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Predicting Hydrologic/Hydraulic Condition of Streams Using Interferometric Synthetic Aperture Radar

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ABSTRACT: Geographic Information Technology as well as aerial imagery and video are being used to assess a 500 mile section of the Sevier River in Utah. The Stream Visual Assessment Protocol (SVAP) and Process for assessing proper functioning condition (PFC): Riparian area management are being used to assess the overall condition of the Sevier River. An attempt will be made to identify Rosgen's Stream Classification and Valley Types using High Resolution Orthographic Auto Correlated DEMs and IFSAR data. Field verification and stream gage analysis will help determine the reliability of predictions using GIS and remote sensing analysis. Predicting stream classification can aid in determining the hydrologic and hydraulic elements within the SVAP and PFC.
KEY TERMS: Rosgen's Stream Classification and Valley Types, Schumm's Channel Elevation Model, geomorphology, Interferometric Synthetic Aperture Radar, Stream Visual Assessment Protocol (SVAP), Process for assessing proper function condition: riparian area management (PFC).

INTRODUCTION

Remote sensing tools, such as Interferometric Synthetic Aperture Radar (IFSAR) (National Oceanic and Atmospheric Administration (NOAA), 2009), High Resolution Imagery, and Soil Survey Geographic (SSURGO) data is being used to identify similar reaches through the Sevier River from the Paiute Reservoir through Delta, Utah. This study is an initial effort to determine the viability of these GIS tools to establish Rosgen's stream classes. ArcGIS ArcInfo 9.2, HEC GeoRAS 4.1.1, HEC RAS, and Excel are used to develop cross section / geometry data, hydraulic analysis, calculations for Rosgen's Stream Classification (Rosgen, 1996) and displays of valley types. Rosgen Stream Classification is used as described by Rosgen (1996) *the objective of classifying streams on the basis of channel morphology is to set categories of discrete stream types so that consistent, reproducible descriptions and assessments of conditions and potential can be developed*. A Stream Visual Assessment Protocol v.2 (SVAP2) (USDA-NRCS, 2009) and Proper Functioning Condition (PFC) (Prichard et al., 1998) assessments of the Sevier River was the catalyst for this study. High resolution aerial photography and oblique flight video from a helicopter were initially used to identify similar reaches to evaluate the Sevier River. After becoming familiar with PFC and SVAP it was determined that a low cost digital elevation model (DEM) might be a viable alternative to determine Rosgen's Stream Classification and Schumm's Channel Evolution Model (CEM) (Schumm *et al*., 1984). This would assist in breaking reaches, help complete SVAP and PFC assessments, and be a systemic approach to working with evaluations of large reaches using SVAP and PFC.

Figure 1. Location Map of Study area and Testing Sites on the Sevier River, Utah

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BACKGROUND

IFSAR data is collected the same way LiDAR data is collected. The only difference is that radar pulses are used instead of laser. The return ground signals are received by two antennas that record elevations. IFSAR can be flown at night and in cloudy conditions (NOAA 2009). The IFSAR data used for this study is 5 meter grids with a root mean square error of 1 meter.

The SVAP is described as follows, *"preliminary qualitative assessment tool to evaluate features that affect overall stream conditions at the property level. The tool assesses visually apparent physical, chemical, and biological features within a specified reach of a stream corridor. Because of its qualitative nature, the protocol may not detect all causes of resource concerns, especially if such causes are a result of land use actions in other parts of the watershed. It does provide a means to assess site conditions in the context of the larger watershed"* (USDA-NRCS, 2009). The PFC is a joint effort between the Department of Interior Bureau of Land Management (BLM), United States Department of Agriculture (USDA), Forest Service and the USDA Natural Resources Conservation Service (USDA-NRCS) and is described as follows *"an effort to restore and manage riparian-wetland areas in 11 Western States. The method for assessing PFC is a qualitative, yet science-based process that considers both abiotic and biotic factors as they relate to physical function. It facilitates communication about the condition of a riparian-wetland area and focuses attention on the physical process before considering values. A standard checklist is used to ensure consistency in reporting the condition of riparian-wetland areas"* (Prichard *et al.*, 1998).

Table 1 shows the relevance of using GIS, aerial imagery, and SSURGO soils data to assist in evaluating SVAP and PFC. Field verification is still required, but these resources can provide estimates for planning purposes. The measure "Very Helpful" directly correlates to the applicability of stream classification and "Somewhat Helpful" is partially surmised from stream classification as well as other types of qualitative measures. "Speculative" was inserted for areas where geomorphologists and biologists may disagree with the data sets but may have some relevance when assessing the terrain.

Table 1. Remote Sensing, Terrain modeling, and Soils relevance for Proper Function Condition and Stream Visual Assessment Protocol		Rosgen Stream type and Valley Type					
PFC Indicators		Very Helpful	Somewhat Helpful	Speculative	Channel Evolution Model	Aerial Photography Interpretation utility	Soils utility
1	Floodplain above bankfull is inundated in "relatively frequent" events	X			X	X	
2	Where beaver dams are present they are active and stable			X		X	
3	Sinuosity, width/depth ratio, and gradient are in balance with the landscape setting (i.e., landform, geology, and bioclimatic region)	X				X	X
4	Riparian-wetland area is widening or has achieved potential extent	X			X	X	
5	Upland watershed is not contributing to riparian-wetland degradation		X		X	X	
6	There is diverse age-class distribution of riparian-wetland vegetation (recruitment for maintenance/recovery)			X		X	
7	There is diverse composition of riparian-wetland vegetation (for maintenance/recovery)					X	
8	Species present indicate maintenance of riparian-wetland soil moisture characteristics						
9	Streambank vegetation is comprised of those plants or plant communities that have root masses capable of withstanding high-streamflow events			X			
10	Riparian-wetland plants exhibit high vigor						

11	Adequate riparian-wetland vegetative cover is present to protect banks and dissipate energy during high flows			X		X	
12	Plant communities are an adequate source of coarse and/or large woody material (for maintenance/recovery)			X		X	
13	Floodplain and channel characteristics (e.g., rocks, overflow channels, coarse and/or large woody material) are adequate to dissipate energy					X	X
14	Point bars are revegetating with riparian-wetland vegetation			X		X	
15	Lateral stream movement is associated with natural sinuosity	X			X	X	
16	System is vertically stable		X				
17	Stream is in balance with the water and sediment being supplied by the watershed (i.e., no excessive erosion or deposition)	X			X	X	X

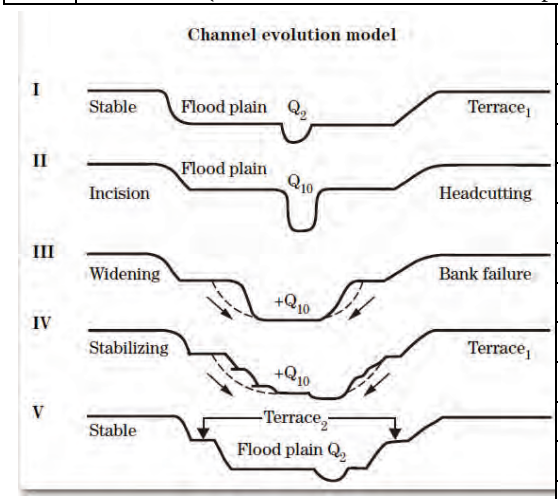

Figure 2. Schumm's CEM (*et al*., 1984) from SVAP2 (USDA-NRCS,2009)

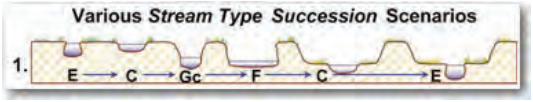

Figure 3. One of twelve potential Stream Type Succession Scenarios (Rosgen, 2006)

	SVAP2 Indicators						
1	Channel Condition	X			X	X	
2	Hydrologic Alteration		X			X	
3	Bank Condition		X		X	X	X
4	Riparian Area Quantity					X	
5	Riparian Area Quality					X	
6	Canopy Cover					X	
7	Water Appearance					X	X
8	Nutrient Enrichment					X	
9	Manure or Human Waste					X	
10	Pools		X			X	
11	Barriers to Movement					X	
12	Aquatic Invertebrate Habitat			X		X	
13	Fish Habitat Complexity			X		X	
14	Embeddedness						X
15	Salinity						X
16	Aquatic Invertebrate Community			X			

ASSUMPTIONS / METHODOLOGY

The assumptions made between Schumm's CEM (see Figure 2) and Rosgen's Stream Classifications (see Figure 3) were that Stage I is a stable system and most often classified as C or E channels (conversation with Dr. Southerland, 2010). Degrading systems (incised) are classified as G and F channels, which are, respectively, Stage II and III CEM. Stage IV is often described as a Bc channel. In Stage IV there are many discernable features such as bars and greater sinuosity, but the active meander belt is still gain width. Finally, a Stage V is a recovering or nearly recovered channel with a stable longitudinal profile, hydraulic geometry, and floodprone width (effective floodplain) most commonly associated with a C, B, or E channel. Aggrading systems are often classified as D streams, which is not identified in Schumm's CEM.

Entrenchment ratios are expected to be the primary basis for identifying stream classifications. Although the A channel is believed to be stable, the entrenchment ratio is high and would lead to the supposition that an A channel would be degrading through assumptions made in this paper. This study assumes that A channels are in first order streams and that width/depth ratios are expected to be difficult to determine using IFSAR data. Therefore, both entrenchment and width/depth ratios are determined using aerial imagery to estimate bankfull width and IFSAR data to determine floodprone width, which is the width at two times depth of bankfull. Slopes are estimated using IFSAR data derived in HEC RAS. Attempts were

made to use SSURGO data to determine bed material. SSURGO data can be used to determine slope stability or cohesion/cementitious properties in soil that allow for vertical walls; such as what is typically found in an F channel.

To determine entrenchment ratio, cross section widths need to be long enough to determine floodprone width. This is done using estimated bankfull width from aerial imagery, then multiplying the value by 2.5 or greater than 2.2. This corresponds to elevations that take into consideration two times the depth to get floodprone width.

Bankfull width is determined using aerial photography and mapped as "Banks" in HEC GeoRAS, and is categorized as Channel Station Left and Right in HEC RAS. The difference between left and right channel stations is used to derive bankfull width. Flow regimes are modeled in HEC RAS to determine floodprone width and discharges that would mimic bankfull widths, which are significantly smaller than bankfull discharges. Bankfull discharges are modeled in HEC RAS to estimate bankfull velocities. This is done to simulate velocities with corresponding energy equations. These velocities with bankfull widths and bankfull discharges are used to determine bankfull depths. Finally, the calculated depths described above were added to the water surface elevation estimated when mimicking bankfull widths to determine floodprone widths, because the bankfull channels are not accurately represented in the IFSAR data. In other words, it is assumed that the IFSAR data only shows an insignificant portion of the actual bankfull channel geometry.

Microsoft Excel is used to calculate HEC RAS results to determine stream classification at most of the cross sections. Two methods are used to determine stream classification. First, if all flow regimes exceeded bankfull widths this proved that IFSAR data is unreliable, and further data evaluation had to take this into consideration. Therefore, velocities may not be adequately determined with IFSAR data alone, so an additional method to simulate those results is established by changing the bankfull discharges but keeping the same width. The second method consisted of using widths that match bankfull flows to determine the appropriate width/depth ratios. Both methods use a series of vertical lookup tables to determine corresponding velocities and estimate floodprone elevations that correspond to floodprone width (i.e. HEC RAS Water Surface Left Bank and Right Bank). Finally, a series of if/and/or and nested if/and/or statements are created to determine the correct stream class for nearly all cross sections. Rosgen Valley Types are used to indicate the appropriate stream classifications that are possible in the stream reaches. Rosgen Valley Types and Rosgen Stream Type Succession Scenarios are used to determine alternatives for stream restoration or reconstructions in the next stages of the project.

Six sites were initially identified during the study. Initial site investigations were made by viewing the site, completing a pedestrian survey, using aerial photography, and using oblique video. SVAP and PFC criteria were evaluated at each site. Initial Rosgen's Stream Classifications were made at the site, and the placement of dikes is also noted in the field. Photographs were taken of the sites.

During the initial site visits the sites were described as follows: Site 1- an F channel around the bend, to a possible C channel with a possible G due to the dike on the left bank and high slopes on the right bank; Site 2 - is believed to be an F channel but could be in the later states of F with a C channel also described as CEM Stage IV or V. No dikes were seen at this site; Site 3- dikes were located on both banks, initial visual stream assessment documented stream as a possible G to an F channel. This site was omitted from the study due to time constraints; Site 4, located below a stream gage, is believed to be a C channel that later develops into a Bc channel. Potential for flooding is possible and the entrenchment ratio is believed to be high. Therefore, possible out-of-channel flow is expected. This site is directly below a dam, so assessment scores are expected to be lower due to hydrologic alterations. Invasive species are relatively low; Site 5 is expected to be classified as a C channel. Pools, channel meandering, and a high riparian corridor with a high entrenchment ratio were observed at the site. Livestock have access to the river. Russian Olive seems to dominate the site. It is believed the site does not have salinity issues and tamarisk does not have an active hold. This site was omitted due to lack of channel characteristics for

Figure 4. Valley type and Stream Type Succession at Testing Sites

study; Site 6 - a tributary to the Sevier River, Muddy Creek, is a high sediment transport system and bisects the reaches into two stream classifications. Above the confluence is believed to be an F channel, below the confluence is a possible F channel with a developing C channel, Schumm's CEM V.

Study areas are located in three different valley types. Sites 1 and 2 are in Valley Type X, associated with glacio- and non-glacial-lacustrine and gentle alluvial slopes (Rosgen, 2006). Site 4 is located in a fault control Valley Type VI. Site 6 is located in a Valley Type VIII, mature, wide, gentle slopes with well developed flood plain features adjacent to river terraces (Rosgen, 2006). Somewhat predictable results occurred at Sites 4 and 6, Valley Types VI and VIII, respectively.

Initially 1-meter orthographic imagery was used, but did not have enough resolution to map and identify estimated bankfull widths. Using the high resolution georeference imagery had significantly better resolution, but using orthographic imagery to georeference images causes some scaling issues. The scaling issues are relatively small.

RESULTS

Results for both Sites 1 and 2 are not what would be expected. Sites 1 and 2 are located in a lacustrine Valley Type X. This being the case, identifying any type of channel geometry is expected to be difficult using IFSAR data. Site 1 did exhibit some C channels, which is expected in a portion of the reach. The majority of the channel is unreliable to use calculations for Rosgen Stream Classification. Site 2 is expected to be identified as the later stages of an F with a C channel. Only a few of the cross sections are identified as unreliable. The model results show C as the majority of channels. E channels might be expected, due to the wetland characteristics and low slope. The use of IFSAR data for stream classification is expected to be poor in a Valley Type X.

Site 4, illustrated in Figure 3, is defined as a relatively reliable run with half of the results being acceptable for stream classification. Using the IFSAR data the reach is defined to have B, C, G, and E channels. The B, Bc, and C channels were expected. Further survey and stream classification may document that the reach may have some Bc cross sections. The sections that are marked as unreliable are predominately classified as E channels. This is a logical result, since the hydraulic geometry of the cross section is not adequately represented in the IFSAR data which then decreases the slope. With slope being decreased, velocity would be decreased which would, in turn, increase the depth, thereby decreasing the width/depth ratio and making the cross section appear as an E channel. Site 4 being in a Valley Type VI suggests that stream classes in this type of valley should be B, C, F, and G channels. This would therefore preclude an E channel being present.

Site 6, illustrated in Figure 4, is located on the Sevier River and is intersected by a high sediment transport tributary, Muddy Creek, that bisects the reaches into two stream classifications above and below the confluence. Below the confluence was modeled as an F channel as predicted. F channels are identified in five cross sections. Unreliable identifications are located at the majority of the reach above the confluence. These are identified as E channels with a few being C channels. These cross sections are expected to be F channels. As stated above, the resolution of the channel does

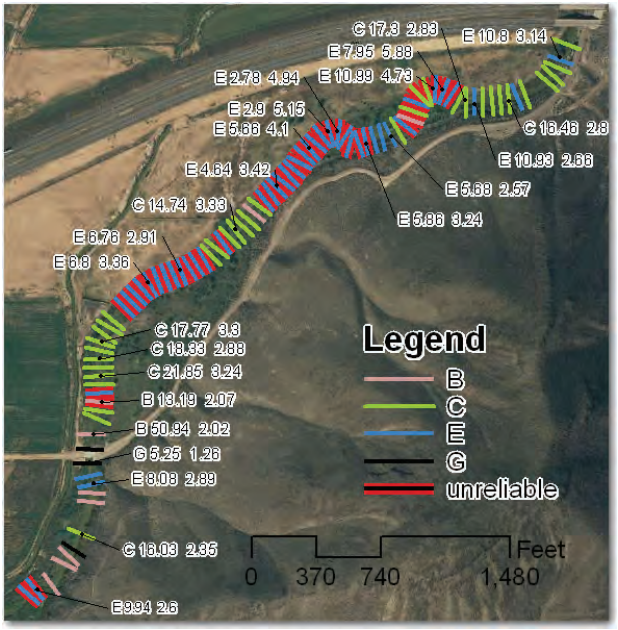

Figure 5. Site 4, Rosgen Stream Class (SC) by Cross Section with IFSAR DTM (SC Width -Depth – Entrenchment).

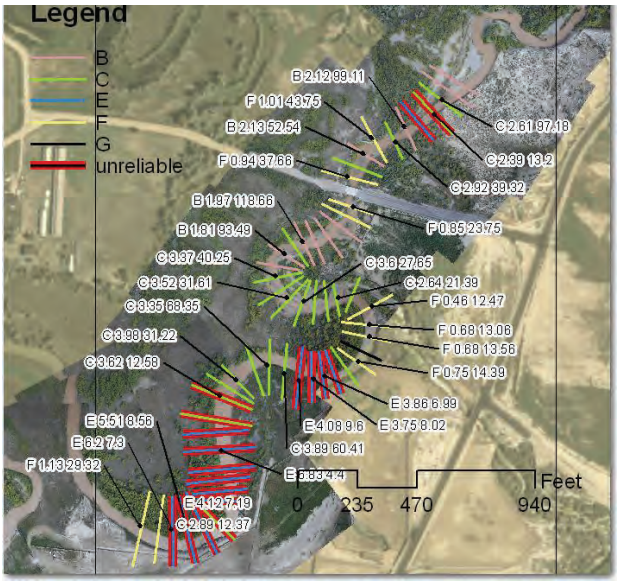

Figure 6. Site 6, Rosgen Stream Class (SC) by Cross Section with IFSAR DTM (SC Entrenchment - Width -Depth).

not have enough representation of the channel geometry to classify the stream for these cross sections. Below the confluence, with the high sediment load, it is expected that a Stage IV or V might be present. B, C, and F channels are identified, which is consistent with what would be expected. B channels can be eliminated since this reach is located in a Valley Type VIII. Corresponding channels in a Valley Type VIII are C, D, E, F, G and potentially Bc as a successional stage.

DISCUSSION / CONCLUSION

This initial study was developed to identify reaches using Rosgen's Stream Classification and Valley Types using IFSAR data for use in evaluating SVAP and PFC criteria. Future studies consist of:

- SSURGO data, which will be examined in more detail during the field assessments to further assist in erosion and bank stability identification
- More comparison and results from stream gages and IFSAR data to understand their relationship
- Analysis of stream order and watershed area relative to SVAP, PFC, and stream classification
- Predicting bankfull estimates intermittently between stream gages to calibrate discharge to area relationships

More time and effort will be devoted to stream classification for this project. This will involve intermittent bankfull discharge estimates, bankfull discharges at stream gages, calibration at stream gages including photography and possible survey. Furthermore, the procedures used in this study will be tested with 1-meter Grid LiDAR data at a different location within Utah.

Unfortunately, the sites selected did not have SSURGO data readily available. Using SSURGO data to determine cohesion could be used to determine vertical bank stability and erodibility. Furthermore, SSURGO engineering properties USDA Texture can be used to determine material type that is bedrock, boulder, cobble, gravel, sand, and silt-clay.

For this project the IFSAR data can be a low cost and reliable data set to determine preliminary results, thus negating the need for an investigation costing thousands of dollars. 2-meter LiDAR data generates a good planning tool and assists in design, while costing tens of thousands of dollars. Alternatively, using 2-foot contour LiDAR data for design and planning may run hundreds of thousands of dollars. Analysis of valley types are inexpensive using 10-meter, 30-meter or 90-meter data and eliminates the need for purchasing high-resolution DEM data. Initial assessments using IFSAR data with field verification may prove an appropriate and cost-effective method until other high-resolution DEM data is available at a lower cost.

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