wetland inventory mapping/GIS system that satisfies these general requirements, several specific objectives were established. These objectives are listed below:

1) Develop a system that would produce hardcopy (paper) maps from the National Wetlands Inventory (NWI) digital line graph tapes.

2) Develop the methodologies to construct hardcopy maps from WSDOT annotated aerial photography.

3) Develop the procedures that would convert all WSDOT wetland maps into the NWI DLG-3 format in order to foster the distribution and exchange of wetland data collected by WSDOT staff.

4) Use GIS functionalities in order to provide the necessary and periodic reports on wetlands.

5) Provide a system that would support wetland interpretive activities such as spatial analysis and modelling.

These objectives echo the findings of Pywell and Wilson (*6*) who believe that for the effective management of wetlands, both detailed maps and status reports are essential "to provide baseline data against which the future policies and activities can be assessed." In this report, wetland mapping and GIS methodologies are defined which provide cost-effective and timely information required to support decisions by WSDOT staff.

Procedures and Results

NWI Tapes

This section describes the conversion of NWI data into the Intergraph .dgn (design file, or graphic file) format. One major objective of this research was to efficiently and easily provide hardcopy maps of wetland areas to the staff of WSDOT. As stated earlier, the NWI maps would be used as a rough indicator of wetlands in any area of concern.

The digital data and some documentation were prepared by the USFWS and were provided to WSDOT through a cooperative work agreement to convert the data into ARC-INFO format (the predominant GIS format throughout the state). The data was provided on both 8mm tape and 9-track tape in ASCII format. Each tape contained 64 files; 32 of these files were the spatial base maps in DLG-3 format, and 32 files were corresponding attribute lists in ASCII text format. The spatial extent of each file was one 7.5 minute USGS quadrangle at 1:24,000 scale. The total coverage consisted of the 32 quadrangles in the Chehalis River 1:100,000 USGS topographic map (Figure 1). The 64 files were read from the 8mm tape and stored on the Intergraph 6240 series Modular GIS Environment (MGE), recently installed within WSDOT.

Several in-house programs were written and off-the-shelf software was used to read the NWI files from the 8mm tape and place the data into the Intergraph system. Once the transfer from the tape to the Intergraph system was made, the files were processed through vendor supplied software which converted the DLG-3 formatted data into the cartographic files. Several "parameter" files were created that allowed the user to specify map projection and coordinate information, drawing attributes (color, line width, text style, etc.), and the "level" at which that data should be drawn.

The wetland DLG-3 data for all of the quads were drawn directly into the Universal Transverse Mercator (UTM), zone 10 projection at the 1:24,000 scale. Thus, 32 spatially correct, individual wetland overlays were obtained. Some of these overlays were converted into the Lambert or Polyconic projections in order that the finished paper plot could be registered to either the WSDOT 1:24,000 base map or the USGS DLG base map series. This was done to spot-check the accuracy of position (latitude-longitude) and content (hydrography). Hardcopy plots were then made of adjacent maps to examine the correctness of graphic presentation and wetland polygon identification across map sheets.

Two major problems were encountered when converting the NWI tapes into the Intergraph format. Initial attempts at processing the wetlands DLG-3 data failed. This was due to node, line, and area unique identifiers that were not consecutively numbered (although these were numbered incrementally). The Intergraph conversion package failed when it encountered this situation. A software program had to be constructed that would re-number all of the element descriptions in each of the spatial data files so that the identifiers became sequential. Using this program and the Intergraph software, wetland polygons were drawn efficiently and labeled correctly.

Another problem (one that has been brought to the attention of the USFWS) was with the modifying terms used in the wetland coding schema. Each corresponding attribute description file contains codes that are all upper case, although the intended description was for upper/lower case depiction. This problem made it rather difficult for the inexperienced individual to use the computer generated maps. Since the USFWS indicated that they were aware of the problem, the research team decided to simply incorporate the changes to the coding schema as they are made available.

Based on the preliminary testing results using the NWI tapes, it is feasible that the WSDOT could store entire state coverage of the NWI DLG-3 data on 8mm tapes and make individual quadrangles available for departmental use in either digital or hardcopy form. Initial procedures and software programs have been developed, suggesting that, once all the NWI tapes are made available, there could be efficient and timely distribution of hardcopy or digital maps throughout the agency. The NWI "wetland layer" could be used in conjunction with existing WSDOT or USGS 1:24,000 base maps to form detailed coverage of a selected area. The basic conversion and distribution of this information could be handled with existing staff, with no additional costs (except for the cost of all the 8mm tapes and the paper plots). There would be no impact on the present computing environment.

Mapping of WSDOT Aerial Photo Interpretations

Described below are the procedures that were used to construct maps depicting the wetland areas identified by the aerial photo interpreters. The WSDOT Geographic Services Branch has the ongoing responsibility to create and maintain state base map series at several scales. Therefore, for this wetland project, the research team simply constructed a "wetland layer" that corresponded to one of the existing base maps. No additional base map preparation was needed for this project.

All of the aerial photography was obtained from the photo interpreters. Each photo had an affixed mylar overlay with wetland polygons outlined in color pencil, along with corresponding classification text labels. Only one set of true-color photos annotated by the same interpreter was used. The selection was based on line consistency, and overall neatness and legibility of the annotated information. The set included three scales: 1:6000, 1:12,000, and 1:24,000. The following detailed procedures were used to construct the wetland layer:

1) At a graphic workstation, a cartographer retrieved the 1:24,000 quadrangles of the two study areas from the base map collection.
2) The two quadrangles were each enlarged to 1:6,000 and 1:12,000 and hardcopy paper plots of all three scales were made.
3) On a light table, each paper plot was registered to the corresponding scale aerial photograph by using identifiable features in both the photo and the map (road bends and intersections, streams, or other features).
4) The annotated information on the photo was traced onto the paper map.
5) The paper maps with the polygon tracings were then affixed to the workstation digitizing table.
6) Using standard "digitizing setup" routines, the maps with the wetland tracings were mathematically "fit" to the digital base map, and the information was digitized as another layer.
7) Once the digitizing was complete, paper plots were made of each map at all three scales. These maps contained the digitized wetlands layer.
8) Using these maps, edits were made, such as line closures and adjustments, and text labels were added.

9) Final paper plots were made of the three map scales (1:24,000, 1:12,000, and 1:6,000).

The basic procedure was simply to enlarge an existing base map to fit the scale of the aerial photography, and then trace the annotations on the base map to form another layer depicting the wetlands. The entire procedure for all of the map scales took approximately 18 hours. The work was performed by a Cartographer 2 with little previous work experience using aerial photography. Computer time and materials costs were not significant for this project and were not calculated. However, during full production, a cost of approximately $5.00 per paper plot can be expected. Because of the "stand-alone" nature of the workstations and the fact that no formal billing procedures for this type of activity have been established, it is anticipated that the computer costs would be minimal. Full production schedules could be maintained with one additional cartographer for the duration of the statewide project.

The methodologies in preparing the base maps with the wetland layer were straightforward and involved simple automated mapping procedures. However, several technical problems did arise. First, by having a cartographic technician rather than a trained photo interpreter transfer the wetland polygons to the base map, there were difficulties in identifying and correctly reading the annotations. Some logic errors were encountered, such as two adjacent polygons that were labeled the same. In some cases, polygons were not labeled and could not be identified correctly. The cartographer was hesitant to make any judgments concerning the content of the photos. With experience, it is expected that these problems would diminish. Second, many of the identified polygons were left open, primarily because the limits of the study area were reached, or the pre-determined maximum distance from the roadway was also reached. This is not a problem for simple CADD maps, but would create erroneous and incomplete results once entered into the GIS environment.

A more fundamental problem remains concerning scale and accuracy. A 1:24,000 base map was enlarged to visually fit the other two scales of photographs. This meant that all the "built in" error, due to normal cartographic generalization and production techniques, of the 1:24,000 base map was carried over to the other two map scales and *magnified*. The alignment procedures of matching the base maps with the aerial photos were also somewhat inaccurate. No attempts were made to remove photo distortions, to determine the exact scales of the photos, or to establish formal ground control. Errors of scale and accuracy probably exist in the final maps and some measurement of these flaws should be attempted before full production proceeds. It is possible that simple "rubbersheeting" techniques during the digitizing phase could remove much of the inherent distortion.

Since there is no larger scale digital base map within the department, the existing map scale of 1:24,000 will have to be utilized for the present. Even with above mentioned imperfections, an adequate base map at 1:24,000 (or enlarged to 1:12,000) with WSDOT identified wetlands can be constructed and made readily available with no substantial costs to the department.

GIS Framework for Wetland Data within WSDOT

GIS concepts are new for transportation applications, and few individuals at WSDOT are familiar with this burgeoning technology. Since there are multiple interpretations of the scope of a functional GIS, the purpose of this section is to provide a brief overview of the strategic approach for the development of the wetland applications within the GIS environment. This development is not complete and is considered an ongoing effort. The framework presented here will concentrate on the wetland data and will demonstrate how this information can be readily disseminated throughout the organization and among agencies that have multiple computer platforms.

The Geographic Services Branch is currently working with the Management Information Services (MIS) division of WSDOT to develop a database schema to accommodate the anticipated requests for wetland data queries and reports. The database is Oracle. Using unique polygon identifiers, data will be linked to the base map files in the Modular GIS Environment (MGE) through standard Intergraph Relational Interface Software (RIS). At present the data model is simple, allowing basic inventory query and GIS functions such as polygon analysis ("show all forested wetlands within transportation district 6," for example). All of the NWI attribute data and the WSDOT identified wetlands will be loaded into the Oracle/MGE system, but will be reported and mapped as separate layers.

The immediate approach to the implementation of a wetland GIS is depicted in Figure B1. This strategy is based on the underlying approach that only one, topologically-structured, cartographic base map will be constructed and maintained. There are multiple digital environments throughout the agency, and the users of these environments are also potential users of the WSDOT wetlands data. Each environment could have a different GIS, but the approach outlined below can accommodate this situation:

1) The Intergraph MGE workstations in Geographic Services will be used to build a topologically structured base map, with all of the necessary spatially defined layers such as wetland polygons. This base map will be developed from a variety of sources: Digital Elevation Models (DEM's), TIGER files, DLG files, NWI files, Department of Natural Resources files, and so forth. The resulting common base map for the GIS is called the "spatial objects base." By using one digital base prepared from multiple sources, features on the spatial objects base could be kept current.

2) A series of attribute data layers could then be linked to the common spatial objects base map. The linking mechanism is a geographic coordinate, or some other

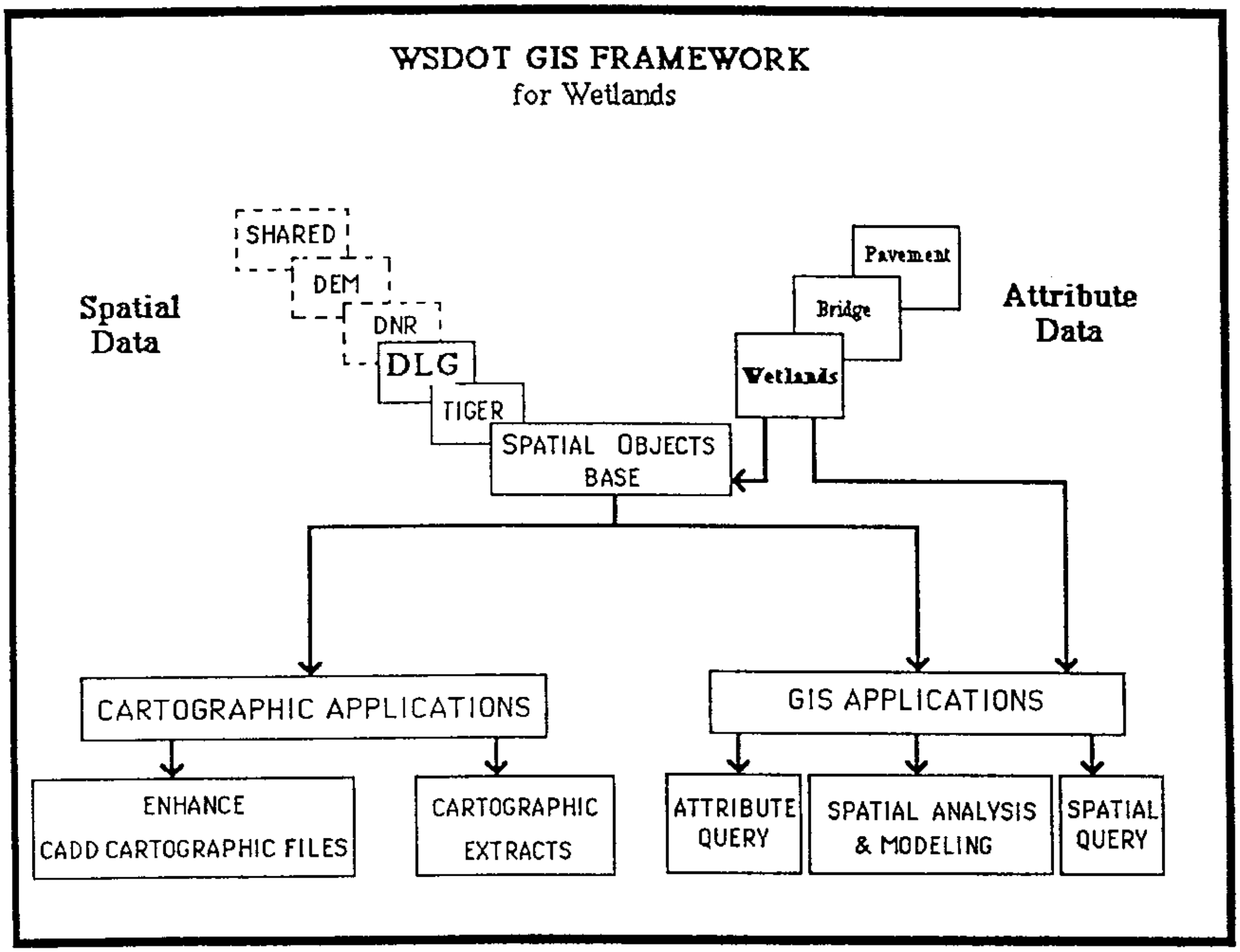

FIGURE B1. WSDOT GIS FRAMEWORK FOR WETLANDS.

unique identifier that is common to both the attribute database and the spatial data. For wetlands, this is the unique polygon identifier.

3) The topological cartographic base with the attached linked attributes could be "passed" to other systems throughout the department or to outside users. It would not matter what GIS or mapping software was in use by the receiving system, as long as it had the ability to interpret the spatial object base (which would be maintained and transferred in DLG-3 format, similar to the NWI files). Individual users could link additional attribute data to the spatial objects base to perform reporting, spatial and attribute query, analysis, and modelling as needed.

4) The common spatial object base could also be used for simple mapping applications by using "cartographic extract" software to create the graphic presentation.

This approach that we are implementing—to develop a common spatial objects base using the DLG-3 format as the standard data transfer structure—is a feasible and economic approach for GIS development. It can be accomplished with existing hardware and software, and it would only increase the digitizing of the wetland layer by about 25 per cent. This implementation should make wetland maps and other information available through a variety of WSDOT workstations. It will also allow this data to be accessed by other agencies concerned with the understanding and protection of Washington's wetland resources.

APPENDIX C: COST ESTIMATES

Cost of aerial photos was based on estimates provided by the WSDOT Photogrammetry Lab. At the 1:6,000 scale, three negatives are needed per linear mile. The 1:12,000 scale requires 1.5 negatives per mile, and 1:24,000 uses 0.75 negative per mile. The state highway system includes 7030 miles of paved highway. The required number of photos was increased by 20% to account for wasted photos generated when the plane must be realigned to follow a curving road. The cost per photo is $17, including aircraft and labor charges. Therefore the total cost of aerial photos at 1:6,000 would be approximately $430,000 (= 7030 * 3 * 120% * 17).

The interpreters who worked on the pilot project estimated that the interpretation took roughly one hour for each highway mile. This time was thought to be slightly less with small scale photos than with large scale, but the differences were minor and would probably not be significant. Therefore, all salary estimates are based on the premise that an interpreter will complete all 7030 miles in 7030 hours. At 24 hours per week (remaining time to be spent in support tasks, including field work), 45 weeks per year (remaining weeks to be used in holidays, vacations, and training), all state highways would be finished in 6.5 years (or 3.25 years with two people doing the work). In addition, one full-time Cartographer would be needed for 4 years to digitize wetland boundaries, enter attribute data into the GIS system, and produce maps. With annual salary and benefits of $40,000 per person, the total cost for salaries is $420,000. Travel costs include $6000 vehicle use fees and $18,000 miscellaneous travel expenses.

APPENDIX D: METRIC CONVERSION FACTORS

Approximate Conversion to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	2.54	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

Approximate Conversion from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	sq. centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	sq. kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F