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Comparison of Floodplain Transect and Remote Sensing Methods For the Lamprey River Instream Flow Project

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COMPARISON OF FLOODPLAIN TRANSECT AND REMOTE SENSING METHODS FOR THE LAMPREY RIVER INSTREAM FLOW PROJECT

1.0 INTRODUCTION

Normandeau Associates, Inc. (Normandeau), the Rushing Rivers Institute (Rushing Rivers) and the University of New Hampshire (UNH) recently completed the Protected Instream Flow (PISF) Study for the Lamprey Designated River (Normandeau, Rushing Rivers and UNH 2008). As part of this study, assessments of the riparian and wetland resources were performed. These assessments used two complementary technical approaches: the Floodplain Transect Method (FTM) and the Remote Sensing Methods (RSM). The purpose of this report is to document the results of a comparison of these methods in assessing wetland and riparian resources for instream flow projects. This comparison includes a discussion of the strengths and weaknesses of the methods used, the cost of each approach, and the potential application of a remote sensing based approach for riparian and wetland resource assessments associated with future instream flow projects.

For the Lamprey River Protected Instream Flow Study, field studies of the aquatic, riparian and wetland resources were performed in 2006 and 2007 to document existing conditions at different streamflows and water levels. The flora and fauna of the Lamprey River channel, channel backwaters, floodplain forests and oxbow wetlands are adapted to hydroperiods (timing and duration of saturation or inundation) that range from rare flood events to semi-permanent inundation. A hydroperiod is a function of water levels relative to landscape position (elevation). Prolonged changes in depth or duration of water levels during critical life stages of aquatic, riparian or wetland floral and faunal communities could cause stress, injury or death, and alter community composition and habitat functions. Using this information, relationships between streamflow, water level, extent of habitat and habitat condition were developed to derive the protected instream flows for specific protected aquatic, riparian and wetland entities.

The FTM is a field intensive method (Section 2.0) that establishes reference transects that span the river and onto the surrounding riparian zone, and, if present, wetlands. Through field visits and surveys at different streamflows, a relationship can be developed between flow, water level and area of inundation. Alternatively, the relationship between streamflow, water level and habitat area can be developed through the acquisition of aerial photography (Section 3.0) at different streamflows. Where the FTM gives a vertical two-dimensional perspective, RSM provide a horizontal two-dimensional perspective. The linking of both the ground based (FTM) and remotely sensed information through modeling (RSM) provides both the cross-sectional and channel length perspective for determining habitat area and its relationship with streamflow.

The FTM and RSM methods could also be used in future instream flow studies performed on other designated rivers. An alternative approach to the one used on the Lamprey River would be to maximize the utilization of the RSM, while minimizing the field work required by the FTM. This combination could result in considerable savings in effort, time and cost for those projects.

The following sections discuss the procedures associated with the floodplain transect and remote sensing methods, the products generated, the strengths and weaknesses of each method, any problems encountered during the Lamprey study, and recommendations for improving each method. Results and

costs of each method are then compared and recommendations presented for the use of these methods on future projects. In addition, a discussion of the field verification of the aerial photography events is provided in the last section of this report.

2.0 FLOODPLAIN TRANSECT METHOD

The floodplain transect method (FTM), as adapted from a method developed at the University of Massachusetts, Amherst (Jackson, unpublished), was the primary method used for riparian flora and fauna during the PISF work on the Lamprey River pilot instream flow project for the Department of Environmental Services (DES). In this method, the landscape positions (relative elevations) of riparian resources including rare plants, natural communities, potential nesting/breeding sites of birds, amphibians and reptiles, etc., that are dependent on or sensitive to river water levels are surveyed along transects through the floodplain and river channel. Observed water levels that inundate or saturate these landscape positions are correlated with water flows recorded concurrently at a USGS gauge (and modeled, if sufficient data is available). The duration and timing of flows required to meet the needs of each sensitive resource are identified based on literature-derived determinations of water level requirements. The floodplain method requires ground survey, aerial photo mapping, multiple site visits, and extrapolation of transect data to adjacent riparian areas (Figures 1 and 2). The level of detail that can be collected on each transect is very high, but extrapolating the collected information to the surrounding landscape requires assumptions about the adjacent habitats and elevations.

The use of the FTM in the assessment of the wetland and riparian resources of the Lamprey Designated River followed specific procedures, which are outlined in the following section.

2.1 PROCEDURES

- Transect locations for the FTM were chosen by consulting maps of known sensitive resources such as: rare, threatened and endangered (RTE) plant and animal species, exemplary natural communities, and riparian habitats considered important for wildlife (marshes, vernal pools, oxbows, etc.). These maps were acquired from state agencies, researchers or other published sources. It was determined that four transects, spaced along the Lamprey Designated River, could represent all of the known sensitive resources.

- Transects were surveyed with a transit and stadia rod, recording elevation relative to a station and distance from the station to cover type boundaries, elevation breaks and features, and standing water at the time of the survey.

- Transect elevations were plotted using computer-aided design (CAD) software (Autodesk Civil 3D 2008) and cross sections were created. Vegetation cover types, other resources and substrate types between points were labeled on the cross sections.

- Cover types around each transect were mapped on non-stereo aerial photos flown at the beginning of the project. Wetlands were classified using the US Fish and Wildlife method (Cowardin, et al.1979). Additional wetland area estimates for the river corridor were made from National Wetland Inventory (NWI) maps.

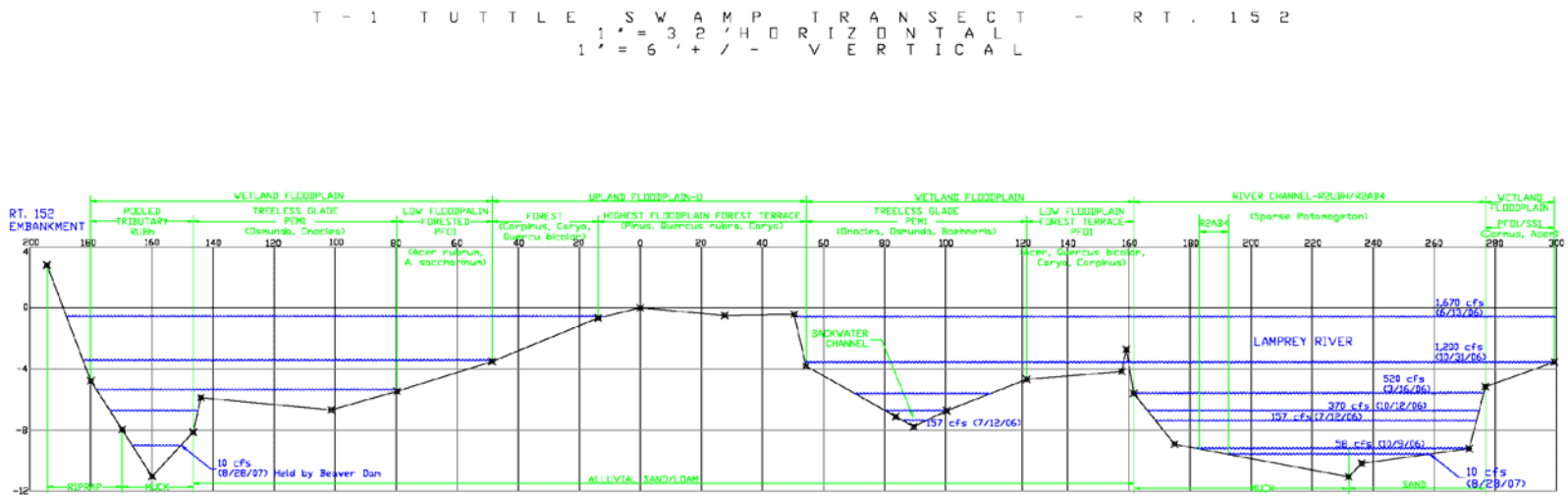

Figure 1: Transect graph developed from ground survey data using the FTM technique.

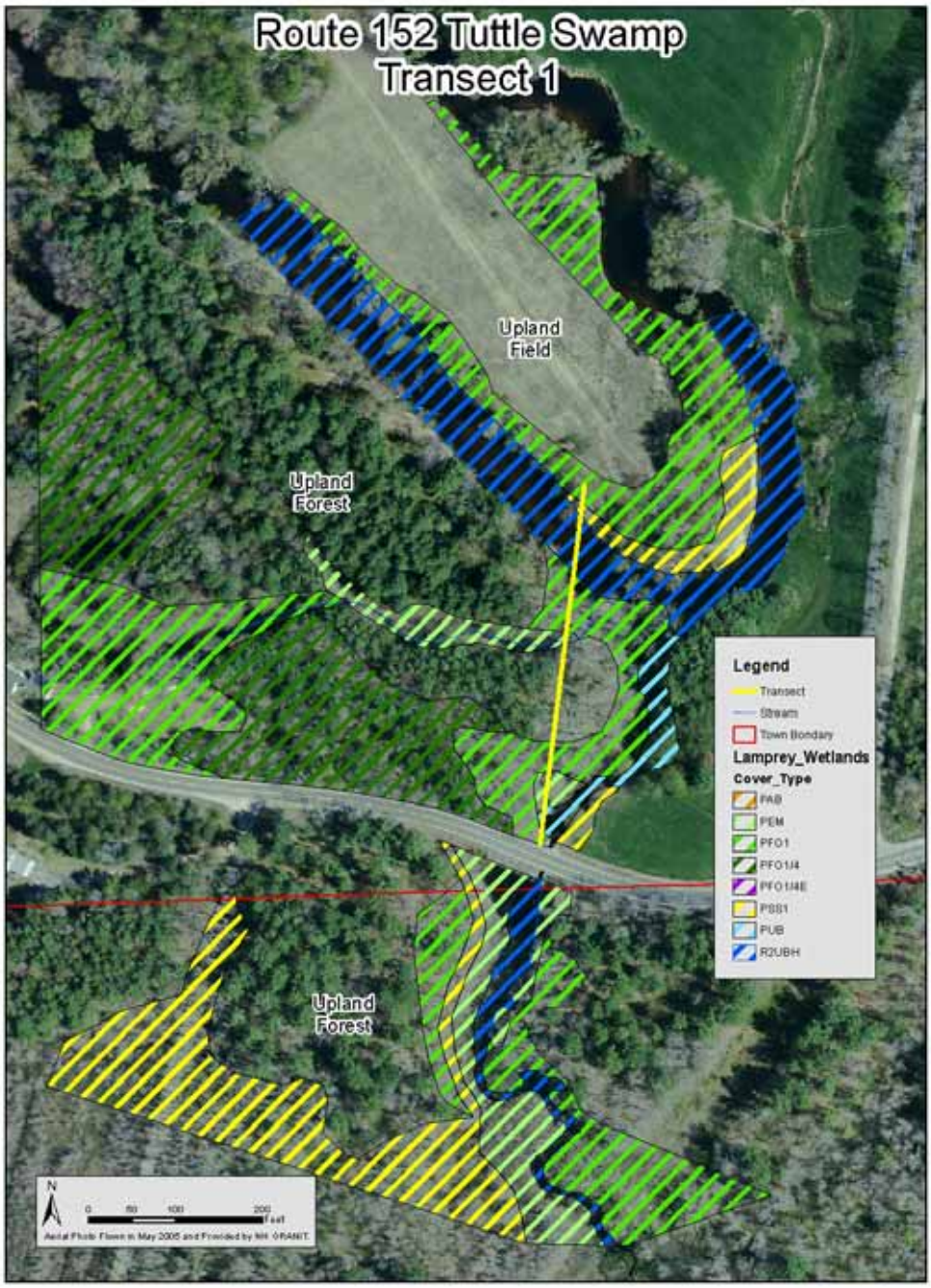

Figure 2: Extrapolation of FTM transect data using the project acquired aerial photography.

- Water levels were to be recorded with electronic water level recording devices installed at stations along the Lamprey Designated River, but most of these were lost or were moved by flood events in 2006. Instead, the observed edge of water was mapped on cross sections during approximately 10 field visits timed to cover a range of flows and seasons. Concurrent flows recorded at the USGS gauge (#01073500) at Packers Falls near Newmarket (as reported on the USGS gauge website) were recorded on the cross section for each site visit.
- Plants and wildlife observed along transects were also recorded during these visits.
- Literature was consulted to identify known hydroperiod adaptations of sensitive resources; some adaptations were inferred from related species and/or habitat information, such as soil maps.
- The flows associated with the water levels required by sensitive resources at various landscape positions, as recorded at the USGS gauge, were identified along with durations and timing of these flows important for resource survival and health.
- The areal extent of different community types that could be affected by permanent changes in flow was determined through the cover type maps and aerial photos.

2.2 PRODUCTS

- Transect cross sections with plant community and sensitive resource information.
- Cover type maps in the vicinity of each transect.
- Flows associated with selected landscape positions on each transect.

2.3 PROBLEMS AND RECOMMENDATIONS

- High water elevations during much of the summer of 2006 delayed transect establishment (floodplains were submerged and river flows were treacherous).
- Ground surveying through most wetlands was difficult during high flows; bathymetry in impounded areas was difficult in all flows with the survey tools at hand.
- Significant travel time was needed for visits (from office to field) to document water elevations along transects at a range of flows.
- Electronic water level recording devices installed at stations along the Lamprey Designated River were lost or moved during flood events early in the project; these were not replaced, so development of a stage-discharge relationship was not possible. Replacements would have provided valuable data to model flows not directly observed, thus filling in observation data gaps.
- Transect surveys were not tied to a standard elevation datum, which, though more costly and time consuming, could have been used in other applications.
- Delineating cover types on non-stereo aerials is less accurate, as relative vegetation height and ground elevation are not discernible.

- Due to intensive data collection, only four transects were surveyed in the Lamprey Designated River. Extrapolation from only these sites to the scale of the entire Designated River involves significant amounts of uncertainty.

3.0 REMOTE SENSING METHOD

A series of aerial photos were acquired in conjunction with on the ground habitat surveys of the Lamprey Designated River. These data sets were used for the correction of hydromorphologic habitat polygons within study sites and to provide information about potential habitat changes in the areas that were not repeatedly mapped. The other main goal in their acquisition was to use the imagery for quantifying the riparian and wetland resources along the Lamprey Designated River. The success of the Remote Sensing Method (RSM) for this type of analysis relied heavily on securing high resolution, georectified imagery with minimal canopy coverage along with access to the appropriate photogrammetric software.

The first method of cover type mapping involved using Leica Geosystems Photogrammetry software suite and the block files that were developed while originally processing the individual flight lines. A block file is a tool that acts as the storage location for all of the processing information applied to the raw individual images along a flight line. This file builds upon the initial spatial information recorded by the flight computer at the instant of image capture and allows for processing the individual files into a seamless image. This file therefore contains multiple processing steps which are accessed to view the imagery in three dimensions (3D). Because of the 60 percent or greater overlap of adjacent images, once processed, the concept of stereo pair viewing can be applied using a specially designed screen to view adjacent images in 3D.

Using this technology, the delineation of vegetation polygons in 3D was attempted, thereby assigning an elevation to each of the defined units. This process involved studying an area in the 3D viewer and toggling through the collection of imagery at different flows on a second monitor to help identify the spatial extent of vegetation unit. The process worked, but was somewhat cumbersome. However, the lack of a detailed digital elevation model (DEM) made it impossible to pinpoint the elevation of individual units with accuracy. Issues relative to the DEM will be discussed further in the sections below.

Additionally, the elevation assigned to each polygon would be based on a height above sea level for the entirety of the polygon, rather than an elevation in reference to river water level. Because of the natural slope of the river corridor and the lack of controlled data on adjacent river elevations, the final polygon elevations would prove difficult to sort based on their position above adjacent water level. It was decided that this approach would require a more robust data set, and the acquired imagery would be better suited to a two-dimensional approach to annotation.

The strength of the imagery dataset lies in the repeated acquisition of data during both different flows, as well as at different times throughout the seasonal growing period. Therefore, all of the available imagery was loaded into ArcInfo, which allowed for the sequential viewing of the riparian corridor areas over the range of captured flows and seasons. Using this method, polygons of cover types were mapped throughout the Lamprey Designated River (Figure 3). Those polygons were edited to minimize gaps, and then overlap and areas were calculated. Finally, a quantification of cover type area was generated and included in the main report.

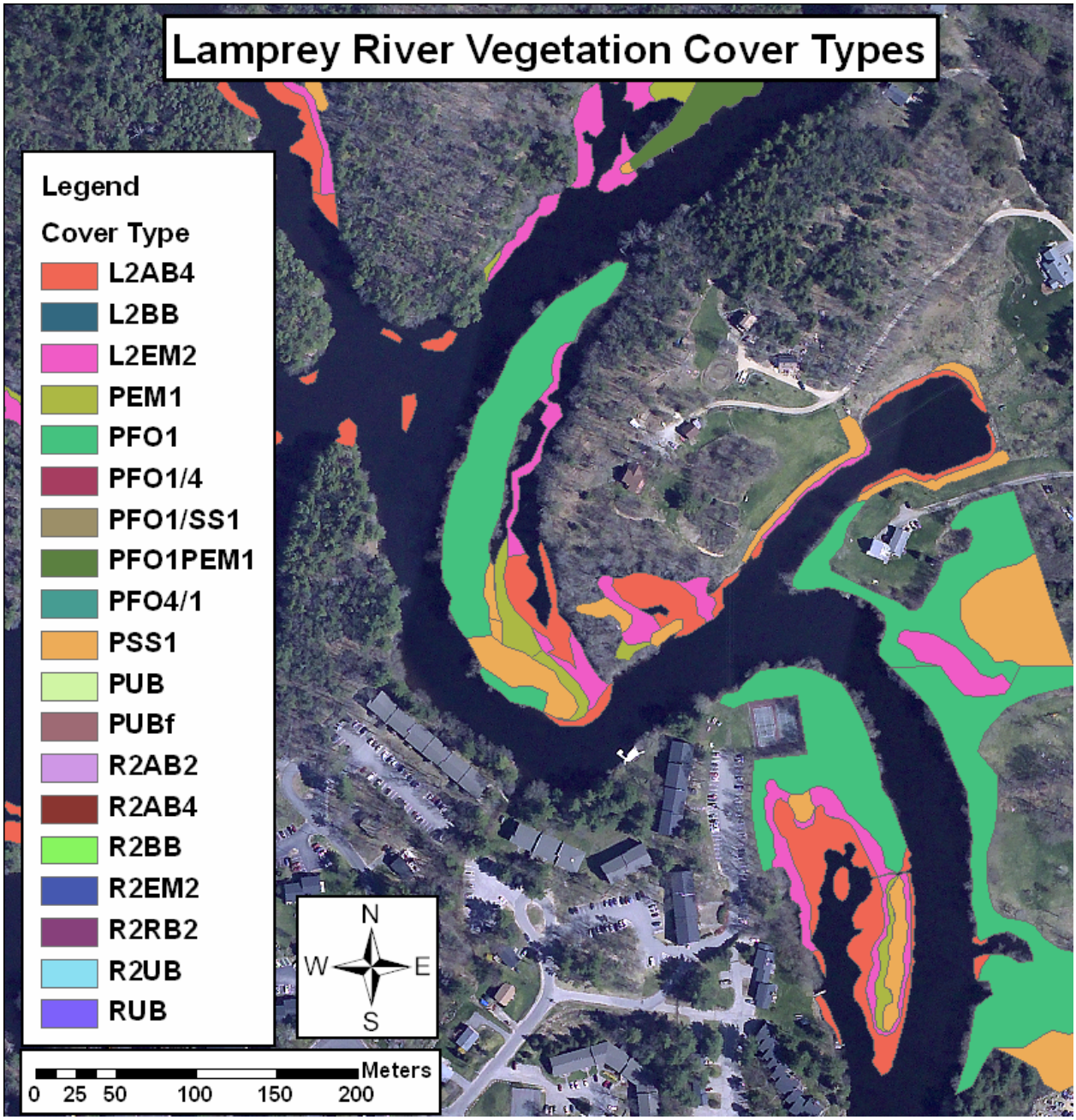

Figure 3: Example of vegetation cover type annotated aerial from a portion of the Macallen Impoundment using the RSM technique.

3.1 PROCEDURES

- Six sets of high-resolution digital coverage of the Lamprey Designated River showing different flow conditions (14 cfs to 251 cfs) were obtained (Table 1) over the course of this study.

Table 1: Flight Date, Target Flow and Approximate Discharge at USGS Gage 01073500 Lamprey River near Newmarket, NH.

Target Flow (CFSM)	Discharge at USGS Gage (CFS)	Flight Date	Pixel Resolution
Reconnaissance	148	11/17/04	30 cm
0.1	14	8/23/07	20 cm
0.2	52	9/28/06	20 cm
0.5	110	8/08/06	20 cm
1.0	183	4/29/06	15 and 40 cm
1.5	251	7/26/06	20 cm

- An initial reconnaissance flight was conducted in association with a planned aerial photography mission on the Souhegan River in November 2004. This imagery was processed by Rushing Rivers for use in project planning prior to the initiation of the on ground studies.

- Complete coverage in natural color at 40 cm per pixel in a solid block of east/west flight lines was collected during the April 2006 flight to provide background imagery and documentation of current land use outside of the immediate riparian corridor.

- Large-scale (20 cm per pixel) multispectral coverage using repeated flight lines on each survey date along the riparian corridor of the Lamprey Designated River were collected by Research Aviation during the five target flows identified by Rushing Rivers. The approximately 400-meter wide sections of imagery were designed to accommodate the needs of the collaborating wetland biologists

- Data collection and processing of the five sets of target flow imagery was contracted.

- Digital elevation models were not generated from these flight lines because it was determined through information communicated from the FTM and through observations of water level change during the range of flows surveyed, that the achievable vertical resolution would not provide any additional useful information. Additionally, image registration and rectification problems ultimately led to abandoning DEM generation.

- Processed aerial imagery was used extensively when editing field annotated instream habitat polygons for each corresponding flow.

- Aerial stereo pairs were viewed by Rushing Rivers and Normandeau using ERDAS LPS softcopy photogrammetry (Imagine 9.1) software. Wetland and floodplains were digitally mapped in ArcView and classified with the US Fish and Wildlife method (Cowardin, et al. 1979).

- Wetland/riparian cover type information collected during FTM field work was used to ground-truth the cover type mapping.

3.2 Products

- Aerial photo record of entire Lamprey Designated River at multiple flows and different months.
- Wetland cover type maps and quantities for most of the Lamprey Designated River, including short-season, non-persistent emergent wetlands not visible on standard leaf-off aerial photos or NWI maps.
- Documentation of pre- and post-flood conditions on the Lamprey Designated River was possible.
- Use as a project planning and development tool.

3.3 Problems and Recommendations

- Due to delays in contracting, some flights and surveys were conducted before the requirements of tasks were fully evaluated. As a result, only some of the procedures necessary were in place to ensure that elevation data recovered from the processed imagery would be accurate enough to allow for digital elevation modeling. Without the ability to reproduce georectified DEMs with sub-meter accuracy, the correlations between vegetation type, elevation, and river flow could not be established. This hindered the extrapolation of inundation extents to additional high and low flows not captured by the aerial photos.
- Flood flow conditions were beyond the scope of mesohabitat data collection; however, aerial photos taken during these high flow events would have been valuable for delineating floodplain forest extent and for identifying flood sensitive areas of the Lamprey Designated River.
- All but one flight (April 2006) were flown during leaf-on conditions because of their association with targeted flows for habitat survey mapping. These flows adequately covered the range needed for MesoHABSIM modeling, but viewing the forest floor below the dense deciduous trees and shrubs proved difficult on the Lamprey River. Coniferous coverage in some locations likewise obscured the ground and water elevations below. A flight conducted in November 2004, as a reconnaissance tool, also took place during leaf-off conditions.
- There was incomplete photo coverage of the Newmarket Pool, located upstream of the Macallen Dam. The initial flight lines were developed to maximize the coverage of the main channel of the Lamprey Designated River and its omission was not realized until the final products were delivered. Full coverage of the Moat Island complex is only available on the April 2006 40 cm image block. Missing this area was disappointing because of its potential for rich assemblages of vegetation cover types.
- The areal extent of water level change did not vary greatly under the range of flows in the aerial photo set, particularly in the impoundments of the Macallen and Wiswall Dams. The water level controls of these large impoundments resulted in water level elevation changes that were difficult to detect, even considering the high resolution of the imagery.

- The imagery acquisition subcontractors excelled at their willingness to prepare for a flight and capture aerial imagery on short notice. Since specific flows were targeted during this project, there were often brief windows of opportunity for data collection. The requirements of stable flows in the target range and acceptable weather conditions were complicated because of the needs to also have good visibility, specific cloud cover conditions and light upper level winds for the photo data acquisition. Fortunately, the contractor was able to meet the timing needs for most requests.

- Processing of the aerial imagery into the requested products did not meet the desired timeline or expected quality standards. Delays in data turn around made it impossible to improve flight lines between each survey. It also led to miscommunication and misunderstanding on the desired product and potential use of the imagery. The quality of the processing was judged to be too low for our purposes. Consistency in format, color balance and quality control was not maintained through the processing. The requested processing steps were not adequately maintained or provided, and the data supplied was in an inconsistent and disorganized format, which makes reprocessing imagery difficult. Ground control points were not adequately utilized, leading to a shift in features along the flight path. Hence, the imagery needed to be further processed to better align the river corridor, leading to some additional undesirable distortion.

- The hardware and software for digital stereo viewing is expensive and not commonly available. Use of the Aerial Photography Lab at Mt. Holyoke College was essential and greatly appreciated. However, a more local station for this time-consuming work would improve efficiency and lower costs. The non-stereo review of the photographs also required the acquisition of a high capacity external hard drive due to the large size of the associated data files.

4.0 HYBRID METHOD

The FTM was the primary assessment tool for determining protected instream flows for riparian species along the Lamprey Designated River. However, as the cover type mapping was completed on the RSM aerial photos, this information became a valuable supplement to the National Wetland Inventory Maps for quantifying wetland types potentially affected by changes in flow. The late summer photos also allowed mapping the maximum extent of non-persistent, emergent, riverine wetlands that are not visible any other time of the year and therefore do not appear on leaf-off photos or most NWI maps. The RSM photographs also provided evidence of limited change in surface water extent in response to flow variation within large impoundments which was considered in the development of PISF values for some protected plant and wildlife species.

The field data and photographs collected for the FTM were used to assign cover classifications to the various plant community signatures on the RSM aerial photos, essentially offering advanced ground-truthing.

5.0 METHOD COMPARISON AND COSTS

5.1 FLOODPLAIN TRANSECT METHOD

The FTM requires elevation surveys and multiple field visits for each transect, but can provide information on sensitive resource landscape position in fine detail. Riparian or channel species with very narrow distributions can be accurately located and assessed if the transect location is chosen well. For example, a rare plant found on the riverbank or cobble bar at a particular elevation relative to seasonal water levels can be accurately mapped. The only limit to the level of detail that can be acquired on a given transect is the accuracy of the survey equipment. However, establishing transects is labor intensive, access can be difficult, and the extrapolation of transect data to the surrounding landscape requires numerous assumptions. The use of survey grade GPS can be limited by extensive canopy cover requiring use of more effort intensive field survey equipment. Therefore, only a few transects could be surveyed, limiting spatial extent of the analysis. For recording water level information, pressure transducer and data logger equipment can be expensive to acquire and is subject to damage or loss from storm events.

Four transects established with the FTM method captured the array of flow-dependent riparian resources along approximately 10 miles of the Lamprey Designated River. The large pool impounded by the Macallen Dam was not covered by the FTM, and therefore two miles of the river were subtracted for costing purposes. The assessment covered 13 state-listed plants and animals, and seven natural communities. The cost (Table 3) for field work, data analysis and cross section development (not including the report, meetings etc.) was approximately $23,350 ($22,150 labor and $1,200 expenses). This is approximately $ 5,840 per transect. The cost per river mile for the FTM as employed on this study is approximately $ 2,335.

Table 2: Labor/Expense Assessment – FTM for Riparian Communities, Plants and Wildlife

Task	**Hours**	**Labor Cost Estimate**	**Expenses**
Field Reconnaissance	20 – Wetland Ecologist	$ 1,900	$200
Transect Surveys, data collection	100 – Wetland Ecologists	$ 9,500	$800 travel $200 GPS
Hydro-data/x-sections/cover type maps	80 – Wetland Ecologist 45 - Draftsman	$ 10,750	
FTM Task Subtotal	**245 Hours**	**$ 22,150**	**$ 1,200**
IPUOCR Report -	40 – Wetland Ecologist	$ 3,800	
PISF Report	200 – Wetland Ecologist	$ 19,000	
Meetings (6) and prep	50 – Wetland Ecologist	$ 4,750	$140 travel
Related Reports and Presentations Subtotal	**290 Hours**	**$ 27,550**	**$140**
Approximate Total:	**535 Hours**	**$ 49,700**	**$ 1,340**

Table 3: Labor and Expense Assessment – RSM

Task	Hours	Labor Cost Estimate	Expenses
Field Reconnaissance	20 – Wetland Ecologist	$1,900	$200
Aerial Photo Flights	Subcontractor		$10,000
Post-processing	40 – GIS Technician	$2,000	
Cover Type Mapping	50 – Wetland Ecologist	$4,750	
Digitizing	20 – GIS Technician	$1,000	
RSM Task Subtotal	**130 Hours**	**$9,650**	**$200**
IPUOCR Report	40 – Wetland Ecologist	$3,800	
PISF Report	200 – Wetland Ecologist	$19,000	
Meetings (6) and prep	50 – Wetland Ecologist	$4,750	$140 travel
Related Reports and Presentations Subtotal	**290 Hours**	**$27,550**	**$140**
Approximate Total:	**420 Hours**	**$37,200**	**$10,340**

Table 4: Summary Table of Data Acquisition, Products and Costs Associated with the Floodplain Transect Method and Remote Sensing Methods.

Feature	Floodplain Transect Method	Aerial Photo Method
Data Acquisition	Ground survey with transit and rod	Aerial photo flights
	Elevation data for selected transects – extrapolate to adjacent habitats	Elevation data for entire Designated River
	Minimal post-processing of survey data required	Complex post-processing of flight data required
	Concurrent stage/discharge data needed and modeled	Concurrent discharge data and DEM modeling
	Detailed resource data on transects; ie. exact plant elevations if necessary; level/accuracy of data consistent between cover types	Less detailed resource data; individual resource elevations extrapolated from cover type data; some loss of detail/accuracy in forested cover types
	Multiple field visits for data collection	Limited ground-truthing required
	Drafting of cross-sections; limited aerial photo review needed – minimal equipment (stereoscope if stereo pairs available)	Detailed aerial photo review; limited availability of necessary equipment (hardware and software)
	Weather/flow can affect field work schedule	Weather can affect flight schedule; flow not a problem
Products	Detailed transect cross sections and modest adjacent cover type maps	Wetland cover type maps and quantities for most of the Designated River
	Measured flows associated with selected landscape positions on each transect	Aerial photo record of entire Designated River at multiple flows (photo documented) and continuous flows (modeled)
Cost	$51,040	$47,540

5.2 REMOTE SENSING METHOD

The RSM reduces the quantity of field survey visits, and provides visible inundation information from areas well beyond the transect location, thereby reducing extrapolation error. This is particularly valuable in complex floodplains with numerous backwaters or oxbows with varying levels of connection to the river, and also in remote areas (unless heavily vegetated). The cost of flights, post-processing of the data, and specialized equipment necessary for digital aerial photo interpretation may be prohibitive on small river reaches. However, the RSM technique allowed for access and assessment of the riparian communities throughout the Lamprey Designated River.

Calculation of cost for the RSM (Table 3) involves the consideration of several components to the project. Five sets of high resolution imagery were collected, georectified and mosaicked covering approximately 15 miles each time or a cumulative 75 miles. Acquisition and processing of this imagery was contracted for $10,000, which equates to approximately $133 per river mile. Additionally, Rushing Rivers was granted $7,000 in salary for our involvement in developing the work plan, assisting in the analysis, quality control and evaluation of the RSM. This amount adequately covered the cost of work plan development, training and data quality control. Additional time was unexpectedly invested in quality control related to the provided imagery, organization and collection of imagery and the re-creation of block files used in the LPS 3D viewing. These additional tasks deviated from the original project plan and led to additional labor costs. It was also determined that mapping of the entire Lamprey Designated River in 3D would have led to a significant increase in project hours because of the technical nature of the software and project.

The RSM method covered the entire Lamprey Designated River, with an approximate cost per river mile of $1,638. The number of transects needed to adequately capture all flow-dependent resources on a given river will vary, but if 0.4 transects/mile is considered as a minimum, then rivers greater than 1.5 miles will be more efficiently assessed by the RSM than the FTM, unless the area of conifer cover is substantial. This calculation assumes that the cost of aerial photo acquisition and processing is similar to that shown in Table 3 below. Since this data is likely the single most expensive component, fluctuations in the cost of its acquisition could greatly affect the cost effectiveness of the project. Considering this, the potential for additional data processing costs on other rivers and the likelihood that the 0.4 transect/mile minimum would be determined to be too fine scale in most projects, it is more likely that projects greater than five miles would have a greater cost effectiveness with the RSM.

6.0 RECOMMENDATIONS FOR FUTURE STUDIES

Continued development of the RSM for use in riparian and channel species assessment can provide useful information about the quantity and distribution of vegetation types throughout a Designated River. The use of an aerial assessment technique can gain the user access to information throughout the riparian corridor and beyond, including areas distal to the river, but potentially still intermittently connected. The strength of this technique is the ability to view high resolution imagery throughout the study area and at several discharge levels. Leaf-off conditions provide the best opportunity to view the extent and distribution of watershed features; however, dense conifers can obscure features year-round, possibly precluding the application of this method from some small rivers. Photography taken throughout the growing season can provide useful information for remotely identifying vegetation based on colors and texture. Finally, aerial photographs captured during flooding or other high flow events can provide

additional information about the range of water elevations throughout the study area as well as the possible extent of flood plain forest. A combination of aerial photography from these three phases would provide the best set of information to successfully access vegetation cover types remotely.

For the Lamprey River Protected Instream Flow study, all of the aerial imagery collected were in association with predetermined targeted flows and concurrent habitat survey mappings. It was believed that the range of flows captured during the study would provide adequate information to assess the vegetation cover types in the Lamprey Designated River. However, it is now our opinion that a different approach to the timing of aerial photography capture would have afforded a greater opportunity for success in this aspect of the project. The five habitat survey flows were chosen to represent a common range of summertime habitat conditions for the Lamprey River. Flows higher than the 1.5 cfsm survey were determined to be too difficult for data collection and presented added dangers to the field technicians. During each of these targeted flow flyovers, field technicians were in the river collecting habitat data which then could be related back to the aerials captured on that day. A similar approach would have been helpful for the RSM aquatic and riparian vegetation assessment. Coordination of surveys with the research biologists, so that field work could be scheduled at the time of the fly-over, could have provided more information about the spectral signatures of vegetation types as well as increase the amount of project ground truthing.

The success of the RSM was severely hampered by a number of factors. The before mentioned contracting delays resulted in the initiation of field work and therefore the capture of aerial photography before plans for use and collaboration of this information could be determined. Furthermore, delivery of the final products took longer than was expected and by the time it was delivered, it was too late to correct any misunderstandings in processing expectations and deliverables. The quality and presentation of the delivered data was lower than expected and the condition of the processing pipe-line data provided made it difficult to reprocess the data without starting over and developing new block files. After reviewing the data and realizing its inadequacies, negotiations for revisiting and reprocessing the data were limited to an agreement that the images should be warped to all match one set of imagery. This, in the end, limited our ability to complete the project as originally expected.

Cooperation in planning flights and the personnel availability on last minute notice, which is often associated with capturing specific discharge levels, was a strength of the imagery contractor. Coordination of fieldwork involving multiple parties can be very difficult. Planning for fieldwork at each of the five target flows required checking the USGS gage daily, forecasting trends in flows accounting for seasonal changes in base flow, daily analysis of multiple weather forecasts to target durations of ideal conditions as well as estimate the impact of any precipitation events on river discharge, preparation of field gear to be ready at the appropriate moment and constant contact with personnel to insure availability of field technicians. This is further complicated by the need to project these periods of survey opportunity far enough in advance to secure the use of the plane, pilot and camera operator. Their availability is also impacted by additional factors such as equipment maintenance/repair, upper level winds, fog and cloud cover. Without the high level of forecasting, planning, coordination and cooperation with the aerial photography contractor, collection of imagery during field work would not have been possible. However, a more detailed contract including explicit request and deliverables would have greatly benefited the project.

Additional communication with the individuals involved in the planning, collection and use of this imagery before the start of the field season would have also led to greater success. With the late start to

the project and the rush to begin data collection before target flow opportunities were missed, some planning details were overlooked. One of these is the use of very accurate ground control points. It was expected that the use of profiling LIDAR (**Li**ght **D**etection **a**nd **R**anging) during image capture along with information directly from the airplane's computer would result in high resolution imagery with excellent reproducibility and highly accurate elevation information. The use of this system allowed for reductions in processing time, but at the cost of spatial precision. Additional control points would have been added to the processing pipeline by placing precisely surveyed targets throughout the watershed and pinning the aerial imagery to these highly accurate points in space during processing.

A great deal was learned about the application of the RSM through this project and we expect that its application on a future project could provide a great deal more information. One recommendation is reducing the collection of aerial photos to three flights, which would be collected at specific flows and growing periods of interest. In early spring, the goal would be to conduct an initial survey during leaf-off conditions, which would also represent a medium to high flow for habitat suitability mapping. Processing this imagery would serve as the basis for any summer field work on the project. The increased visibility, minimal amounts of vegetation and high amount of inundation would provide a lot of information about the location of areas of interest throughout the study area. Based on targets selected from these areas of interest, biological FTM cross-sections could be planned to take place concurrently with summer low flows, the low discharge target habitat suitability survey, and the second aerial photo fly-over. Information gathered at the FTM locations would then serve as quality control data for the RSM, which could then be used to classify aquatic and riparian vegetation. A final set of imagery would be acquired during a high-flow event, which would help in establishing stage/discharge relationships throughout the Lamprey Designated River. The high flow event would help to establish the extent of floodplain forests and would make recreating inundation times based on discharge time series possible. This set of imagery would coincide with a discharge level too high for use in habitat suitability mapping and additional flights for this purpose may be necessary depending on the river and the scope of the project.

There are several actions and procedures which would make future RSM based studies more successful and cost effective:

- Due to the seasonal and instantaneous nature of data collection, sufficient time for preparation of survey logistics and coordination between the collaborating parties is crucial to the success of the floodplain transect and remote sensing methodologies.

- Image capture should not be limited to only the range of flows associated with the mesohabitat survey. Low flows are valuable for identifying the typical range of summer water levels, but the addition of a flood or near-flood event could provide useful information on extent of flood plain forests and the relationship between discharge and stage at ecologically sensitive areas of the Designated River.

- Additional focus on acquiring imagery during leaf-off conditions would allow for viewing the extent of some wetland areas normally obscured by canopy during summer months.

- The use of quality controlled GPS targets throughout the watershed as ground control points in data processing would ensure higher reproducibility of georectification as well as the ability to create a high resolution DEM.

- Continued advancements in software and technology will aid in dealing with the processing times and memory storage issues.
- Closer collaboration with a wetland biologist involved in the study could lead to better decisions in the location of quality control sites.
- Timing site visits with the period of imagery capture could be useful in automating classification of pixel signatures associated with vegetation types, providing rapid assessments of vegetation inventories.
- The use of the combined FTM and RSM techniques may be river size dependent. Smaller rivers, especially in areas with significant rainfall, may be obscured by vegetation over large portions of the study area and would favor a more field oriented investigation. Larger river systems having wider channels and less canopy coverage or rivers in urbanized/impacted areas will tend to have a lower proportion of obscured areas, which would favor the use of RSMs.
- Logistic difficulties in coordinating habitat suitability and riparian vegetation surveys call for the use of separate data sets and may operate on conflicting time scales. Collection of imagery for these purposes separately may be limited by available budgets (as it was for the Lamprey River project) and some level of compromise in the goals and use of the data may be needed.
- With better campaign preparation, the RSM carries great promise and further development could lead to the design of a valuable resource accounting and management tool for instream flow projects in the future.

7.0 FIELD VERIFICATION OF AERIAL PHOTOGRAPHY

Mesohabitat mapping of the Lamprey Designated River using aerial photographs at four or five flows in the range between 0.05 cfsm and 2 cfsm was proposed as the primary approach to describing flow-related habitat changes. At each target flow, a flight would capture a 3,000 ft wide corridor along the river from an elevation of approximately 4,000 feet, providing high resolution aerial images of this portion of the river.

Accompanying these flights, ground truthing surveys were planned, which together with the results of the reconnaissance survey from Task 1, were designed to help calibrate and validate image recognition software for use in mesohabitat delineation. Although the system was to be flown four or five times (each at a different flow), the originally proposed work included only one or two field events, in which a field crew would be on the ground at the time of the flights. The ground personnel would be mapping and collecting habitat information, and then the mapped data would be used to calibrate the computer interpretation of the aerial images.

Additional work was requested by the DES to verify the results of each of the air photo surveys by ground truthing each of the events. This was to include remapping of 20-30 hydromorphological units on the same day as the aerial over flights. These results were to be used to verify the computer interpretation of the river conditions.

7.1 PROCEDURES

Aerial photos of the study area were recovered for five target flows during the Lamprey River study (Table 1). During the reconnaissance flight, in November 2004, the length of the Designated River was flown and images recorded along a 3,000 ft wide corridor. Subsequent flights captured images of the length of the Designated River, but the corridor width was reduced to 1,200 ft due to the camera used and the processing of the images.

Close coordination with the technician and pilot allowed for Rushing Rivers field technicians to be present in the river collecting habitat data at the time of each aerial flyover. The original plan was to sample mesohabitat units throughout the study area to cover the range of possible habitat types for use in pixel classification training and validation data. The acquired imagery and HMU annotations would then be analyzed by pixel pattern recognition software that once trained, would then classify the remaining river area of the Lamprey Designated River. The goal of this approach was to reduce the time and cost of multiple foot surveys, which focus on a small representative percentage of the river, and instead assess the habitat assemblage at the segment scale without the need for representative site extrapolation.

7.2 PROBLEMS AND RECOMMENDATIONS

The success of this portion of the project depended on the continued development and use of a pixel classification computer program developed in conjunction with the computer science department at the University of Massachusetts Amherst. At the time of the first habitat survey, the pixel classification software was not working properly, so a decision was made to expand the field data collection efforts to that of a traditional field based mesohabitat study.

A product of the original reconnaissance survey was the division of the Lamprey Designated River into discrete sections, as well as the identification of representative sites for detailed hydromorphologic unit field mapping. Since the pixel classification software was not ready, the entire study area was floated or walked and each of the representative sites was fully mapped at the mesohabitat level. This method is typically used in this type of mesohabitat study, and was the same technique applied to the Souhegan River. The completed survey would provide ample calibration data as well as serve as a backup if the computer classification was unsuccessful. While work was continuing on the development and repair of the pixelization program, additional target flows were available and data collection, as well as aerial photography, continued in the same manner. In the end, all five mesohabitat surveys were completed before the software was available.

Initial testing of the program on the aerial photography and ground survey data proved to be unsatisfactory. The dense canopy cover obscured large portions of the river, especially significant areas along the river's shoreline. Additionally, areas with dense assemblages of HMU's tended to have greater amounts of canopy cover reducing the visibility of the distinct units.

Due to the problems experienced during the initial testing of the pixel classification program the decision was made to map all of the turbulent and habitat diverse areas of the river in the field on foot. The entire study area was covered by Rushing Rivers field technicians six times over the course of the study, which exceeds the requested remapping of 20-30 HMUs for verification. As a result, there is a high level of confidence that all of the dynamic portions of the river, under the range of conditions studied, were documented. In fact, the representative sites covered all but a handful of very small riffles leaving mostly impounded areas unmapped. These areas were easily accounted for in the adjustment between

representative site and section with the SimStream software. The final result was a much more detailed analysis, because of the intensive field survey.

Continued research and development of the pixel recognition and habitat classification program could provide valuable information on future habitat studies. The ability to rapidly assess large areas of river at low costs can be very valuable, especially in remote areas or rivers that present significant technical difficulties which would make a foot or boat survey less cost effective. The use of this approach on projects like the Lamprey River in the future may provide a low cost tool for river habitat assessment. The technology is available to remotely classify mesohabitat units as well as wetland vegetation. However, further research and development is needed to refine that technology and its application to each project area. The quality of the final product using this method must take into account a well thought out work plan, where there is a seamless transition from the reconnaissance survey, flight line development, aerial image acquisition and processing, field verification and sampling, data processing and, finally, a presentation of results. Good weather conditions (ensuring a smooth flight and appropriate lighting conditions) along with an unobstructed view of the river are critical to successful data collection. A consistent and repeatable approach to the image processing and image analysis is needed to save time and, thereby costs, and allow for the greatest amount of information recovery and project success. Additional investment in this technique and technology is highly recommended. The technology will continue to develop and improve, and its application in watershed ecology is very promising.

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