STUDY DESIGN FOR DIRECTED VEGETATION RESEARCH ON THE PLATTE RIVER

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1. BACKGROUND and PROBLEM

In planform, rivers exhibit a continuum of form with three end-members: braided, meandering and straight (Leopold and Wolman, 1957). A number of definitions of the term 'braided river' have appeared in the literature. Friedkin (1945: 16) noted that rivers are described as braided when "the channel is extremely wide and shallow and the flow passes through a number of small interlaced channels separated by bars". The most commonly cited definitions are those of Lane (1957) and Leopold and Wolman (1957). Combining these definitions, a braided river can be defined as one that "flows in two or more anastomosing channels around alluvial islands" (Leopold and Wolman, 1957: 53) "presenting from the air the intertwining effect of a braid" (Lane, 1957: 88).

Classically, braiding has been associated with a combination of factors such as high slope, abundant bedload, coarse grain size, and flashy discharge (e.g. Leopold and Wolman, 1957; Schumm and Khan, 1972; Fredsøe, 1978; Schumm et al., 1987). In contrast to these findings, Friedkin (1945) noted that in his laboratory tests conducted at constant discharge, braiding resulted even when no sand was fed at the entrance of the flume, provided that the banks were readily eroded. Paola (2001: 22) stated that braiding "is the fundamental instability of streams flowing in noncohesive material." Channels formed in material with little or no cohesion or vegetative stability to restrict channel widening tend to braid (e.g. Simpson and Smith, 2001). Those with cohesive banks (Thorne and Abt, 1993) and/or vegetation (Mosley, 2001) become progressively more sinuous (i.e. meandering) or anastomosed (Smith and Smith, 1980; Nanson and Knighton, 1996), especially if there is some base-level control.

These latter points are of significant importance for the present study. The diversion and storage of water for agricultural, municipal and industrial uses has caused significant alteration of the hydrologic regime of the central Platte River. High flows have been largely eliminated, low flows have been elevated, and there has been a decrease in sediment supply (Williams, 1978; Hadley et al., 1987). Data from USGS gauge 06768000 (Platte River near Overton, NE) show that between 1920 and 2009, decadal-average annual peak flows declined from 527 m^3s^{-1} to 106 m^3s^{-1}. Exposed sand bars have, therefore, been progressively colonized by vegetation, leading to the formation of semi-permanent islands, and narrowing of the braided, wide and shallow channels of the Platte by 30-90% (Williams, 1978). The loss of exposed sand bar habitat may prove critical for nine threatened or endangered species that use the central Platte River Valley for habitat, including the whooping crane (*Grus americana*), least tern (*Sterna antillarum*) (U.S. Fish and Wildlife Service, 1967; 1985a), and piping plover (*Charadrius melodus*) (U.S.

Fish and Wildlife Service, 1985b). Simultaneously, wetland meadow habitat, which provides a key source of protein for cranes, has decreased (Sidle et al., 1989).

In response to the progressive encroachment of riparian vegetation and the associated loss of up to 97% of optimal Sandhill crane roosting habitat (Sidle and Faanes, 1997), the Platte River Recovery Implementation Program (Program) was initiated early in 2007 to address endangered species issues. Specifically, the Program seeks to maintain and create habitat for whooping crane, least tern, and piping plover by re-creating a dynamic, braided channel. To fulfill this objective, it is necessary to reduce the resistance of the boundary sediments by removing vegetation from in-channel sand bars and then manage future re-colonization. At present, these tasks are undertaken through costly and time-consuming disking and spraying of vegetation. This study is intended to address a series of questions (see Objectives and Sub-Objectives) to better inform the Program of the mechanisms by which elevated in-stream flows may remove vegetation and the magnitude and duration of the flows necessary to accomplish removal.

To accomplish this, the Program requires detailed, quantitative information on the resistance that vegetation provides against flow and erosion. Determining the effectiveness of in-stream flows in removing vegetation is a matter of quantifying the driving forces provided by the flow acting on the channel boundary (predominantly sand) and modified by the drag provided by the above-ground biomass, and the resistance of the boundary as modified by the additional resistance provided by roots.

The approach proposed for this study is based on quantifying the resisting forces provided by the sediment and plant roots against the driving force provided the flow. The proposed research focuses first on quantifying pullout and breaking resistance of plant roots through direct measurement at field sites. These data will be used for input into the RipRoot root-reinforcement model to determine species-specific resistance for different burial depths and different times of the growing season. The second primary focus of the proposed research will employ laboratory experiments to determine the drag and alteration of hydraulic shear provided by the above-ground biomass over the range of expected flow conditions. The third focus of the proposed research will bring together these two aspects by quantifying the magnitude of scour depth produced by flows of different magnitudes and durations. In combination with analysis of expected Platte River flows, these results will provide reliable predictions of species-specific scour thresholds over the range of flow magnitudes and durations.

1.1 OBJECTIVES

The overall project objective is to determine erosion thresholds of different early succession species growing on bars within the Platte River to short duration, high flows of varying magnitude and duration, as part of the Program's FSM strategy.

1.2 SUB-OBJECTIVES:

1) Quantify root and rhizome parameters required to calculate the resistance of different plant species (to include: *Phragmites australis; Populus deltoides; Phalaris arundinacea*) of varying ages and plant densities, to removal by the flow of water in the Platte River;
2) Quantify changing plant resistance to removal by flow with increasing scour of sediment;
3) Quantify the depth of substrate scour that would occur under flows of different magnitude and duration;
4) Quantify the driving forces acting on different vegetation types at different flow depths/ discharges; and
5) Determine what depth of scour and thus what magnitude-duration of flow is required to remove plants of various species and ages from the substrate, at various times of the year.

2. FIELD EXPERIMENTS TO MEASURE PLANT AND ROOT PROPERTIES

A range of sites on the Platte River will be selected to find areas of *Phragmites australis* that have been sprayed, and areas that are undisturbed, so that the forces for removal under these two options can be compared. In addition, sites with cottonwood seedlings (*Populus deltoides*) up to 2-3 years old will be selected, along with sites with Reed canary grass (*Phalaris arundinacea*). For each species and each age range, where applicable, the force required to remove entire plants from their substrate will be measured using a plant-pulling device, based on a scaled up version of a root-puller device. At least 20 plants of each age class of each species will be measured during each of the field trips.

To pull each plant out of the ground, the plant will be winched from a tripod erected a distance away from the stem of each plant. The force being applied to each plant will, therefore, be acting in a horizontal direction, to simulate the drag force applied by the flow of water. The force required to bend a plant through a set angle (for example, 45^{o}) will be measured using a load cell calibrated in tension (as used in the root-pulling device). The plant will then continue to be winched until entire plant removal has occurred. Two sets of experiments will be conducted on separate field specimens. First, plants will be allowed to bend naturally, allowing elastic energy loss. Second, collars of a stiff material will be secured around the stem of a plant from the base of the stem to a given height, in order to prevent bending and to ensure efficient force transfer to the root mass. The drag (pulling) force will then be applied at that height. The difference between the average moment (F_d × height) required for plant removal for each of the two populations will represent the elastic energy loss (i.e. the amount of energy that is applied to the stems by the flow, but is not transferred to the roots). It is important to know the magnitude of elastic energy loss for each species, so that when the driving force of the flow is compared to the resisting force of a given plant, the force acting on the roots can be modified according to the energy absorbed by the stems.

Once the plants have been removed, their root diameters will be measured using digital calipers sensitive to 0.1 mm, along with the root lengths, burial depth and rooting depth for the plant will be estimated. Digital photos will also be taken to allow for analysis of root architecture and rooting extent using the root software WinRhizo. The forces measured to remove the plants will be used to validate the modeled values of plant-pullout resistance obtained using the RipRoot model.

Other plants at the same site will have part of their root networks excavated by carefully clearing the substrate away from the roots. The root-puller shown in Figure 3 will then be used to test the tensile strength of different diameter roots. A sample size of >30 roots, and preferably >100 roots for each species will be collected to establish a relation between root diameter and root tensile strength. For cottonwood and Reed canary grass, the data collected on the Platte will be compared to previously collected tensile strength data for these species, and if there is no significant difference in the populations, the additional data will be added to the Platte field data to strengthen any relations found. In the case of *Phragmites australis*, tensile strength will be measured for both roots and rhizomes, as in this type of species, both play an important role in anchoring the plants. Plant density will also be measured at a range of sites. This is an important input parameter for the RipRoot model, as it allows conversion of the resistance of individual plants to prediction of the resistance of patches of plants of different densities to pullout. These root parameters will be measured during two to three field trips between June and October, representing times of the year near the peak and towards the end of the growing season.

A soil sample will also be taken as near to each plant as possible, without disturbing the tests themselves. The soil samples will be tested for bulk unit weight, moisture content, and particle size. These soil parameters are required not only for RipRoot parameterization, but also in calculations of potential scour, which will be discussed in following sections.

Table 1. Summary of the input parameters that are required for the Monte Carlo version of the RipRoot model (modified from Thomas and Pollen-Bankhead, 2010), reasons each parameter is required and method of measurement in the field.

Variable to measure	Reason for measuring	Method of measurement
Root/ Rhizome tensile strength	Each species has a characteristic root tensile strength relation with root diameter that plays a critical role in determining plant resistance to removal; parameter is required in RipRoot	Use Root-Puller device shown in Figure 3, on the roots of plants that have been pulled out of the substrate.
Root/ Rhizome diameter distribution	Because root tensile strength is related to root diameter, knowledge of the range of root diameters and their frequency distribution for each species is required; parameter is required in RipRoot	Measure the root diameters of plants that have been pulled out of the substrate using digital calipers.
Root /Rhizome lengths	Knowledge of root lengths allows calculation of root pullout forces; parameter required in RipRoot	Measure root lengths of plants that have been pulled out of the substrate using a tape measure.
Rooting depth/ burial depth	Required input for the RipRoot model to allow determination of plant and patch resistance to pullout after scour or deposition of sediment	Rooting depth will be estimated in the field from measurement of root lengths added to any burial measured above the initiation point of root growth at the base of the stem
Soil bulk unit weight	Required to calculate root or rhizome pullout forces in RipRoot	Bulk density samples will be taken at various field locations to obtain the typical range of bulk unit weights of the substrate in each study reach.
Soil friction angle	Required to calculate root or rhizome pullout forces in RipRoot	Will be measured using a Borehole Shear test device if the substrate contains any cohesive material, or estimated from literature values for sand based on the D_{50} if the substrate is non-cohesive in nature.
Particle size data	Required to calculate rates of scour under different flow magnitudes and durations	Samples will be collected at a range of field sites to allow characterization of minimum and maximum rates of scour under different flow conditions. Particle size samples will be shipped to USDA-ARS-NSL, Oxford, MS for analysis in the soils lab.
Plant pullout force	These values will be used to validate RipRoot model predictions of plant pullout based on root and rhizome parameters collected in the field. It is expected that the field data would lie within the limits of the values predicted using RipRoot. This data will also be used to test changing plant resistances with different burial/scour depths.	Plant pullout forces will be measured using a larger version of the Root-Puller, set up with a bigger tripod and a load cell that can withstand a higher peak force.

3. LABORATORY EXPERIMENTS: ROOT NETWORK RESISTANCE TO REMOVAL

Some of the plants and seedlings removed from bars on the Platte River will be transported back to the USDA-ARS-NSL for further testing. As plant resistance to pullout is sensitive to rooting depth or burial depth, more detailed experiments are required to establish how plant-pullout resistance changes as scour occurs. For each individual plant, a box containing a representative substrate (based on the particle size data collected in the field) will be set up, with the substrate being filled in around the root network of the plant in question. As the substrate is expected to be dominated by sand it is expected that the particles will easily fill in around the plant's root network. The substrate will be added to a given depth, and the plant puller used to measure the force required to remove the plant. This test will then be repeated for progressively greater depths of substrate, using the same plant to ensure repeatability, and measurement of forces with the same root network. The shallowest substrate depth will be measured first to minimize breaking of roots, and try to maintain the integrity of the root network so that the results for each substrate depth are comparable. This set of tests will be repeated for at least 10 plants per species to try to establish the change in pullout resistance with increasing scour. If the particle size data collected in the field shows significant variability, these tests will also be repeated for different substrates. Additionally, tests under different moisture conditions could be added, if time permits.

If root breaking occurs during testing and the same plant cannot be used for multiple tests, another plant of a similar age and size will be used to replace it. In all cases the root networks of the plants will be photographed and analyzed digitally to measure root length, surface area and volume. These experiments will produce relations between rooting parameters and pullout force at different substrate depths and for different age classes of each species. The obtained values will be compared to field-measured values for plant pullout to ensure the values are within the same range. If the two datasets show significant differences, and/or substrate conditions from the field cannot be replicated in the laboratory, additional field tests will be added. In these field tests, different depths of sediment would be removed from around plants so that pullout forces at different burial depths could be measured in the field instead of the laboratory. The benefit of the laboratory tests over the field tests is the ability to control other variables in the lab, such as substrate moisture, but field tests can be added if the laboratory tests prove difficult or unsuccessful. All three species, *Phragmites australis*, *Populus deltoids*, and *Phalaris arundinacea* will be tested for changing resistances with sediment depth.

4. MODELING USING RIPROOT

The field data and laboratory experiments proposed in the previous two sections will allow for parameterization and validation of the Monte Carlo version of the RipRoot model. Field measurements of plant pullout will have a sample size of between 20 and 50 plants per species. Potential plant resistances to pullout will be modeled by inputting the full range of field data (Table 1) into RipRoot. The results of plant pullout forces with changing sediment depths will also be used in RipRoot to model changing pullout forces for varying amount of scour. The RipRoot model will be run for at least 25,000 iterations to account for all variability in each parameter. RipRoot modeling will allow prediction of mean plant and patch resistances with upper and lower bounds for:

1) Different species
2) Different ages of each species, with seasonal variations
3) Different depths of burial and scour
4) Different substrate types
5) Different densities of plants growing on a given bar

The depths of scour required for plant removal, and the flow magnitudes and durations required to reach the threshold at which driving forces exceed resisting forces, can be calculated once the resisting forces of the plants or patches of plants have been determined. In addition, the increased resistance of plants to removal following deposition of sediment can also be estimated using the RipRoot model. This will allow PRRIP to consider the potential effects of planned sediment augmentation. The following section will describe the field and flume experiments that will be required to calculate the **driving forces** acting on the different species to be tested in this study, under different flow conditions.

5. LABORATORY EXPERIMENTS: MEASURING DRIVING FORCE

The drag coefficient (C_D) of each species is a function of the flexibility of the plant, extent of submergence and the flow velocity. To overcome this issue, an experimental study has been designed to estimate vertical profiles of the drag coefficient. Flume experiments will be repeated for each vegetation species to make measurements of channel slope, vegetation areal density and vertical profiles of the downstream velocities and turbulent fluctuations under uniform, steady flow conditions.

5.1 FLUME SPECIFICATIONS.

Experiments will be conducted in a 6.05 × 0.61 × 0.61 m recirculating flume set at a fixed slope of 0.001 m m^{-1}, approximating that observed on the Lower Platte River (Smith, 1970). In order to dampen turbulence and provide uniform flow, water will pass through a rock-filled baffle box and an array of 0.30 m long, 0.02 m diameter tubes (flow straighteners). Instantaneous at-a-point 3-D velocities will be monitored with a 10 MHz Nortek miniature Acoustic Doppler Velocimeter (ADV) and time-averaged velocity fields will be monitored with Ultrasonic Doppler Velocity Profiling (UDVP). ADV data will be filtered and processed using the WinADV software Version 2.027 (Wahl, 2009). Water surface elevations will be monitored continuously using an acoustic depth probe and a point gauge.

5.2 VELOCITY MONITORING OVERVIEW.

Ultrasonic Doppler Velocity Profiling (UDVP) will be used to record high precision directional velocity data across the entire flow field. The choice of an acoustic measurement technique rather than an optical technique overcomes the limitation imposed by poor optical transmission (Buckee et al*.,* 2001). In all the experiments, up to 9 transducers will be multiplexed (where each transducer records a profile in turn), so that while each profile takes up to 18 × 10^{-3} s to record, they are separated by a 15 × 10^{-3} s delay between transducers, yielding a total sampling time of up to 33 × 10^{-3} s. The delay ensures that there are no echo effects or cross talk between the transducers, resulting in a data capture rate of approximately 40 Hz.

5.3 SCALING OF VEGETATION PROPERTIES.

Though both artificial and natural flexible woody vegetation has been used in some studies to determine the value of resistance coefficients (Fathi-Moghadam and Kouwen, 1997; Freeman et al., 2000; Järvelä , 2002; Wilson et al., 2006), most flume experiments of stream channels use woody vegetation in the simplest form, represented as wooden dowels or similar rigid structures (Pasche and Rouvé, 1985; McBride et al., 2007; White and Nepf, 2008). Accounting for the flexibility of woody vegetation is important in accurately estimating vegetative resistance (Fathi-Moghadam and Kouwen, 1997). To determine the flexibility of artificial vegetation, Young's modulus of elasticity (E) will be obtained for Eastern cottonwood and scaled for the physical model. Young's modulus can be estimated by:

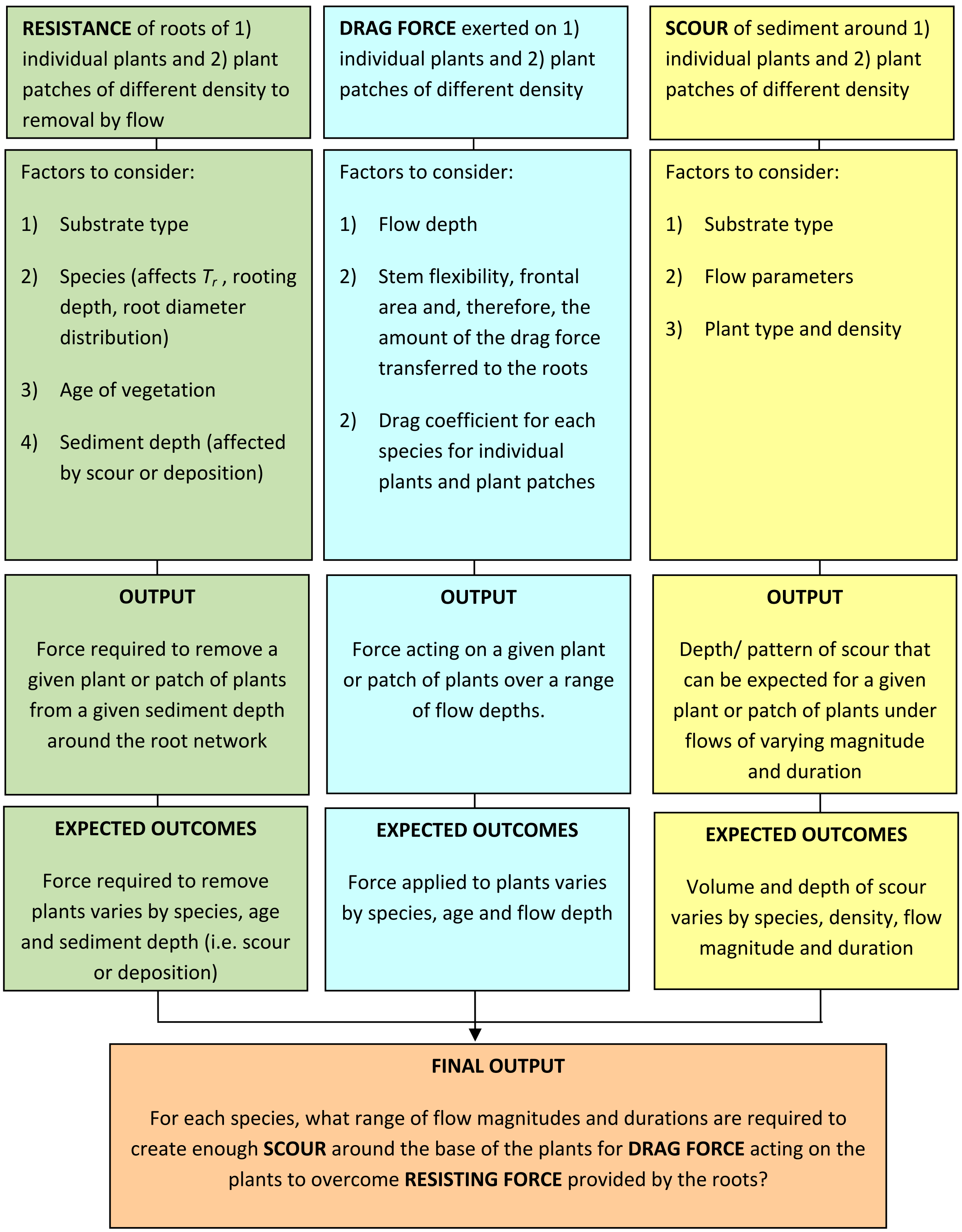
$$E = \frac{J}{I} = \frac{F_d a^2}{2\delta I(3L - a)} \qquad (1)$$

where E is Young's modulus of elasticity (N m^{-2}), J = flexural stiffness (N m^2), I is the second moment of inertia ($I = \pi D_s^4/64$, in m^4), D_s is stem diameter (m), F_d = drag force (N), a = distance from the base of the stem to the point at which F_d is applied (m), δ = deflection of the stem (m), and L = stem length (m).

Recent tests conducted at the USDA-ARS-NSL on 2 m-tall, 20 mm-diameter sandbar willows suggest that 4.54 mm-diameter acrylic rods with a J-value of 0.04 N m^2 may be appropriate artificial woody vegetation. Artificial leaves and branches will also be constructed from appropriate materials (again, recent tests on sandbar willows suggest that ten 28-gauge wire "branches" and ten 25 × 35 mm "leaves" made of contact paper (875 mm^2 total) spaced to reflect a pattern of projected area found by Wilson et al. (2006) may be appropriate). C_D-values for *Phragmites australis* have been reported for a variety of submergences and velocities by James and co- workers (James et al., 2001; 2004; 2008; Jordanova et al., 2006), and so it is hoped that only a limited number of flume tests will be needed to verify previous values. Conversely, at the present time and pending fieldwork, the project team may decide to place live specimens of Reed canary grass in the flume or select artificial materials to simulate its behavior. When placed in the flume, the areal density of vegetation will also be appropriately scaled.

6. LINKING FORCE AND RESISTANCE TO DETERMINE SCOUR THRESHOLDS

Combining field and modeling results of the resisting forces required for root breakage and/or pullout with experimental results on species-specific fluid drag will provide a means to calculate scour thresholds for plant removal. This framework is set out below.



In combination with analysis of expected Platte River flows, these results will provide reliable predictions of species-specific scour thresholds over the potential range of flow velocities, depths and durations. To link these thresholds to available flow rates, existing data relating velocity and discharge predictions from either 1D or 2D hydraulic modeling of selected reaches (Lexington to Odessa, and Kingsley Dam to Columbus, NE) or USGS gage data will be used to estimate the discharge and flow durations required to remove individual plants and patches of plants.

HOW DO THE EXPECTED OUTCOMES OF THIS PROJECT RELATE TO FLOW HYPOTHESES 3 AND 5?

Flow hypothesis 3: Increasing the peak flow (1.5-year recurrence interval) will increase plant mortality. The results of this study will help to establish whether plant rooting resistance can be overcome by increasing the peak flow (up to 8,000 cfs) and therefore the drag forces acting on the plants.

Flow hypothesis 5: Increasing the magnitude and duration of the 1.5-year recurrence interval flow will increase plant mortality. If the drag forces acting on the vegetation within the channel margins are not sufficient to uproot the plants alone (within the 8,000 cfs limit permissible for the peak flow in the channel), additional scour of the substrate will be required to initiate uprooting of the plants. The amount of scour occurring around the plants is a function of the magnitude of the flow and the duration of the flow. This study aims to determine the range of flow magnitudes and durations over which plant uprooting of 1-2 year old vegetation will occur.

7. BUDGET

1. SALARIES AND BENEFITS

	# weeks	Salaried time	Benefits	Paid by USDA-ARS	TOTALS
Dr. Andrew Simon	8	$ 18,769.23	$ 6,569.23	$ 25,338.46	
Dr Natasha Pollen-Bankhead	14	$ 26,923.08	$ 9,423.08	-	
Dr Robert Thomas	18.5	$ 35,910.46	$ 12,568.66	-	
Postdoc. Research Associate	8	$ 15,384.62	$ 5,384.62	-	
Research Associate	8	$ 9,230.77	$ 3,230.77	-	
Hydrologic Technician	8	$ 9,230.77	$ 3,230.77	-	
Hydrologic Technician	8	$ 9,230.77	$ 3,230.77	$ 12,461.54	
					$ 130,517.58

2. TRAVEL

Field trip 1 4 ppl, 13 days 1 person 9 days	Fieldtrip 2 2 ppl, 13 days	Fieldtrip 3 2 ppl, 13 days	Meetings 3ppl, 3 days	TOTALS
$ 3,866.00	$ 3,866.00	$ 3,866.00	$ 2,046.00	
$ 3,008.00	$ 3,008.00	$ 3,008.00	$ 1,848.00	
$ 3,866.00	-	-	$ 1,848.00	
$ 3,008.00	-	-	$ 1,500.00	
$ 2,544.00				
				$ 37,282.00

3. EQUIPMENT

			TOTALS
Plant puller		$ 2,300.00	
Vectrino		$ 9,980.00	
Refitting flume		$ 5,000.00	
			$ 17,280.00

4. SUPPLIES

			TOTALS
Construction materials for plant collars		$ 500.00	
Materials to construct model plants for flume		$ 800.00	
Shipping of samples and equipment		$ 1,000.00	
Gasoline (1 trip to and from NE from MS)		$ 2,000.00	
Truck maintenance		$ 1,000.00	
Sample analysis	100 samples	$ 75.00	
			$ 12,800.00

5. INDIRECT COSTS

	TOTALS
University of Tennessee	**$ 15,235.17**
USDA-ARS	**$ 46,885.25**

6. TOTAL

	TOTALS
	$ 260,000.00

8. SCHEDULE OF WORK (assuming money has been received by USDA-ARS by June 1st)

Month	Fieldwork	Laboratory Experiments/ Modeling/ Analysis
May		Prepare flume for experiments to measure drag coefficients for species to be tested
June/July	Two week field trip to: 1) Measure below ground root parameters required for RipRoot model 2) Measure plant pullout forces for different species, and different age plants 3) Measure bending moments and flexural properties of species to be tested to measure elastic energy loss for each species, and to inform flume vegetation study	Following field trip select material to simulate vegetation types in flume experiments based on flexural properties measured in field Start to run flume experiments Conduct experiments of plant pullout forces under different burial depths using plants brought back from fieldtrip
August	Additional two week field trip.	Continue experiments of plant pullout forces under different burial depths using plants brought back from fieldtrip Continue flume experiments Start to run RipRoot model using root parameters collected during first/second fieldtrips. These values will represent a near maximum (summer value) for plant resistance.
September		Continue to run RipRoot model
October	Final two week field trip to repeat measurements of above and below ground plant properties, and obtain values at the end of the growing season.	Run RipRoot model for data collected during second field trip. These values will represent an autumn value for plant resistance Model scour potential for flow events of different magnitudes and durations
November	Final modeling and analysis to be completed. Write up report.	
December	Present results to PRRIP	

REFERENCES

Buckee, C., Kneller, B.C., and Peakall, J., 2001. Turbulence structure in steady solute-driven gravity currents. In: W.D. McCaffrey, B.C Kneller and J. Peakall, eds. Particulate Gravity Currents. Blackwell Science, Oxford, UK: . In: W.D. McCaffrey, B.C Kneller and J. Peakall (eds.), Particulate Gravity Currents, Oxford: Blackwell Science; pp.173-188.

Fathi-Moghadam, M., and Kouwen, N., 1997. Nonrigid, nonsubmerged, vegetative roughness on floodplains. Journal of Hydraulic Engineering, ASCE, 123(1),): 51-57.

Fredsøe, J. 1978. Meandering and braiding of rivers. Journal of Fluid Mechanics, 84(4): 609-624.

Freeman, G.E., Rahmeyer, W.H., and Copeland, R.R. 2000. Determination of resistance due to shrubs and woody vegetation. USACE Report ERDC/CHL TR-00-25. USACE ERDC, Vicksburg.

Friedkin, J.F. 1945. A Laboratory Study of the Meandering of Alluvial Rivers. US Waterways Experiment Station, Vicksburg.

James, C.S., Birkhead, A.L., Jordanova, A.A., and O'Sullivan, J. 2004. Flow resistance of emergent vegetation. Journal of Hydraulic Research, 42(4): 390-398.

James, C.S., Goldbeck, U.K., Patini, A., and Jordanova, A.A. 2008. Influence of foliage on flow resistance of emergent vegetation. Journal of Hydraulic Research, 46(4): 536-542. doi:10.3826/jhr.2008.3177.

James, C.S., Birkhead, A.L., Jordanova, A.A., Kotschy, K.A., Nicolson, C.R., and Makoa, M.J. 2001. Interaction of Reeds, Hydraulics and River Morphology. Water Research Commission, South Africa Report 856/1/01.

Järvelä, J. 2002. Flow resistance of flexible and stiff vegetation: a flume study with natural plants. Journal of Hydrology, 269(1-2): 44-54.

Jordanova, A.A., James, C.S., and Birkhead, A.L. 2006. Practical estimation of flow resistance through emergent vegetation. Proceedings of the Institution of Civil Engineers, Water Management, 159(WM3): 173-181.

Lane, E.W. 1957. A study of the shape of channels formed by natural streams flowing in erodible material. Missouri River Division Sediment Series 9. U.S. Army Engineer Division, Missouri River, Omaha, NE.

Leopold, L.B. and Wolman, M.G. 1957. River channel patterns: braided, meandering and straight. U.S. Geological Survey Professional Paper 282-B. U.S. Government Printing Office, Washington, D.C.

McBride, M., Hession, W.C., Rizzo, D.M., and Thompson, D.M. 2007. The influence of riparian vegetation on near-bank turbulence: a flume experiment. Earth Surface Processes and Landforms, 32(13): 2019-2037.

Mosley, M.P. 2001. Discussion of Paola, C. Modelling stream braiding over a range of scales. In: M.P. Mosley, ed. Gravel-Bed Rivers V. New Zealand Hydrological Society, Wellington: 11-46.

Nanson, G.C., and Knighton, A.D. 1996. Anabranching rivers: their cause, character and classification. Earth Surface Processes and Landforms, 21: 217-239.

Paola, C. 2001. Modelling stream braiding over a range of scales. In: M.P. Mosley, ed. Gravel-Bed Rivers V. New Zealand Hydrological Society, Wellington: 11-46.

Pasche, E., and Rouvé, G. 1985. Overbank flow with vegetatively roughened flood plains. Journal of Hydraulic Engineering, ASCE, 111(9): 1262-1278.

Schumm S.A., and Khan, H.R. 1972. Experimental study of channel patterns. Geological Society of America Bulletin, 83(6): 1755-1770.

Schumm, S.A., Mosley, M.P., and Weaver, W.E. 1987. Experimental Fluvial Geomorphology. John Wiley & Sons, Inc., New York, NY.

Sidle, J.G., and Faanes, C.A. 1997. Platte River ecosystem resources and management, with emphasis on the Big Bend reach in Nebraska. US Fish and Wildlife Service, Grand Island, Nebraska. Northern Prairie Wildlife Research Center Online, Jamestown, ND. Available: http://www.npwrc.usgs.gov/resource/habitat/plrivmgt/index.htm (Accessed 03/04/2010).

Simpson, C.J., and Smith, D.G. 2001. The braided Milk River, northern Montana, fails the Leopold–-Wolman discharge-gradient test. Geomorphology, 41: 337-353.

Smith, N.D. 1970. The braided stream depositional environment: comparison of the Platte River with some Silurian clastic rocks, North-Central Appalachians. Geological Society of America Bulletin, 81(10): 2993-3014.

Smith, D.G., and Smith, N.D. 1980. Sedimentation in anastomosed river systems: examples from alluvial valleys near Banff, Alberta. Journal of Sedimentary Petrology, 50(1): 157-164.

Thorne, C.R., and Abt, S.R. 1993. Analysis of riverbank instability due to toe scour and lateral erosion. Earth Surface Processes and Landforms, 18: 835-843.

U.S. Fish and Wildlife Service. 1967. Endangered species list-1967. Federal Register, 32, FR4001.

U.S. Fish and Wildlife Service. 1985a. Interior population of least tern to be endangered. Federal Register, 50, FR221784-21792.

U.S. Fish and Wildlife Service. 1985b. Determination of endangered and threatened status for piping plover. Federal Register, 50, FR50726-50734.

Wahl, T. 2009. WinADV Version 2.027. U.S. Bureau of Reclamation, Water Resources Research Laboratory, Denver, CO.

White, B.L., and Nepf, H.M. 2008. A vortex-based model of velocity and shear stress in a partially vegetated shallow channel. Water Resources Research, 44(1): W01412. doi:10.1029/2006WR005651.

Wilson, C.A.M.E., Yagci, O., Rauch, H.-P., and Stoesser, T. 2006. Application of the drag force approach to model the flow-interaction of natural vegetation. International Journal of River Basin Management, 4(2): 137-146.