Report as of FY2007 for 2006VT26B: "An Adaptive Management System using Hierarchical Artificial Neural Networks and Remote Sensing for Fluvial Hazard Mitigation "

Publications

Project 2006VT26B has resulted in no reported publications as of FY2007.

Report Follows

1.. ***Title:*** **An Adaptive Management System using Hierarchical Artificial Neural Networks and Remote Sensing for Fluvial Hazard Mitigation**

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1. INTRODUCTION

Adaptive management of hydrologic systems requires modeling of dynamic, nonlinear relationships and the assimilation of volumes of disparate data types over variable temporal and spatial scales. Artificial neural networks (ANNs) offer the capability to assimilate such complex data in real-time and are, therefore, promising tools for evaluating management alternatives. We propose to develop and test a hierarchical ANN system to more effectively integrate, model, and manage spatial and temporal hydrologic and fluvial geomorphic data. To demonstrate the efficient performance of ANN architectures in data assimilation, reduction, and classification at multiple scales, we will develop methods to enhance the GIS-based tools currently in use in Vermont watersheds to characterize the geomorphic condition and sensitivity of river reaches in response to historic and current watershed and corridor stressors. Input to the ANNs will include available GIS data layers, field data collected under (River Management Program's (RMP) geomorphic assessment protocol, and new data to be derived from high spatial resolution (0.16 – 2.4 m) remotely sensed aircraft and satellite data on stream sinuosity, and channel and valley slope. Recent advances in remote sensing technology make it possible to greatly improve the quantity and quality of input data in support of the proposed ANN. The proposed study will be conducted on five stormwater impaired watersheds in Chittenden County. These sites have been selected in cooperation with DEC RMP collaborators to take advantage of the availability of Phase I and Phase II geomorphic assessment data and multispectral remote sensing imagery (including LIDAR and QuickBird satellite data). Evaluation of the new data products will be conducted by ground surveys. Sensitivity analyses also will be conducted based on the results of the proposed ANN system to address the relative importance of the various ground and remote sensing data sources to meet and improve upon RMP's current fluvial modeling capabilities.

The proposed modeling system is directly applicable to the fluvial hazard mitigation mission of the River Management Program (ANR/DEC), but will differ sharply from conventional hydrologic models currently in use by the volume, variety, and types of spatial and temporal data assimilated. Moreover, the architecture of the proposed hierarchical ANN system is sufficiently flexible to allow for its continual update and refinement in light of advances in our understanding of fluvial geomorphology. This research will evaluate not only a new and innovative data assimilation and analysis methodology, but also data products derived from remote sensing imagery that we believe will substantially improve hydrological modeling in Vermont. In addition, it will compliment the existing RMP state program, taking advantage of existing data, protocols, and personnel – a modeling approach that could be adopted statewide. Our long-term goal is to build hydrologic information technology that provides watershed managers (regulators, regional planning organizations, municipalities, citizen groups, landowners, and other stakeholders) with an easy-to-use, graphical infrastructure for adaptive and effective decision-making at multiple spatial and temporal scales.

2. SUMMARY OF PROGRESS - YEAR 1

This research focuses the development and testing of a hierarchical ANN system to effectively integrate, model, and manage spatial and temporal hydrologic and fluvial geomorphic data.

RESULTS TO DATE: The specific objectives are:

Objective 1: Refine, test, and evaluate a set of simple classification ANNs for assessing the geomorphic condition and inherent vulnerability of stream reaches.

Objective 2: Derive and evaluate improved hydrologic information derived from remote sensing observations to be used as input parameters in the ANN hierarchy. These new data include: a) stream sinuosity, b) channel slope and valley slope, and c) other select yet critical variables identified as part of the ANN sensitivity analyses.

Task 1.1—Refine Geomorphic and Inherent Vulnerability ANNs (Modules B & C, Fig. 1) incorporating remote sensing data.

Research and development has been performed on a proof-of-concept prototype of the proposed counterpropagation ANN tool. A hierarchal system of ANNs has been developed to predict stream sensitivity using VTANR Phase II rapid stream assessment data (hereafter referred to as the Phase II dataset). The first of the two ANNs in series, Figure 1(a), utilizes inputs of channel geometry and bed form to predict a Rosgen channel classification (stream type). This ANN was tested using Phase II data collected on the five selected streams. Of the 89 reaches and segments, 72 (81%) were classified by the ANN correctly when compared to stream type classification reported in the Phase II assessment. The second of the two ANNs, Figure 1(b), is used to predict stream sensitivity (as described by VTANR) using inputs of stream type (output from first ANN) and stream condition (Phase II RGA score). The same 89 reaches were used to evaluate the performance of this ANN. Of the 89 reaches and segments, the stream sensitivity of 62 (70%) were classified by the ANN correctly compared with the Phase II assessment.

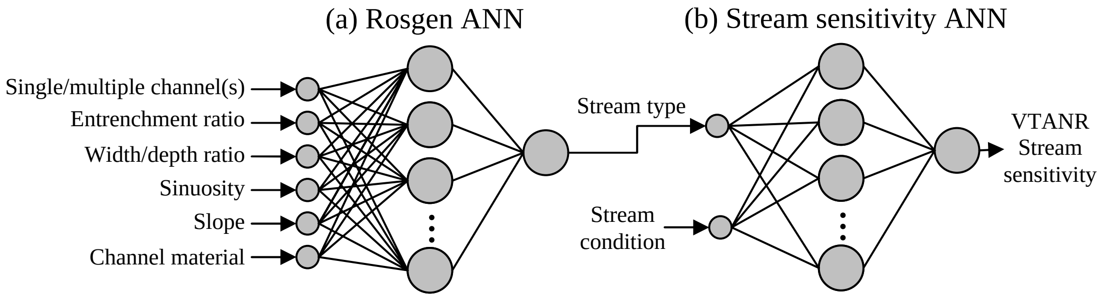

Figure 1. Graphical representation of (a) Rosgen ANN to determine stream type and (b) ANN for determining VTANR stream sensitivity using inputs of stream type and condition.

This first cut "Rosgen" ANN was implemented simply for development and testing purposes. This computational infrastructure can be modified easily and will provide the starting point for the proposed sensitivity ANN. These results are adequate (surprisingly good) for a first proof-of-concept. We believe they can be improved substantially by accounting for the ranges of values associated with stream geometry data (*i.e.* entrenchment can vary by ±0.2 units) and other subtle pieces of information provided by an expert. This will involve meetings with VT ANR.

ANN Task 1.2 – Identify "critical" geomorphic variables: A preliminary sensitivity analysis was performed to identify "critical" geomorphic variables needed for the proposed stream sensitivity ANN. First, we examined which of the available VTANR Phase I and Phase II geomorphic assessment data are most influential (statistically) for predicting stream sensitivity and geomorphic condition (using multivariate statistics). Stepwise discriminant and canonical analysis are multivariate statistical methods commonly used for classification prediction.

Table 1 displays the impact of each of the geomorphic variables ranked in decreasing order of importance when used as a predictor of classified stream sensitivity. Stream sensitivity provided in the Phase II database was classified into 6 categories using the geomorphic assessment (integer values ranging from very low = 1, low = 2, moderate = 3, high = 4, very high = 5 and extreme = 6). This rank ordered list was produced using discriminant analysis (*SAS Version 8.0*).

Table 1. Geomorphic variables rank ordered in importance for predicting stream sensitivity.

Rank	Variable	Number Class	Code Value
1	Substrate D50	Integer	1=sand, 2=gravel, 3=cobble, 4=boulder and 5=bedrock
2	Watershed size	Continuous	>=0
3	Width/depth ratio		>=1
4	Number of stormwater inputs	Integer	0, 1, 2, 3, etc
5	Change in valley slope	Continuous	+ to - infinity
6	Change in channel slope	Continuous	+ to - infinity
7	Upstream sinuosity	Continuous	>=1
8	Entrenchment		>=1
9	Cumulative urban watershed size (%)	Continuous	>=0 (summation of upstream conditions)
10	Urban watershed size (%)	Continuous	>=0
11	Number of grade controls	Integer	0, 1, 2, 3, etc
12	Confinement ratio	Continuous	>=1
13	Number of upstream stormwater inputs	Integer	0, 1, 2, 3, etc
14	Least forwarded buffer width	Integer	1=<5ft, 2=5-25ft, 3=26-50ft, 4=51-100ft, 5=>100ft
15	Channel slope	Continuous	>= 0
16	Valley slope	Continuous	>= 0
17	Sinuosity	Continuous	>=1
18	Straightening	Binary	1-yes, 0-no

Note that change in channel and valley slope over time and upstream sinuosity (ranked 5, 6 and7 respectively) are among the four most important variables specifically related to stream morphology. In contrast, measures of channel and valley slope at any point in time and sinuosity for a given reach are among the least important variables. This is due to the relative importance of variables 5 through 7 (Δ valley slope, Δ in channel slope and upstream sinuosity).

Table 2 summarizes the stream reach sensitivity classification results using the discriminant equations. For the 58 stream reaches that make up the study area, the stepwise discriminant equations were able to correctly classify the stream sensitivity for 41 of the 58 reaches. This results in 17 of the reaches being misclassified (with 12 reaches that should be classified as type 5 (very high) classified as type 4 (high); and another 9 that should have classified as type 6 (extreme) classified as type 5 (very high).

A similar analysis was performed on each of the four predictor variables (degradation, widening, aggradation and change in planform) that make up the total VTANR RGA score. The statistical results confirmed the four variables were equally important in predicting the geomorphic condition of the stream reach. Channel widening was less important than the other variables.

Table 2. Results of predicting stream sensitivity prediction using discriminant analysis.

		Classified by Discriminant Analysis					
	Class	**1**	**2***	**3**	**4**	**5**	**6**
Classified in Phase II Assessment	**1**	1	0	0	0	0	0
	2*	0	0	0	0	0	0
	3	0	0	3	0	0	0
	4	0	0	0	12	8	0
	5	1	0	0	9	24	0
	6	0	0	0	0	0	1

*Note: There were no classifications of 2 (low sensitivity) in the dataset.

The final ANN predictions/classifications may later be compared with the classifications produced from this statistical method. By ranking the importance of the Phase II variables using discriminant analysis, the ANN can be used to perform a sensitivity anslysis. Two ANNs in series were used to derive stream sensitivity based on Rosgen stream type and stream condition (Phase II protocols). As a result, a single ANN capable of incorporating channel geometry data and condition to predict stream sensitivity may be developed using kowledge gained from the stepwise discriminant analysis; therefore, consolidating the ANN portion of this project.

To study the influence of reach-scale channel geomorphic stability and physical habitat condition on benthic macroinvertabrate populations, Fitzgerald and Bowden [2006] performed preliminary statistics to test the following hypothesis: *Macroinvertabrate integrity declines as geomorphic stability and physical habitat conditions decline.*

For 26 stream reaches in a select set of stormwater impaired watersheds, they tested whether the stream reaches/segments (grouped by different channel evolution stage) had different mean values when compared against the VT ANR Biota Data (represented as EPT Richness). The results were very encouraging with a high average EPT richness scoring high (~ 25) for channels with an evolution stage of I, followed by a sharp decline (~8) for channels with an evolution stage of II and a gradual increase in average EPT richness for channel stages III, IV and V (~7, ~10, and ~13 respectively) [Fitzgerald and Bowden, 2006 and personal communication]

In an attempt to capture this temporal evolution for the streams examined in this work, we repeated this statistical analysis to further explore the existing correlations/links between the VT ANR habitat, geomorphic condition and the channel evolution stage of the stream reach data. We tested whether the stream reaches/segments (grouped by different channel evolution stage) have different mean values of habitat and geomorphic condition rating. The existing VT ANR Phase I and II dataset had channel evolution stages classified into five stages. Stage I represents the stable channels where sediment transport capacity is in equilibrium with sediment load. Stage II channels have lost access to their flood prone area via the process of bed degradation or floodplain buildup. In Stage III the channel is still entrenched and widening through bank erosion; and in Stage IV the channel dimension and planform adjustment continues. Stage V channels have reached a new stable or equilibrium condition.

Included are some results that suggest both habitat and geomorphic ratings have different means for the 5 stages but only the habitat ratings are statistically significant. Figure 3 displays evidence that the habitat rating scores are not statistically similar for streams at different stages of evolution. Streams in stage I have statistically higher habitat ratings than streams in stages II, III and IV. We only had one stream that classified as stage V within the study area data set.

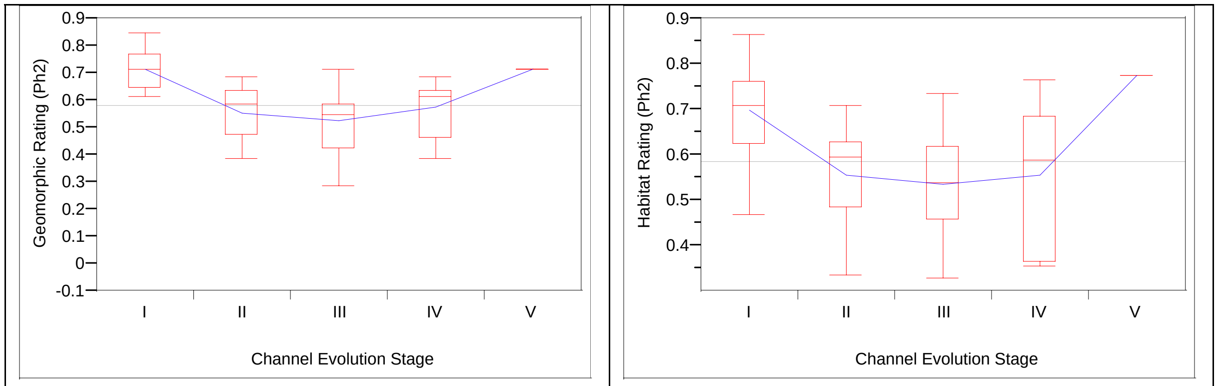

Figure 3. Stem and box plots comparing (a) geomorphic and (b) habitat rating scores grouped by channel evolution stage for Phase II data from selected streams with LIDAR data.

Similar results are observed in the mean geomorphic condition scores, when grouped by evolutionary stage. Stage I streams have higher geomorphic condition scores that the other stages. There is a slight increase in geomorphic condition in stream evolution stage IV compared to stage II and III. However these differences are not statistically separable for this dataset. These statistical findings provide reassurance that training the ANN using this existing dataset may be sufficient to capture the temporal component in the evolution of channel stage adjustment.

REMOTE SENSING Task 2.1 – Monitor stream sinuosity over time.

As part of our initial efforts to employ remote sensing and advanced digital image processing techniques to map and monitor stream sinuosity over time, recent aircraft (1:1250 CCMPO and 1:5000 Vermont digital orthophotography) and satellite (QuickBird) imagery were acquired for all stormwater impaired watersheds in Chittenden County and compiled within a GIS database. For the Allen Brook watershed, stream centerlines were digitized from the QuickBird and CCMPO imagery and sinuosity calculated for each stream reach using the Phase I valley length data. These preliminary analyses were limited to

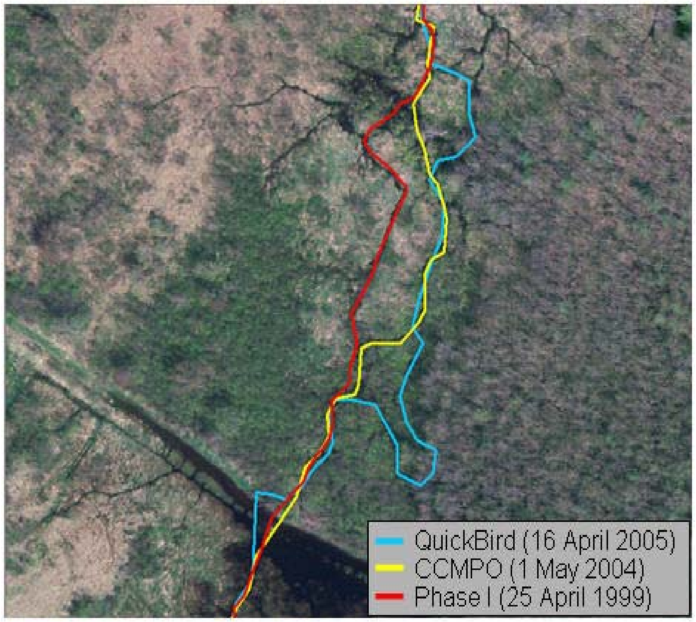

Figure 5. Stream centerlines derived from the QuickBird satellite data, Phase I (1:5000) data, and 1:1250 CCMPO imagery are shown for a section of reach M09 Allen Brook

the 9 reaches where QuickBird imagery was available. Sinuosity for each stream reach computed from the QuickBird imagery and as part of the Phase I stream geomorphic assessment (derived from the 1:5000 VT Hydrography dataset) was then compared with that computed from the higher spatial resolution CCMPO imagery.

Figure 5 documents areas of overlap as well as significant shifts in the Allen Brook channel between 1999 and 2004 and again between 2004 and 2005. More importantly the preliminary results demonstrate that over the range of sinuosity observed (1.01 to 4.1; n = 9) measures derived from the QuickBird imagery and Phase I data agreed well with those derived from the high spatial resolution CCMPO data (Figure 6).
The correlation between Phase I and CCMPO-derived measures of sinuosity was 0.984 (n = 7), whereas that between the QuickBird and CCMPO data was (0.998; n = 7), excluding the only reach with a sinuosity greater than 1.5 (M04, Phase I sinuosity = 3.98) and reach M09 which had undergone significant channel planform change. Note that although the stream channel for reach M09 changed course significantly from 1999-2004, sinuosity values changed little (1.18 to 1.21 as computed from Phase I CCMPO data respectively). The increase in sinuosity associated with the channel migration between 2004 and 2005, however, was much larger (1.21 to 1.38) as calculated from the CCMPO and QuickBird satellite data.

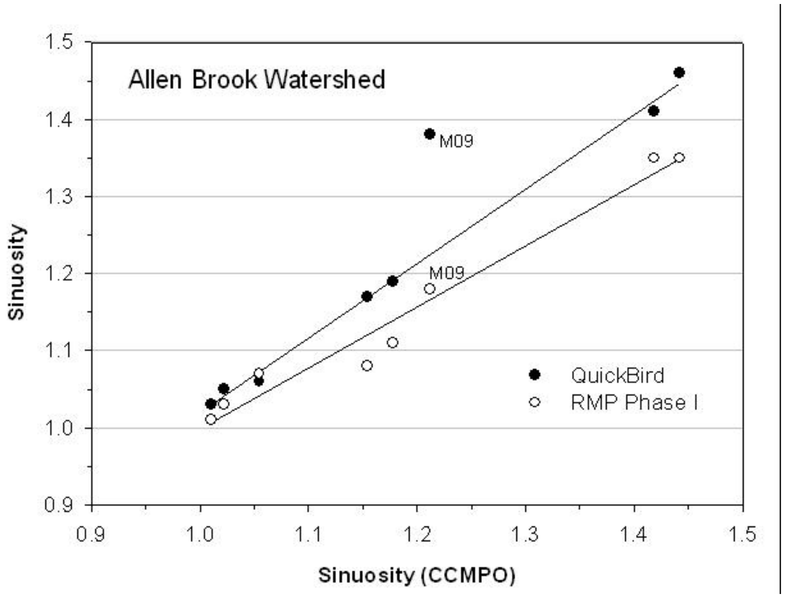

Figure 6. Channel sinuosity derived from QuickBird satellite imagery and Phase I (1:5,000) data compared to values calculated from photointerpretation of 1:1250 CCMPO imagery for the Allen Brook stream reaches. Data for reach M04 (sinuosity = 3.98) were not included in the correlation analyses nor were data for reach M09 because of the significant change in channel morphology between each of the image acquisition years (see Figure 5).

The channel migration between 2004 and 2005, however, resulted in a larger sinuosity value (1.38) as calculated from the QuickBird satellite data. These results support the value of remote sensing and QuickBird satellite imagery specifically as a tool for baseline mapping and monitoring of stream sinuosity and planform change over time.

Task 2.2 - Generate high spatial resolution elevation derivatives from LIDAR data, and quantify stream channel and valley slope at the reach scale.

We have initiated efforts to generate elevation data based on geostatistical kriging interpolation techniques. The computational requirements for kriging the immense LIDAR dataset for Allen Brook has resulted in processing the data using an ordinary Kriging algorithm written in MatLAB V8.0 rather than ArcGIS. Once the elevation data are derived, they will be evaluated against survey data that we have already acquired. Following QA/QC of the resultant data, we will derive channel and valley slopes for Allen Brook and at least one other watershed.