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Research, Education, and Economics
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Imogene Holmes
Lake Tahoe Basin Research
USDA Forest Service
Pacific Southwest Research Station
800 Buchanan St.
West Annex Building
Albany, CA 94710

Dear Ms. Holmes,

Thank you for the opportunity to submit a proposal for consideration to conduct research in support of the Lake Tahoe Environmental Improvement Program. The attached research proposal, entitled, "Application of Enhanced Stream-Corridor Modeling Tools for Adaptive Management of Tahoe Basin Streams" builds on previous research conducted by the principal investigators at the USDA-ARS National Sedimentation Laboratory to quantify magnitudes and sources of fine-sediment loadings to Lake Tahoe.

The proposed study directly addresses Theme 2, Water Quality, Sub-theme B "…to improve our understanding of stream channel erosion dynamics and historical changes in stream channel morphology; customize stream channel models for use by resource managers with the aim of developing restoration approaches that achieve sediment loading reduction, in concert with habitat preservation." The proposed work will quantify potential load reductions from stream-channel sources and provide state-of-the-art numerical tools for resource managers to evaluate existing and future restoration treatments and projects.

Please do not hesitate to contact us if you have any questions or require any additional information. We look forward to hearing from you in the near future.

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Proposal to Conduct Research in Support of the Lake Tahoe Environmental Improvement Program

Application of Enhanced Stream-Corridor Modeling Tools for Adaptive Management of Tahoe Basin Streams

Submitted to

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I. Project Team and Contact Information

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Theme and Sub-Theme

The proposed study is primarily supportive of Theme 2, Water Quality, Sub-theme B "…to improve our understanding of stream channel erosion dynamics and historical changes in stream channel morphology; customize stream channel models for use by resource managers with the aim of developing restoration approaches that achieve sediment loading reduction, in concert with habitat preservation."

This work is also important in relation to Theme 6, Cross Cutting All Science Areas, Sub-theme B, since specific it will produce guidance for pre- and post-project monitoring of all stream treatments in the Basin consistent with model application.

II. Justification Statement

Substantial progress has been made on understanding and quantifying the contribution of stream channel erosion to sediment loading of Lake Tahoe (Simon et. al. 2003, Simon 2006). Streambank erosion has been estimated to account for about 25% of the total fine-sediment load entering Lake Tahoe (Simon, 2006). Much of this material emanates from unstable reaches of the Upper Truckee River, while Blackwood and Ward Creeks are also large contributors. Stream restoration has been accepted as an appropriate method to mitigate bank and channel instability, improve water quality, and contribute to other Basin Thresholds, with significant investment in planning, design, and implementation over several years. However, there are continuing needs for improved predictive modeling of channel processes with tools validated in the Lake Tahoe Basin at both watershed and project-specific scales, including representation of typical restoration features (channel, bank, and floodplain morphology, materials, hydrology, and vegetation). Modeling tools are needed that: 1) simulate channel response and quantify water quality performance of alternative restoration designs prior to approval and construction; and 2) estimate channel adjustments following implementation to inform adaptive management decisions.

As open systems, alluvial streams operate in a balance (dynamic equilibrium) between the upstream delivery of sediment and the transport capacity. Changes to this balance, either through direct modification of the channel or by indirect changes in sediment delivery or hydrology (ie. land use changes), adjusts the stream's ability to transport sediment and consequently cause erosion and deposition. Thus, the best intended projects still represent "disturbances" to the fluvial system and must be designed/constructed to maintain a balance of flow energy and sediment transport so that stabilization of one reach does not lead to instability in adjacent reaches. This is referred to as sediment continuity. For instance, if sediment delivery from an upstream reach is cut off, it is possible that the imbalance between transport capacity and sediment delivery to the downstream reach will induce renewed streambed incision and associated streambank erosion.

On the Upper Truckee River for example, at least three projects along adjacent reaches are in the planning stages by different design groups, yet none of these projects explicitly analyze for streambank stability or account for sediment contributed by bank failures in calculations of sediment continuity. Estimating future channel stability, migration, bank erosion, and resultant water quality for the project designs is hindered by the lack of geotechnical information and accepted tools. Similarly, restoration projects implemented on Angora Creek and Trout Creek have been monitored, but lack quantified information on performance of streambank and other restoration treatments, leading to the following questions regarding potential fine-load reductions from streambank erosion:

1. Are the restoration treatments performing as designed?
2. Why are some treatments more successful than others?
3. Have fine-loadings to the lake been reduced, and by what magnitude?
4. Have projects resulted in a properly functioning channel that supports habitat for native species?

There is a critical need for a comprehensive planning and prediction tool that deterministically incorporates bed and bank processes. Furthermore, with the widespread use of vegetation and bio-engineering techniques in restoration projects, data and numerical tools are required to account for the effects of riparian vegetation on geotechnical and hydraulic resistance of channel materials.

III. Background/Problem Statement

The California Regional Water Quality Control Board, Lahontan Region (Lahontan) and the Nevada Division of Environmental Protection (NDEP) are conducting a total maximum daily load (TMDL) study for Lake Tahoe to estimate nutrient and sediment loads and identify methods to reduce loads and restore lake clarity to its approximately 100-foot Secchi depth standard. As part of the TMDL Phase 1 research, the conservational channel evolution and pollutant transport system (CONCEPTS) model (Langendoen 2000; Langendoen *et al,.* 2001) was used successfully to simulate sediment transport and channel changes on three streams tributary to Lake Tahoe: Upper Truckee River, Ward Creek, and General Creek (Simon *et al.*, 2003). The Principal Investigators of this study are conducting Phase 2 TMDL studies for Lahontan and NDEP to identify and evaluate options to reduce loads from Tahoe Basin stream channels. Despite increased monitoring of stream restoration projects nationwide

(Palmer *et al*., 2005) very few have more than a few years of post-implementation data (Kondolf per. comm. 2007). Therefore, quantitative estimates of 'effectivity' using extrapolation of performance from site to site and region to region remain difficult and possibly misleading. We are using long-term simulation runs with CONCEPTS to quantify potential load reductions from stream channel treatments on four key Tahoe Basin watersheds (Upper Truckee, Blackwood, Ward, and Rosewood (within Third Creek basin).

CONCEPTS is part of U.S. EPA's "tool box" of approved models, used successfully in diverse regions of the country by TMDL agencies to predict sediment sources and loadings. The deterministic, numerical model is unique in accounting for hydraulic and geotechnical processes that control streambank erosion in addition to bed processes and the routing of flow and sediment. The bank-stability algorithms are similar to those included in the Bank-Stability and Toe-Erosion Model (BSTEM) developed at the National Sedimentation Laboratory (NSL)(Simon *et al*., 1999; 2000; Simon and Pollen, 2005) and used along a reach of the Upper Truckee River to predict critical conditions for bank stability and the reinforcing effects of riparian vegetation (Simon *et al*., 2006). This model, also supported by U.S. EPA, is particularly useful for designing stable-bank configurations that include the effects of riparian vegetation.

These existing numerical tools are ideal for addressing the types of critical issues concerning stream-restoration design and performance aimed towards reducing fine-sediment loadings to Lake Tahoe. Model enhancements to address load reductions from specific treatments and projects would provide long-term benefits to basin agencies. Recent research has shown that the two most critical variables to accurately predicting bank strength, stability and channel-widening rates are cohesion and pore-water pressure (Langendoen and Simon, in press). Vegetation plays a large role in controlling these variables. Work by Pollen and Simon (2005) using fiber-bundle theory and direct shear experiments of root-permeated soils showed that predictions of the magnitude of cohesion provided by root reinforcement were being overestimated by as much as 100% using conventional techniques. The Riparian Ecosystem Management Model (REMM) which simulates hydrology, nutrient dynamics and plant growth in riparian buffers has been incorporated into CONCEPTS (Langendoen *et al*., 2005). The integrated CONCEPTS/REMM model has been shown to satisfactorily simulate streambank hydrology of an incised stream for both herbaceous and woody species (Langendoen *et al*., 2005; 2006; 2007). The technology incorporated in REMM makes it well-suited to simulate the long-term functioning of a riparian buffer along both banks of a stream corridor. Enhancements to the CONCEPTS and BSTEM models to include a near-bank groundwater model, and quantification of the role of riparian roots on hydraulic resistance to erosion would improve predictive abilities. Addition of a lateral migration component to CONCEPTS would then complete a state-of-the-art set of tools for adaptive management of streams tributary to Lake Tahoe. Field experiments of erosion resistance of bio-engineered treatments and numerical simulations of channel and treatment response could be validated with time-series data collected from selected streams in the Tahoe Basin.

The proposed research will link nicely with ongoing TMDL Phase 2 analyses and produce updated performance evaluation and modeling tools at a timely point in the decision process for several proposed river restoration projects.

IV. Goals, Objective(s), and statement of hypotheses to be tested

The primary objectives of the proposed study are to enhance and further validate the predictive, numerical models CONCEPTS and BSTEM to fully realize their potential as state-of the-art tools for stream management, in the Lake Tahoe Basin and elsewhere. The project-scale data collection and resultant model enhancement will specifically inform adaptive management strategies for local restored streams and, the validated models will be available for use in evaluating design and expected performance of proposed restoration projects. Specific study objectives include:

- Quantifying the effects of riparian vegetation and bio-engineered treatments on the resistance of bank materials to hydraulic erosion and bank undercutting for inclusion into both models;
- Developing a near-bank groundwater model to integrate with CONCEPTS and BSTEM for the purpose of simulating pore-water pressures dynamically;
- Developing algorithms for CONCEPTS to simulate lateral migration of meandering channels in a deterministic fashion by accounting for hydraulic and geotechnical controls; and
- Validate the use of the CONCEPTS and BSTEM models at the project-scale for existing and restored reaches of selected Tahoe basin streams using time-series historical data on flow, sediment transport and channel geometry.

The underlying hypothesis of this research effort is that with improved definition of the effects of vegetation and other bio-engineered treatments on boundary resistance coupled with enhanced algorithms to simulate channel response, resource managers in the Lake Tahoe Basin will have the ability to accurately evaluate restoration strategies to reduce fine-sediment loadings to the lake with state-of-the-art numerical tools.

V. Approach, Methodology, and Geographic Location of Research

The scope of the proposed research is selected reaches of the Upper Truckee River and Angora Creek, as well as Trout Creek. Angora and Trout creeks are included because they contain well documented restoration efforts that have been installed for several years. Field-data collection and experiments will take place along the selected reaches, while laboratory experiments will be conducted at the NSL, Oxford, MS in specialized flumes and with a laboratory, direct-shear apparatus.

The approach combines field and laboratory experiments on the effects of vegetation, bio-engineered treatments and hydraulics in meander bends with the development and validation of process-based algorithms to better simulate pore-water pressure distributions, streambank erosion, lateral migration of meanders, and fine-sediment loadings. The approach builds on prior field data and modeling efforts in the same stream systems, and validation opportunities provided by post-project monitoring of implemented projects.

Quantifying the Effects of Vegetation and Bio-Engineered Treatments

To accurately evaluate the susceptibility of root-permeated and bio-engineered streambanks to erosion, channel widening and lateral migration, the hydraulic and geotechnical resistance of these features must be quantified. A series of field experiments will be conducted using a root tensile-strength testing device (Abernethy and Rutherford, 2001) in conjunction with root mapping to quantify root reinforcement (Simon and Collison, 2002; Pollen and Simon, 2005) of meadow and other riparian vegetation throughout the bank profiles. Submerged jet-test devices (Hanson, 1990; Tolhurst *et al*., 1999) will be used to determine hydraulic resistance (critical shear stress and erodibility) of bank sediments with and without riparian roots as well as bio-engineered treatments. Results of these field experiments will provide values of critical shear stress (τ_c; stress for incipient motion of particles) and the erodibility coefficient (k; erosion volume per unit of stress, per unit of time) that are important input parameters into both numerical models for predicting bank-toe erosion and undercutting (Hanson and Simon, 2001). Laboratory experiments using specially-designed boxes containing vegetation of various root densities, and scale analogs of bio-engineered treatments will be installed in a recently constructed flume at NSL. These experiments will similarly provide values for the increases in critical shear stress and decreases in erodibility associated with these treatments. Data obtained from these experiments and associated field data will be used to define erosion resistance for the various layers and surfaces comprising the channel boundary.

Near-Bank Groundwater Model: Dynamic Pore-Water Pressure

Sub-models will be developed or enhanced for BSTEM and CONCEPTS to simulate: (1) the spatial distribution of pore-water pressure in a streambank and along a stream-riparian corridor; and (2) the effectiveness of different riparian species in controlling streambank erosion by increasing the resistance of the bank to hydraulic and geotechnical forces. Because BSTEM and CONCEPTS operate at different spatial and temporal scales, the technology incorporated into the sub-models of BSTEM and CONCEPTS will be different. However, the simulated processes that affect soil water will be the same: (1) infiltration, (2) evapotranspiration, and (3) interaction of the bank with stream and aquifer.

Data will be collected at selected sites on Trout and Angora Creeks as well as along selected, sinuous reaches of the lower Upper Truckee River to determine: permeability, soil texture, soil water retention curve, above- and below-ground plant biomass, volumetric soil water content, pore-water pressure, and groundwater table elevation. Data on groundwater levels and pore-water pressure distributions are available for some reaches (EDAW, 2006; Simon *et al*., 2006). Additional pore-water pressure data for model validation will be obtained using digital tensiometers installed at various depths and distances from the channel along selected reaches representing a range of riparian-buffer systems (i.e., meadow vegetation, woody species). This approach has been successfully used for Lemmon's willow and Lodgepole pine along the Upper Truckee River (Simon *et al*., 2006). The data will be used to: (1) develop species-specific data bases for BSTEM and CONCEPTS/REMM, and (2) test and validate the above sub-models. Validation runs will be conducted to compare simulated pore-water pressure distributions with time-series pore-water pressure data obtained with the digital tensiometers along the study streams. The effects of different vegetation and bio-engineered treatments will then be simulated with the validated models to evaluate and compare the effectiveness of various treatments. The models will be tested and validated against observed morphological changes over a range of spatial and temporal scales.

CONCEPTS-REMM Integration

It is proposed to enhance the integration between CONCEPTS and the Riparian Ecosystem Management Model (REMM). REMM was developed as a tool to aid natural resource agencies in making decisions regarding management of riparian buffers to control non-point source pollution (Altier *et al*., 2002). Langendoen *et al*. (2007) found that two areas of improvement are needed in REMM to better predict pore-water pressure dynamics. These improvements include: an improved transpiration algorithm, and representation of movement of subsurface water parallel to the stream. First, the transpiration algorithm will be updated using the canopy processes model of Forseth and Norman (1991) that treats the canopy as two sets of leaves, sunlit and shaded. Norman (1980) showed that this division in leave classes provides a substantial improvement in prediction over models which simply assumed an exponential decline in light through homogeneously lit canopy layers, which is the present technique incorporated in REMM. Second, the flux of subsurface water at the transition of adjacent riparian buffers defined at each CONCEPTS cross section will be quantified based on longitudinal groundwater-table gradient and local permeability to determine the movement of subsurface water parallel to the stream. Required data for input and validation will be provided from representative sample data described above.

BSTEM

To provide management agencies with a predictive tool for streambank-restoration design and performance a two-dimensional (2D) variably-saturated flow model will be incorporated and enhanced from existing model codes (VS2D; Lapalla *et al*., 1987). The 2D Richards equation will be solved by a finite-difference method. Boundary conditions will be adjusted to account for gains of soil water by infiltrating precipitation and recharge of the streambank from the stream and aquifer, and losses of soil water by evapotranspiration and seepage to stream and aquifer. Required data inputs will be provided from representative sample data described above.

Lateral Migration of Meanders (CONCEPTS)

To accurately predict channel evolution in sinuous streams and to evaluate restoration strategies that include re-meandering of channels, a sub-model will be developed for CONCEPTS to simulate the lateral migration of meandering streams. The approach of Kean (2003) that extends the meandering-flow model of Smith and McLean (1984) to streams of arbitrary cross section geometry will be used. This approach more accurately determines near-bank flow and boundary shear stresses, which are critical for determining the enhanced erosive forces on the outside of meander bends. Combining this technology with the process-based streambank erosion algorithms of CONCEPTS will provide a comprehensive, physically-based model of lateral channel migration at engineering time scales. The combined model will improve upon current, commonly used quasi two-dimensional models derived using perturbation analysis (e.g., Larsen, 1995; Sun *et al*., 2001) that are limited to cross sections of simple geometry with vertical banks linear transverse bed slope, at constant width. These models relate lateral retreat to near-bank velocity through an empirical erosion coefficient, and, therefore, are less useful for simulating lateral erosion rates of specific bends where materials and treatments may vary. By simulating the lateral distributions of flow and boundary shear stress, the enhanced model will be able to predict the divergence of sediment-transport rates and bank-toe scour within sinuous streams.

Evaluating Performance of Restoration Treatments and Validating Model Results

Validation of simulations with deterministic, numerical models such as CONCEPTS and BSTEM is best conducted with high-quality field data to define the available forces and boundary resistance that control the specific processes being simulated. Because the models simulate erosion by both hydraulic and geotechnical forces, field data quantifying channel dimensions, hydraulic resistance (particle-size for coarse sediments and jet tests for cohesive sediments) and geotechnical resistance (cohesion, friction angle bulk unit weight, pore-water pressure and root reinforcement) will be collected along the selected reaches. Fortunately, a wealth of data already exists along a number of the proposed study reaches of Trout Creek (3 km)(Figure 1) Angora Creek (2.7 km) (Figures 2 and 3) and on the Upper Truckee River (Figure 4), having been collected as part of earlier studies (Walck, 2001, Walck 2003; Simon *et al*., 2003; Swanson Hydrology and Geomorphology, 2004). Rapid geomorphic assessments will be conducted along all of the study reaches to determine the relative stability and dominant geomorphic processes that are active along channels and treatments. This technique, which has been used at more than 300 sites in the basin (Simon et al., 2003) provides an index of channel stability and the performance of treated reaches.

Bed- and bank-material particle size data will be collected at cross sections along previously un-sampled reaches as will geotechnical data to define shear strength (cohesive and frictional) of the bank materials. The latter will be conducted *in situ* for at least two layers in each bank profile using a borehole shear-test (BST) apparatus (Lutenegger and Hallberg, 1981). Since the enhanced CONCEPTS model will simulate meander migration, sampling and shear-strength testing will also be undertaken along floodplain transects extending from the outside of meander bends to account for lateral changes. Critical shear stress and the erodibility coefficient of fine-grained bank materials will also be measured *in situ* using submerged jet-test devices (Hanson, 1990; Tolhurst *et al*., 1999). Both of these types of instruments have been used successfully in previous data-collection efforts along Tahoe basin streams. Vegetation surveys to account for vegetation type, leaf and stem densities, root density and depth will be conducted along floodplains of the study reaches to populate the REMM sub-model. Additional surveys of the study reaches will be conducted where needed to bring data sets up to date.

BSTEM simulations will provide site specific predictions of appropriate streambank design and performance criteria using selected geometry, vegetation or other treatments. In contrast, CONCEPTS simulations will provide quantifiable evaluations of the cumulative impact of all treatments within the reach on fine-load reduction as well as any downstream impacts on channel processes and morphology. The CONCEPTS simulations of the Angora and Trout Creek reaches are for the purpose of validating model enhancements and for evaluating the performance of various restoration treatments within those reaches. CONCEPTS simulations along the Upper Truckee River are for the purpose of validating the lateral migration sub-model over a longer time period (15 years). BSTEM simulations on all three streams will be conducted to validate the near-bank groundwater model and to test performance of specific bio-engineered treatments on streambank stability and reduction of fine-sediment loads.

VI. Deliverables/Products

The primary products of the proposed research are: (1) a set of numerical tools (CONCEPTS-REMM and BSTEM that can be utilized by resource agencies (and others) to develop scientifically defensible designs and adaptive-management strategies for restoration of streams in the Lake Tahoe Basin, and (2) an evaluation of existing restoration treatments to provide guidance on the types of treatments and overall designs that are best suited to reduce fine-sediment loads from channel sources. Specific guidance will be provided on streambank restoration using a range of geometries and treatments. A final, comprehensive report of model enhancements and study results, including all field and validation data will be provided. In addition, peer-reviewed journal articles will be produced from this work. The enhanced CONCEPTS and BSTEM models, including user interface and manuals will be delivered as a final product. Training sessions with local managers and other interested parties on data-collection techniques, model use and applications will be conducted in the basin. Training sessions will also provide the opportunity for feedback on monitoring approaches and protocols that are consistent with requirements for applied modeling of restoration projects.

Schedule of Events/Reporting and Deliverables

The study is designed with a two year duration from the receipt of funding (assumed to be June 30, 2007).

Activity/Deliverable	Start Date*	Duration	Completion Date*
Finalize field and lab plan	July 1, 2007	2 weeks	July 14, 2007
Install tensiometers and data loggers	July 15, 2007	1 month	August 30, 2007
Download of digital data	August 1, 2007	18 months	January 15, 2009
Collect field data (surveys, strength testing, erodibility)	July 15, 2007	3 months	October 15, 2007
Sediment analysis	August 1, 2007	5 months	December 31, 2007
Conduct laboratory experiments	August 1, 2007	18 months	January 15, 2009
CONCEPTS/REMM Integration - Development and Testing	July 1, 2007	12 months	June 30, 2008
CONCEPTS/REMM Integration - Validation	July 1, 2008	3 months	September 30, 2008
CONCEPTS: Lateral migration algorithm – Development and Testing	July 1, 2007	20 months	February 28, 2009
CONCEPTS: Lateral migration algorithm –Validation	March 1, 2009	4 months	June 30, 2009
BSTEM Enhancement: Groundwater model - Development	July 1, 2007	12 months	June 30, 2008
BSTEM Enhancement: vegetation effects - Development	July 1, 2007	20 months	February 28, 2009
Draft report on vegetation effects (field data)	December 1, 2007	1 month	January 1, 2008
Draft results report	February 1, 2009	3 months	April 30, 2009
Draft manuals for models	July 1, 2008	9 months	March 31, 2009
Draft guidance for design and adaptive management applications	October 1, 2008	6 months	March 31, 2009
In-Basin Training sessions	June 2009	1 week	June 2009
Final results report	May 1, 2009	2 months	June 30, 2009
Final manuals for models	April 1, 2009	3 months	June 30, 2009
Final guidance for design and adaptive management applications	April 1, 2009	3 months	June 30, 2009
Prepare Journal Articles Submissions for Peer-Review	July, 1, 2008	ongoing	June 30, 2009

*Start and completion date estimates assume that grant award and funding is completed by June 30, 2007. Delay in funding would shift the start and completion dates based on the durations.

References

Abernethy, B., and Rutherford, I.D., 2001. The distribution and strength of riparian tree roots in relation to riverbank reinforcement. Hydrological Processes, 15: 63-79.

Altier, L. S., Lowrance, R. R., Williams, R. G., Inamdar, S. P., Bosch, D. D., Sheridan, J. M., Hubbard, R. K., and Thomas, D. L., 2002. Riparian ecosystem management model: Simulator for ecological processes in riparian zones. Conservation Research Report 46, U.S. Department of Agriculture, Agricultural Research Service.

City of South Lake Tahoe May 1999. Trout Creek Stream Restoration and Wildlife Habitat Enhancement Project Phase 1 PWC No. 1996-06. (Plans and Specifications, Haen Engineering/Watershed Restoration Associates 5/99).

City of South Lake Tahoe May 2000. Trout Creek Stream Restoration and Wildlife Habitat Enhancement Project Phase II PWC No. 1996-06. (Plans and Specifications Haen Engineering/Watershed Restoration Associates, "preliminary" bid docs 3/00).

City of South Lake Tahoe May 2001. Trout Creek Stream Restoration and Wildlife Habitat Enhancement Project Phase III PWC No. 1996-06. (Plans and Specifications by Haen Engineering/Watershed Restoration Associates 4/27/01).

EDAW, Inc. July 18, 2006. Upper Truckee River Watershed Framework Monitoring Plan-Discussion Paper 'work in progress draft' complied for the California Tahoe Conservancy.

Forseth, I.N., and Norman, J.M., 1991. Modeling of solar irradiance, leaf energy budget, and canopy photosynthesis. In Techniques in Photosynthesis and Productivity Research for a Changing Environment, D.O. Hall, J.M.O. Scurlock, H.R. Bolhar-Nordenkampf, R.C. Leegood, and S.P. Long, Eds., Chapman & Hall, London, UK.

Kean, J.W., 2003. Computation of flow and boundary shear stress near the banks of streams and rivers, Ph.D. thesis, University of Colorado, Boulder, CO, 168 p.

Hanson, G.J., 1990. Surface erodibility of earthen channels at high stresses. Part II- developing an in situ testing device. Trans., American Society of Agricultural Engineers, 33(1):132-137.

Hanson, G.J., and Simon, A., 2001. Erodibility of cohesive streambeds in the loess area of the Midwestern United States. Hydrological Processes, 15: 23-38.

Langendoen, E.J., 2000. "CONCEPTS – Conservational channel evolution and pollutant transport system" Res. Rep. 16, U.S. Department of Agriculture, Agricultural Research Service, National Sedimentation Laboratory, Oxford, MS.

Langendoen E.J., Lowrance, R., Williams, R.G., Pollen, N., and Simon, A., 2005. Quantifying the impacts of riparian buffer systems on stream stability and ecology. In Proceedings of EWRI 2005 Conference, Anchorage, Alaska. On CD.

Langendoen, E.J., and Simon, A., 2007. Numerical modeling of streambank erosion in incised streams. Journal of Hydraulic Engineering, ASCE (in press).

Langendoen, E.J., Simon, A., Pollen, N., Williams, R.G., Lowrance, R.R., 2005. A comprehensive stream-riparian corridor model to study the impact of riparian buffers on channel and edge-of-field processes: Simulation of streambank hydrology. In Proceedings of the 3rd Interagency Hydrologic Modeling Conference, Reno, Nevada, April 2006. On CD

Lappala, E.G., Healy, R.W., and Weeks, E.P., 1987. Documentation of computer program VS2D to solve the equations of fluid flow in variably saturated porous media: U.S. Geological Survey Water-Resources Investigations Report 83-4099, 184 p.

Larsen, E.W., 1995. Mechanics and modeling of river meander migration, Ph.D. thesis, University of California, Berkeley, CA.

Lutenegger, J.A., and Hallberg, B.R., 1981. Borehole shear test in geotechnical investigations. American Society of Testing Materials, Special Publication 740: 566-578.

Norman, J.M., 1980. “Interfacing leaf and canopy light interception models” In Predicting Photosynthesis for Ecosystem Models, J.D. Hesketh and J.W. Jones, Eds., CRC Press, Boca Raton, FL, 49-67.

Pollen, N., and Simon, A., 2005. Estimating the mechanical effects of riparian vegetation on streambank stability using a fiber bundle model. Water Resources Research., 41, doi: 10.1029/2004WR003801.

Prudic, D.E., Green, J.M., Wood, J.L., and Henkelman, K.K., 2005. Changes in ground-water flow and chemistry after completion of Cattleman’s Detention Basin, South Lake Tahoe, California - November 2001 to November 2003. USGS Scientific Investigations Report, 2005-5260.

Simon, A., 2006. Estimates of fine-sediment loads to Lake Tahoe from channel and watershed sources. National Sedimentation Laboratory Technical Report 52, USDA-ARS National Sedimentation Laboratory, Oxford, MS. 59 p.

Simon, A., and Collison, A.J.C., 2002. Quantifying the mechanical and hydrologic effects of vegetation on streambank stability. Earth Surface Processes and Landforms, 27: 527-546.

Simon, A., Curini, A., Darby, S.E., and Langendoen, E.J., 1999, Streambank mechanics and the role of bank and near-bank processes in incised channels. Chapter 6, In S.E. Darby and A. Simon (Eds.), Incised River Channels: Processes, Forms, Engineering and Management, John Wiley and Sons, London, 123-152.

Simon, A., Curini, A., Darby, S.E., and Langendoen, E.J., 2000, Bank and near-bank processes in an incised channel. Geomorphology, 35: 193-217.

Simon, A., Langendoen, E., Bingner, R., Wells, R., Heins, A., Jokay, N., and Jaramillo, I., 2003. Lake Tahoe Basin Framework Implementation Study: Sediment Loadings and Channel Erosion. National Sedimentation Laboratory Technical Report 39, USDA-ARS National Sedimentation Laboratory, Oxford, MS. 320 p.

Simon, A. and Pollen, N., 2005. A model of streambank stability incorporating hydraulic erosion and the effects of riparian vegetation. Proceedings of the 8th Federal Interagency Sedimentation Conference, Reno, Nevada, April 2006. On CD.

Simon, A., Pollen, N., and Langendoen, E., 2006. Influence of two woody riparian species on critical conditions for streambank stability: Upper Truckee River, California. Journal, American Water Resources Association, 42(1): 99-113.

Smith, J.D., and. McLean, S.R., 1984. A model for flow in meandering streams. Water Resources Research, 20(9): 1301-1315.

Sun, T., Meakin, P., and Jøssang, T., 2001. A computer model for meandering rivers with multiple bed load sediment sizes. 1. Theory. Water Resources Research, 37(8), 2227-2241.

Swanson Hydrology and Geomorphology, 2004. Trout Creek Meadow Restoration, 2001-2003 Geomorphic Monitoring: Final Report. Swanson Hydrology and Geomorphology.

Tolhurst, T.J., Black, K.S., Shayler, S.A., Mather, S., Black, I., Baker, K.M., and Paterson, D.M., 1999. Measuring in-situ erosion shear stress of intertidal sediments with the cohesive strength meter (CSM), Estuarine Coastal and Shelf Science, 49: 281–294.

Walck C., 2001. Angora Creek and Washoe Meadows Wildlife Enhancement Project Golf Course and Historic Meadow Reach Final Report. Internal California Department of Parks & Recreation Report.

Walck, C., 2004. Angora Creek and Washoe Meadows Wildlife Enhancement Project Phase IV Sewer Meadow Reach Final Report. Internal California Department of Parks & Recreation Report.

Western Botanical Services, Inc., 2003. Post Construction Vegetation Monitoring Report: Trout Creek Stream Restoration and Wildlife Enhancement Project. Western Botanical Services, Inc. Prepared for the City of South Lake Tahoe.

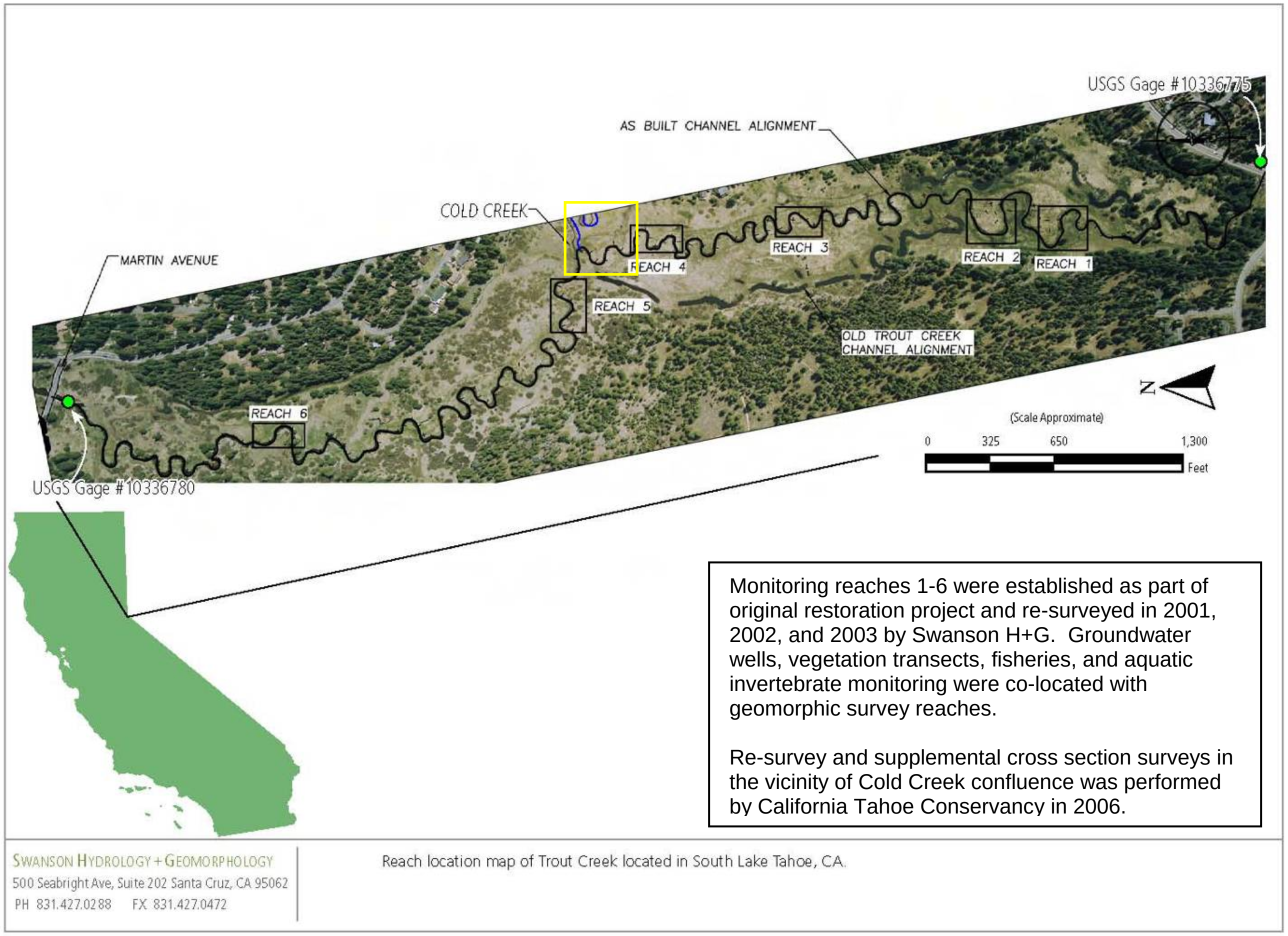
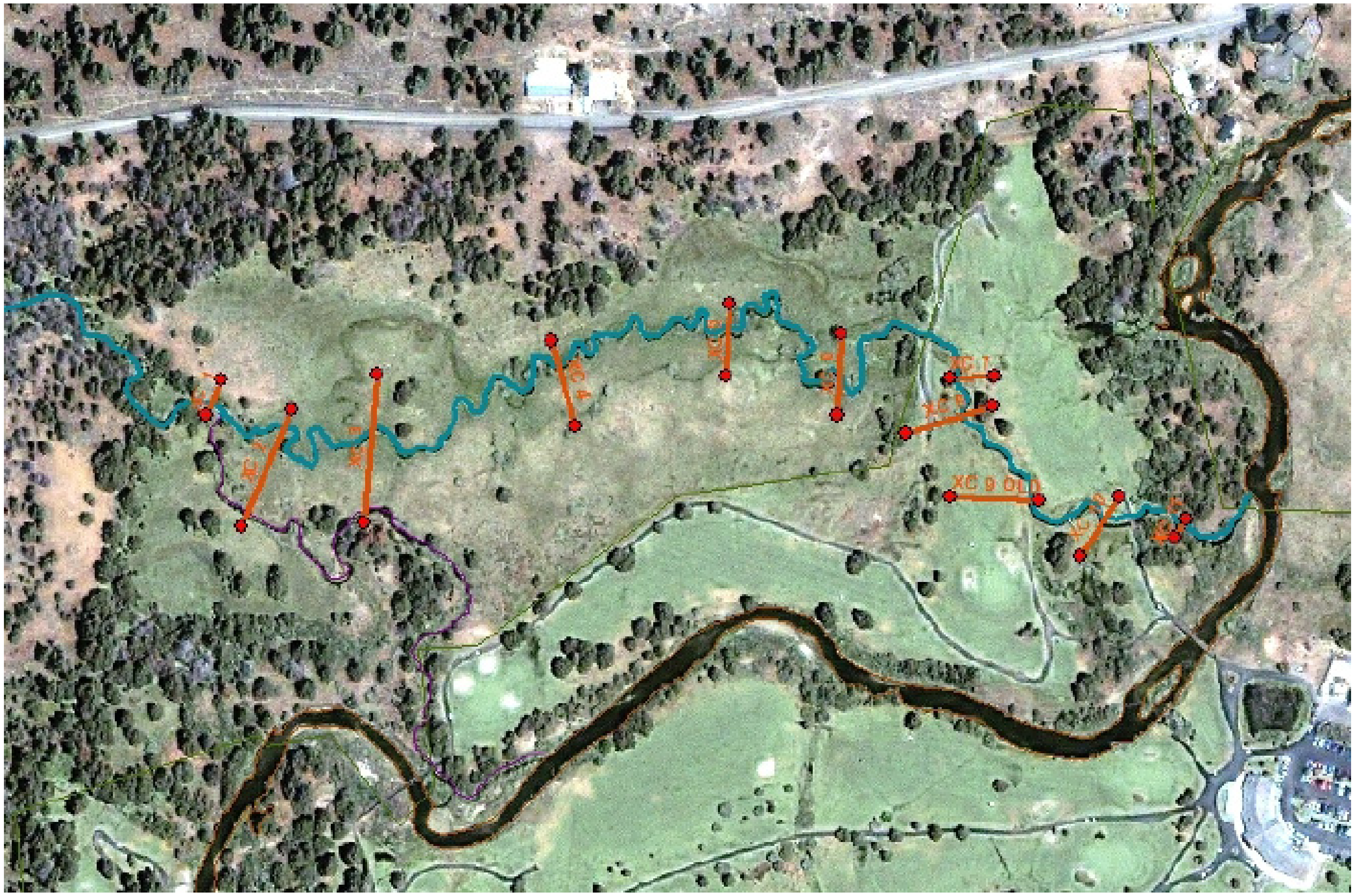


Figure 1: Trout Creek Restoration Project Monitoring Locations

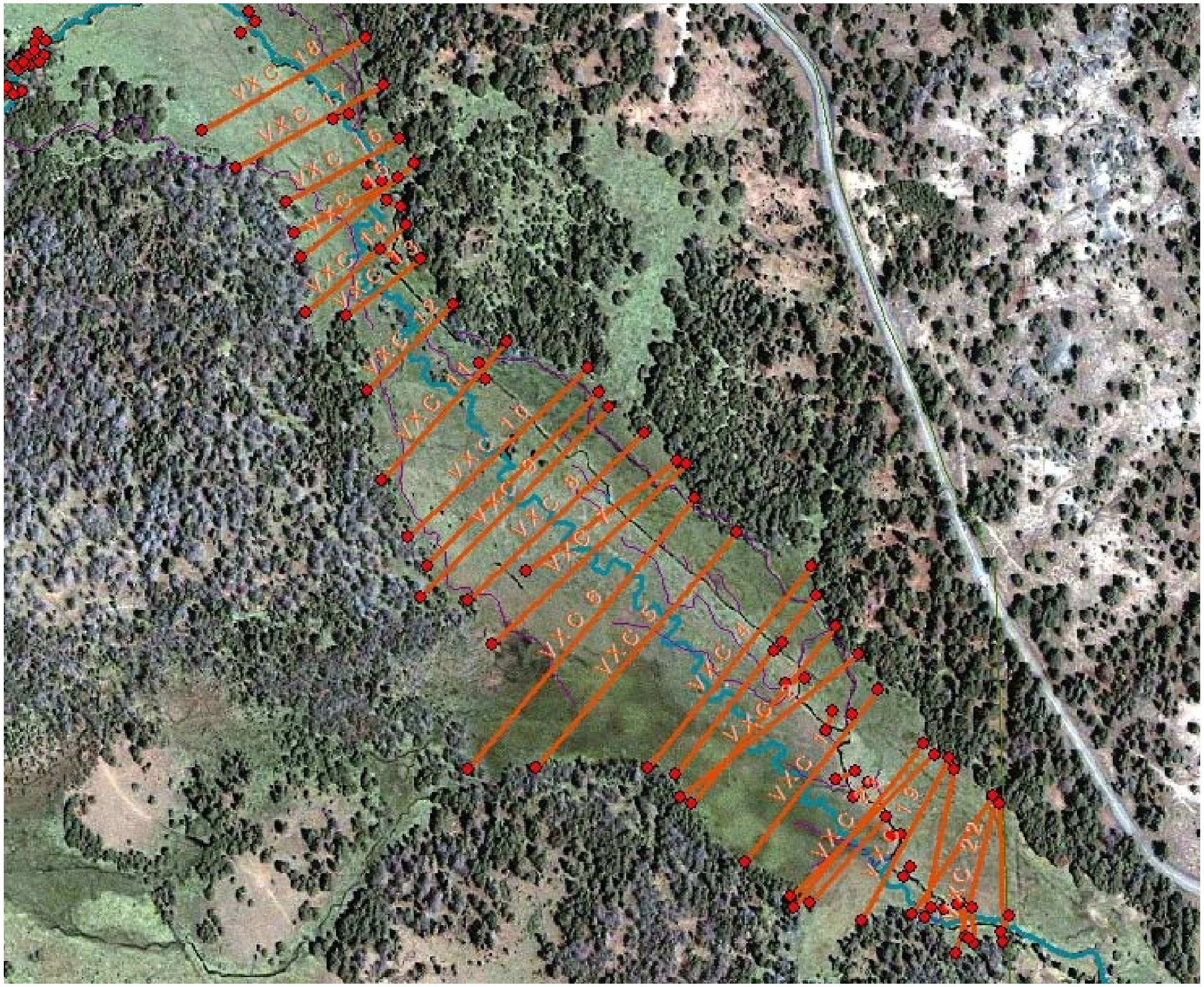
The City of South Lake Tahoe stream restoration project on ~3 km of Trout Creek was constructed in 1999-2000 and has pre- and post-project data suitable for model validation and enhancement studies. The designed/constructed data is available from the City (1999, 2000, 2001) and geomorphic monitoring was conducted at 24 monumented cross-sections in 2001-2003 (Swanson Hydrology and Geomorphology, 2004), with additional re-surveys near Cold Creek conducted in 2006 (S. Carroll, per. comm. 2007). Vegetation (species and cover) was monitored at 17 monumented transects and 23 bank treatment sites in 2000 and 2002 (Western Botanical Services, 2003). Twenty four shallow wells were used for pre- and post-project observations and may be re-activated. Surface water data includes the upstream and downstream USGS data and project-specific data compiled by the Desert Research Institute (DRI). The Cold Creek tributary also has detailed surface and groundwater data available for 2001-2003 (Prudic et. al. 2005).



Two California Department of Parks & Recreation restoration projects on Angora Creek have pre- and post- project data suitable for model validation and enhancement studies. The ~1.5 km “golf course” reach was constructed in 1998 (Walck, 2001), with monitoring at 9 monumented cross sections and associated shallow groundwater wells that can be re-activated. Streamflow data is available for parts of the post-project period and observations of vegetation, aquatic habitat, and erosion and sedimentation have been made (Walck, per. comm., 2007).

Source: California State Parks (Walck 2001)

Figure 2: Angora Creek Golf Course Restoration Project Monitoring Locations



Two California Department of Parks & Recreation restoration projects on Angora Creek have pre- and post- project data suitable for model validation and enhancement studies. The ~1.2 km 'sewer' reach was constructed in 2002 (Walck, 2004), with 24 pre-project cross sections, 9 post- project cross sections and 11 shallow groundwater wells that continue to be monitored. Streamflow data is available for parts of the post-project period and observations of vegetation, aquatic habitat, and erosion and sedimentation have been made (Walck, per. comm., 2007).

Source: California State Parks (Walck 2004)

Figure 3: Angora Creek Sewer Line Restoration Project Monitoring Locations

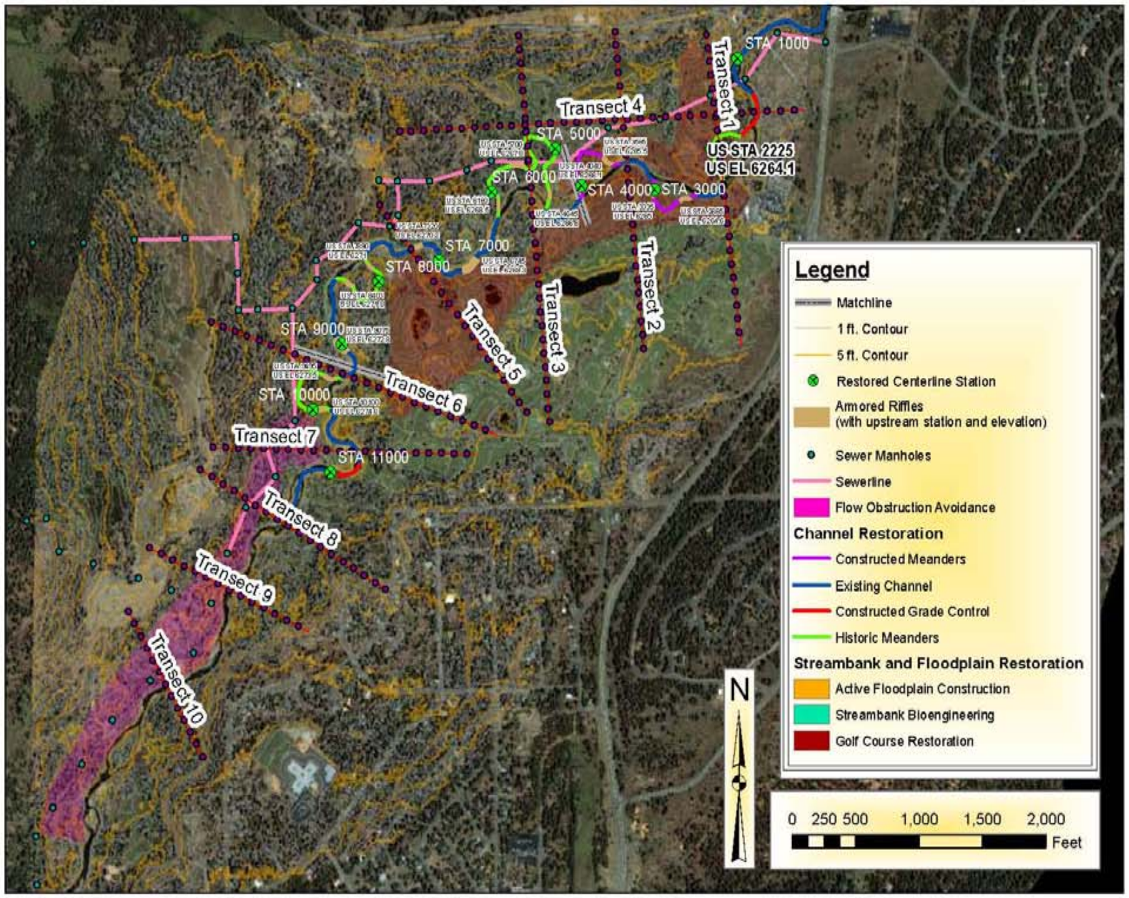


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Figure 20: Transect Locations Tics are 100 ft markers, with stationing starting from the left side facing downstream.

Time-series cross-section surveys are available for 31 transects along the 2.8 km "golf course" reach of the Upper Truckee River starting in 1992. Surveying was conducted by California Department of Parks & Recreation (C. Walck, written comm., 2002) and by the NSL (Simon *et al.*, 2003). Groundwater monitoring wells have recently been established in this reach (EDAW, 2006). Bed- and bank-material particle-size data, along with geotechnical data on bank-material shear strength and erodibility were collected in 2002. Streamflow and sediment-transport data are available for the study reach.

Figure 4: Upper Truckee River "Golf Course Reach" Restoration Project Monitoring Locations